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Physiology and Hygiene for Secondary Schools

by Francis M. Walters, A.M.

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"It is quite possible to give instruction in this subject in such a manner as not only to confer knowledge which is useful in itself, but to serve the purpose of a training in accurate observation, and in the methods of reasoning of physical science."—*Huxley.*

Preface

The aim in the preparation of this treatise on the human body has been, first, to set forth in a *teachable* manner the actual science of physiology; and second, to present the facts of hygiene largely as *applied physiology*. The view is held that "right living" consists in the harmonious adjustment of one's habits to the nature and plan of the body, and that the best preparation for such living is a correct understanding of the physical self. It is further held that the emphasizing of physiology augments in no small degree the educative value of the subject, greater opportunity being thus afforded for exercise of the reasoning powers and for drill in the *modus operandi* of natural forces. In the study of physiology the facts of anatomy have a place, but in an elementary course these should be restricted to such as are necessary for revealing the general structure of the body.

Although no effort has been spared to bring this work within the comprehension of the pupil, its success in the classroom will depend largely upon the method of handling the subject by the teacher. It is recommended, therefore, that the *relations* which the different organs and processes sustain to each other, and to the body as a whole, be given special prominence. The pupil should be impressed with the essential unity of the body and should see in the diversity of its activities the serving of a common purpose. In creating such an impression the introductory paragraphs at the beginning of many of the chapters and the summaries throughout the book, as well as the general arrangement of the subject-matter, will be found helpful.

Since the custom largely prevails of teaching physiology in advance of the sciences upon which it rests—biology, physics, and chemistry—care should be exercised to develop correct ideas of the principles and processes derived from these sciences. Too much latitude has been taken in the past in the use of comparisons and illustrations drawn from "everyday life." To teach that the body is a "house," "machine," or "city"; that the nerves carry "messages"; that the purpose of oxygen is to "burn up waste"; that breathing is to "purify the blood," etc., may give the pupil phrases which he can readily repeat, but teaching of this kind does not give him correct ideas of his body.

The method of teaching, however, that uses the pupil's experience as a basis upon which to build has a value not to be overlooked. The fact that such expressions as those quoted above are so easily remembered proves the value of connecting new knowledge with the pupil's experience. But *the inadequacy of this experience must be recognized* and taken into account. The concepts of the average pupil are entirely too indefinite and limited to supply the necessary *foundation for a science* such as physiology. Herein lies the great value of experiments and observations. They supplement the pupil's experience, and increase both the number and definiteness of his concepts. No degree of success can be attained if this phase of the study is omitted.

The best results in physiology teaching are of course attained where laboratory work is carried on by the pupils, but where this cannot be arranged, class experiments and observations must suffice. The Practical Work described at the close of most of the chapters is mainly for class purposes. While these serve a necessary part in the development of the subject, it is not essential that all of the experiments and observations be made, the intention being to provide for some choice on the part of the teacher. A note-book should be kept by the pupil.

To adapt the book to as wide a range of usefulness as possible, more subject-matter is introduced than is usually included in an elementary course. Such portions, however, as are unessential to a proper understanding of the body by the pupil are set in small type, to be used at the discretion of the teacher.

The use of books of reference is earnestly recommended. For this purpose the usual high school texts may be employed to good advantage. A few more advanced works should, however, be frequently consulted. For this purpose Martin's *Human Body* (Advanced Course), Rettger's *Advanced Lessons in Physiology*, Thornton's *Human Physiology*, Huxley's *Lessons in Elementary Physiology*, Howell's *A Text-book of Physiology*, Hough and Sedgwick's *Hygiene and Sanitation*, and Pyle's *Personal Hygiene* will be found serviceable.

In the preparation of this work valuable assistance has been rendered by Dr. C.N. McAllister, Department of Psychology, and by Professor B.M. Stigall, Department of Biology, along the lines of their respective specialties, and in a more general way by President W.J. Hawkins and others of the Warrensburg, Missouri, State Normal School. Expert advice from Professor S.D. Magers, Instructor in Physiology and Bacteriology, State Normal School, Ypsilanti, Michigan, has been especially helpful, and many practical suggestions from the high school teachers of physiology of Kansas City, Missouri, Professor C.H. Nowlin, Central High School, Dr. John W. Scott, Westport High School, and Professor A.E. Shirling, Manual Training High School, all of whom read both manuscript and proofs, have been incorporated. Considerable material for the Practical Work, including the respiration experiment (page 101) and the reaction time experiment (page 323), were contributed by Dr. Scott. Professor Nowlin's suggestions on subject-matter and methods of presentation deserve special mention. To these and many others the author makes grateful acknowledgment.

F.M.W.

MISSOURI STATE NORMAL SCHOOL,
SECOND DISTRICT, May 1, 1909.

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PHYSIOLOGY AND HYGIENE

PART I: THE VITAL PROCESSES

CHAPTER I - INTRODUCTION

To derive strength equal to the daily task; to experience the advantages of health and avoid the pain, inconvenience, and danger of disease; to live out contentedly and usefully the natural span of life: these are problems that concern all people. They are, however, but different phases of one great problem—the problem of properly managing or caring for the body. To supply knowledge necessary to the solution of this problem is the chief reason why the body is studied in our public schools.

Divisions of the Subject.—The body is studied from three standpoints: structure, use of parts, and care or management. This causes the main subject to be considered under three heads, known as anatomy, physiology, and hygiene.

Anatomy treats of the construction of the body—the parts which compose it, what they are like, and where located. Its main divisions are known as gross anatomy and histology. *Gross anatomy* treats of the larger structures of the body, while *histology* treats of the minute structures of which these are composed—parts too small to be seen with the naked eye and which have to be studied with the aid of the microscope.

[002] *Physiology* treats of the function, or use, of the different parts of the body—the work which the parts do and how they do it—and of their relations to one another and to the body as a whole.

Hygiene treats of the proper care or management of the body. In a somewhat narrower sense it treats of the "laws of health." Hygiene is said to be *personal*, when applied by the individual to his own body; *domestic*, when applied to a small group of people, as the family; and public, or *general*, when applied to the community as a whole or to the race.

The General Aim of Hygiene.—There are many so-called laws of health, and for these laws it is essential in the management of the body to find a common basis. This basic law, suggested by the nature of the body and conditions that affect its well-being, may be termed the *Law of Harmony: The mode of living must harmonize with the plan of the body*. To live properly one must supply the conditions which his body, on account of its nature and plan, requires. On the other hand, he must avoid those things and conditions which are injurious, *i.e.*, out of harmony with the body plan. To secure these results, it is necessary to determine what is and what is not in harmony with the plan of the body, and to find the means of applying this knowledge to the everyday problems of living. Such is the general aim of hygiene. Stated in other words: Hygiene has for its general aim the bringing about of an essential harmony between the body and the things and conditions that affect it.[1]

[1] The body is affected by what it does (exercise, work, sleep), by things taken

Relation of Anatomy and Physiology to the Study of Hygiene.—If the chief object in studying the body is that of learning how to manage or care for it, and hygiene supplies this information, why must we also study anatomy and physiology? The answer to this question has already been in part suggested. In order to determine what things and conditions are in harmony with the plan of the body, we must know what that plan is. This knowledge is obtained through a study of anatomy and physiology. The knowledge gained through these subjects also renders the study of hygiene more interesting and valuable. One is enabled to see *why* and *how* obedience to hygienic laws benefits, and disobedience to them injures, the body. This causes the teachings of hygiene to be taken more seriously and renders them more practical. In short, anatomy and physiology supply a necessary basis for the study of hygiene. [003]

Advantages of Properly Managing the Body.—One result following the mismanagement of the body is loss of health. But attending the loss of health are other results which are equally serious and far-reaching. Without good health, people fail to accomplish their aims and ambitions in life; they miss the joy of living; they lose their ability to work and become burdens on their friends or society. The proper management of the body means health, and it also means the capacity for work and for enjoyment. Not only should one seek to preserve his health from day to day, but he should so manage his body as to use his powers to the best advantage and prolong as far as possible the period during which he may be a capable and useful citizen.

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into it (food, air, drugs), and by things outside of it (the house in which one lives, climate, etc.). That phase of hygiene which has for its object the making of the surroundings of the body healthful is known as *sanitation*.

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CHAPTER II - GENERAL VIEW OF THE BODY

External Divisions.—Examined from the outside, the body presents certain parts, or divisions, familiar to all. The main, or central, portion is known as the *trunk*, and to this are attached the *head*, the *upper extremities*, and the *lower extremities*. These in turn present smaller divisions which are also familiar. The upper part of the trunk is known as the *thorax*, or chest, and the lower part as the *abdomen*. The portions of the trunk to which the arms are attached are the *shoulders*, and those to which the legs are joined are the *hips*, while the central rear portion between the neck and the hips is the *back*. The fingers, the hand, the wrist, the forearm, the elbow, and the upper arm are the main divisions of each of the upper extremities. The toes, the foot, the ankle, the lower leg, the knee, and the thigh are the chief divisions of each of the lower extremities. The head, which is joined to the trunk by the neck, has such interesting parts as the eyes, the ears, the nose, the jaws, the cheeks, and the mouth. The entire body is inclosed in a double covering, called the *skin*, which protects it in various ways.

The Tissues.—After examining the external features of the body, we naturally inquire about its internal structures. These are not so easily investigated, and much which is of interest to advanced students must be omitted from an elementary course. We may, however, as a first step in this study, determine what
[005] kinds of materials enter into the construction of the body. For this purpose the body of some small animal should be dissected and studied. (See observation at close of chapter.) The different materials found by such a dissection correspond closely to the substances, called *tissues*, which make up the human body. The

main tissues of the body, as ordinarily named, are the *muscular* tissue, the *osseous* tissue, the *connective* tissue, the *nervous* tissue, the *adipose* tissue, the *cartilaginous* tissue, and the *epithelial* and *glandular* tissue. Most of these present different varieties, making all together some fifteen different kinds of tissues that enter into the construction of the body.[2]

General Purposes of the Tissues.—The tissues, first of all, *form the body*. As a house is constructed of wood, stone, plaster, iron, and other building materials, so is the body made up of its various tissues. For this reason the tissues have been called the *building materials* of the body.

In addition to forming the body, the tissues supply the means through which its work is carried on. They are thus the *working materials* of the body. In serving this purpose the tissues play an active rôle. All of them must perform the activities of growth and repair, and certain ones (the so-called active tissues) must do work which benefits the body as a whole.

Purposes of the Different Tissues.—In the construction of the body and also in the work which it carries on, the different tissues are made to serve different purposes. The osseous tissue is the chief substance in the bony framework, or skeleton, while the muscular tissue produces the different movements of the body. The connective tissue, which is everywhere abundant, serves [006]
the general purpose of connecting the different parts together. Cartilaginous tissue forms smooth coverings over the ends of the bones and, in addition to this, supplies the necessary stiffness in organs like the larynx and the ear. The nervous tissue controls the body and brings it into proper relations with its surroundings, while the epithelial tissue (found upon the body surfaces and in the glands) supplies it with protective coverings and secretes

[2] When classified according to their essential structure, the tissues fall into four main groups: epithelial and glandular tissue, muscular tissue, nervous tissue, and connective tissue. According to this system the osseous, cartilaginous, and adipose tissues are classed as varieties of connective tissue. See page 18.

liquids. The adipose tissue (fat) prevents the too rapid escape of heat from the body, supplies it with nourishment in time of need, and forms soft pads for delicate organs like the eyeball.

Properties of the Tissues.—If we inquire how the tissues are able to serve such widely different purposes, we find this answer. The tissues differ from one another both in composition and in structure and, on this account, differ in their properties.[3] Their different properties enable them to serve different purposes in the body. Somewhat as glass is adapted by its transparency, hardness, and toughness to the use made of it in windows, the special properties of the tissues adapt them to the kinds of service which they perform. Properties that adapt tissues to their work in the body are called *essential* properties. The most important of these essential properties are as follows:

1. Of osseous tissue, hardness, stiffness, and toughness. 2. Of muscular tissue, contractility and irritability. 3. Of nervous tissue, irritability and conductivity. 4. Of cartilaginous tissue, stiffness and elasticity. 5. Of connective tissue, toughness and pliability. 6. Of epithelial tissue, ability to resist the action of
[007] external forces and power to secrete.

Tissue Groups.—In the construction of the body the tissues are grouped together to form its various divisions or parts. A group of tissues which serves some special purpose is known as an *organ*. The hand, for example, is an organ for grasping (Fig. 1). While the different organs of the body do not always contain the same tissues, and never contain them in the same proportions, they do contain such tissues as their work requires and these have a special arrangement—one adapted to the work which the organs perform.

In addition to forming the organs, the tissues are also grouped in such a manner as to provide supports for organs and to form cavities in which organs are placed. The various cavities of the

[3] The properties of substances are the qualities or characteristics (color, weight, etc.) by means of which they are recognized.

Fig. 1—Hand and forearm, showing the grouping of muscular and connective tissues in the organ for grasping.

body are of particular interest and importance. The three largest ones are the *cranial* cavity, containing the brain; the *thoracic* cavity, containing the heart and the lungs; and the *abdominal* cavity, containing the stomach, the liver, the intestines, and other important organs (Fig. 2). Smaller cavities serving different purposes are also found.

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Organs and Systems.—The work of the body is carried on by its various organs. Many, in fact the majority, of these organs
[009] serve more than one purpose. The tongue is used in talking, in masticating the food, and in swallowing. The nose serves at least three distinct purposes. The mouth, the arms, the hands, the feet, the legs, the liver, the lungs, and the stomach are also organs that serve more than one purpose. This introduces the principle of economy into the construction of the body and diminishes the number of organs that would otherwise be required.

The various organs also *combine* with one another in carrying on the work of the body. An illustration of this is seen in the digestion of the food—a process which requires the combined action of the mouth, stomach, liver, intestines, and other organs. A number of organs working together for the same purpose form a *system*. The chief systems of the body are the digestive system, the circulatory system, the respiratory system, the muscular system, and the nervous system.

The Organ and its Work.—A most interesting question relating to the work of the organ is this: Does the organ work for its own benefit or for the benefit of the body as a whole? Does the hand, for example, grasp for itself or in order that the entire body may come into possession? Only slight study is sufficient to reveal the fact that each organ performs a work which benefits the body as a whole. In other words, just as the organ itself is a part of the body, the work which it does is a part of the necessary work which the body has to do.

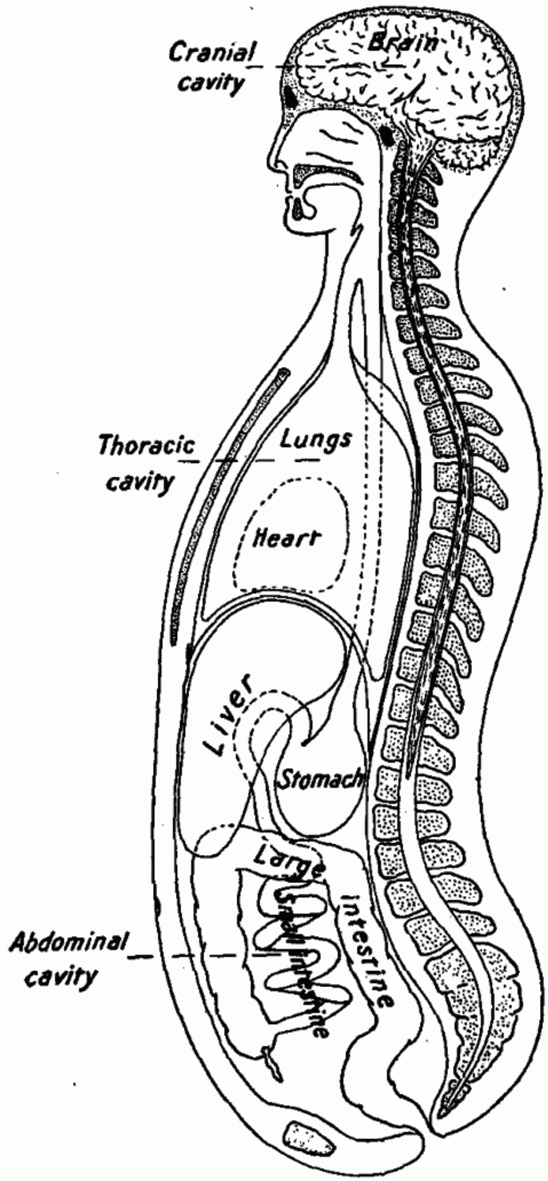

Fig. 2—Diagram of a lengthwise section of the body to show its large cavities and the organs which they contain.

But in working for the general good, or for the body as a whole, each organ becomes a sharer in the benefits of the work done by every other organ. While the hand receives only a little of the nourishment contained in the food which it places in the mouth or of the heat from, fuel which it places on the fire, it is aided and supported by the work of all the other organs of
[010] the body—eyes, feet, brain, heart, etc. The hand does not and cannot work independently of the other organs. It is one of the partners in a very close combination where, by doing a particular work, it, shares in the profits of all. What is true of the hand is true of every other organ of the body.

An Organization.—The relations which the different organs sustain to each other and to the body as a whole suggest the possibility of classifying the body as an organization. This term is broadly applied to a variety of combinations. An organization is properly defined as *any group of individuals which, in working together for a common purpose, practices the division of labor*. This definition will be better understood by considering a few familiar examples.

A baseball team is an organization. The team is made up of individual players. These work together for the common purpose of winning games. They practice the division of labor in that the different players do different things—one catching, another pitching, and so on. A manufacturing establishment which employs several workmen may also be an organization. The article manufactured provides the common purpose toward which all strive; and, in the assignment of different kinds of work to the individual workmen, the principle of division of labor is carried out. For the same reason a school, a railway system, an army, and a political party are organizations.

An organization of a lower order of individuals than these human organizations is to be found in a hive of bees. This is made up of the individual bees, and these, in carrying on the general work of the hive, are known to practice the division of labor.

Is the Body an Organization?—If the body is an organization, it must fulfill the conditions of the definition. It must be made [011] up of separate or individual parts. These must work together for the same general purpose, and, in the accomplishment of this purpose, must practice the division of labor. That the body practices the division of labor is seen in the related work of the different organs. That it is made up of minute, but individual, parts will be shown in the chapter following. That it carries on a *general work* which is accomplished through the combined action of its individual parts is revealed through an extended study of its various activities. *The body is an organization.* Moreover, it is one of the most complex and, at the same time, most perfect of the organizations of which we have knowledge.

Summary.—Viewed from the outside, the body is seen to be made up of divisions which are more or less familiar. Viewed internally, it is found to consist of different kinds of materials, called tissues. The tissues are adapted, by their properties, to different purposes both in the construction of the body and in carrying on its work. The working parts of the body are called organs and these in their work combine to form systems. The entire body, on account of the method of its construction and the character of its work, may be classed as an organization.

Exercises.—1. Name and locate the chief external divisions of the body.

2. What tissues may be found by dissecting the leg of a chicken?

3. Name the most important properties and the most important uses of muscular tissue, osseous tissue, and connective tissue.

4. Define an organ. Define a system. Name examples of each.

5. Name the chief cavities of the body and the organs which they contain.

6. What tissues are present in the hand? How does each of these aid in the work of the hand?

[012] 7. Define an organization. Show that a railway system, an army, and a school are organizations.

8. What is meant by the phrase "division of labor"? In what manner is the division of labor practiced in a shoe or watch factory? What are the advantages?

9. What are the proofs that the body is an organization?

PRACTICAL WORK

Observation on the Tissues.—Examine with care the structures in the entire leg of a chicken, squirrel, rabbit, or other small animal used for food. Observe, first of all, the external covering, consisting of cuticle and hair, claws, scales, or feathers, according to the specimen. These are similar in structure, and they form the epidermis, which is one kind of *epithelial* tissue. With a sharp knife lay open the skin and observe that it is attached to the parts underneath by thin, but tough, threads and sheaths. These represent a variety of *connective* tissue. The reddish material which forms the greater portion of the specimen is a variety of *muscular* tissue, and its divisions are called muscles. With a blunt instrument, separate the muscles, by tearing apart the connective tissue binding them together, and find the glistening white strips of connective tissue (tendons) which attach them to the bones. Find near the central part of the leg a soft, white cord (a nerve) which represents one variety of *nervous* tissue. The bones, which may now be examined, form the *osseous* tissue. At the ends of the bones will be found a layer of smooth, white material which represents one kind of *cartilaginous* tissue. The *adipose*, or fatty, tissue, which is found under the skin and between the other tissues, is easily recognized.

Relation of the Tissues to the Organs.—Observe in the specimen just studied the relation of the different tissues to the organ as a whole (regarding the leg as an organ), *i.e.*, show how each of the tissues aids in the work which the organ accomplishes.

Show in particular how the muscles supply the foot with motion, by tracing out the tendons that connect them with the toes. Pull on the different tendons, noting the effect upon the different parts of the foot.

[013]

CHAPTER III - THE BODY ORGANIZATION

What is the nature of the body organization? What are the individual parts, or units, that make it up? What general work do these carry on and upon what basis do they practice the division of labor? The answers to these questions will suggest the main problems in the study of the body.

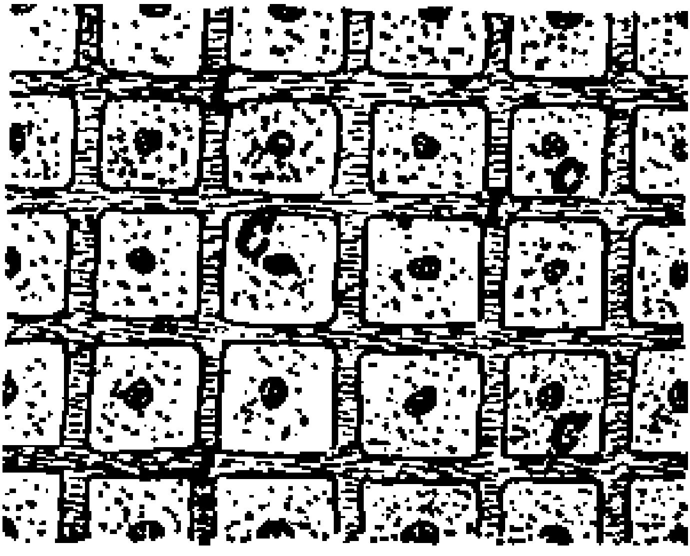

Fig. 3—Diagram showing the relation of the cells and the intercellular material. *C.* Cells. *I.* Intercellular material.

Complex Nature of the Tissues.—To the unaided eye the tissues have the appearance of simple structures. The microscope, however, shows just the reverse to be true. When any one of the tissues is suitably prepared and carefully examined with this instrument, at least two classes of materials can be made out. One of these consists of minute particles, called *cells*; the other is a substance lying between the cells, known as the *intercellular material* (Fig. 3). The cells and the intercellular material, though varying in their relative proportions, are present in all the tissues.

The Body a Cell Group.—The biologist has found that the bodies of all living things, plants as well as animals, consist either of single cells or of groups of cells. The single cells live independently of one another, but the cells that form groups are attached to, and are more or less dependent upon, one another. In the first condition are found the very lowest forms of life. In [014]
the second, life reaches its greatest development. The body of man, which represents the highest type of life, is recognized as a group of cells. In this group each cell is usually separate and distinct from the others, but is attached to them, and is held in place by the intercellular material.

Protoplasm, the Cell Substance.—The cell is properly regarded as an *organized* bit of a peculiar material, called *protoplasm*. This is a semi-liquid and somewhat granular substance which resembles in appearance the white of a raw egg. Its true nature and composition are unknown, because any attempt to analyze it kills it, and dead protoplasm is essentially different from living protoplasm. It is known, however, to be a highly complex substance and to undergo chemical change readily. It appears to be the only kind of matter with which life is ever associated, and for this reason protoplasm is called the *physical basis of life*. Its organization into separate bits, or cells, is necessary to the life activities that take place within it.

Structure of the Cell.—Though all portions of the cell are formed from the protoplasm, this essential substance differs both in structure and in function at different places in the cell. For this reason the cell is looked upon as a complex body having several distinct parts. At or near the center is a clear, rounded body, called the *nucleus*. This plays some part in the nourishment of the cell and also in the formation of new cells. If it be absent, as is sometimes the case, the cell is short-lived and unable to reproduce itself. The variety of protoplasm contained in the nucleus is called the *nucleoplasm*.

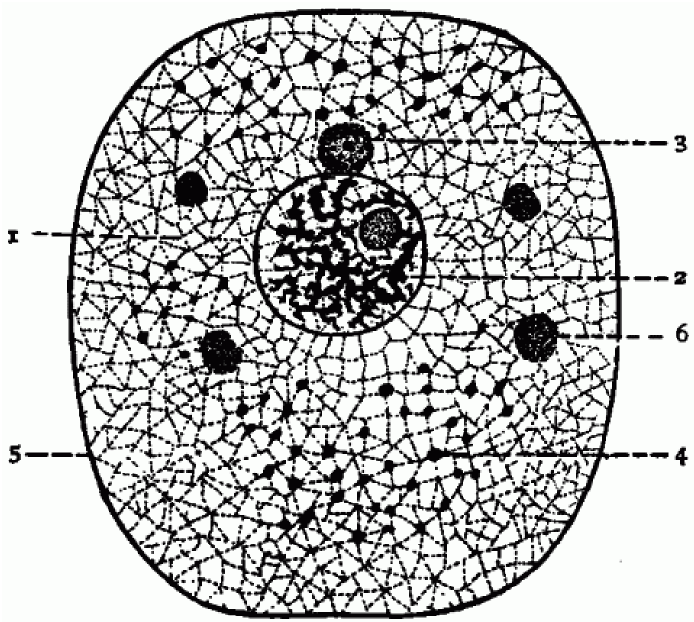

Fig. 4—Diagram of a typical cell (after Wilson). 1. Main body. 2. Nucleus. 3. Attraction sphere. 4. Food particles and waste. 5. Cell-wall. 6. Masses of active material found in certain cells, called plastids.

Surrounding the nucleus is the *main body* of the cell, sometimes referred to as the "protoplasm." Since the protoplasm forms [015] all parts of the cell, this substance is more properly called the *cytoplasm,* or cell plasm. Surrounding and inclosing the cytoplasm, in many cells, is a thin outer layer, or membrane, which affords more or less protection to the contents of the cell. This is usually referred to as the *cell-wall.* A fourth part of the cell is also described, being called the *attraction sphere.* This is a small body lying near the nucleus and coöperating with that body in the formation of new cells. Food particles, wastes, and other substances may also be present in the cytoplasm. The parts of a typical cell are shown in Fig. 4.

Importance of the Cells.—The cells must be regarded as the living, working parts of the body. They are the active agents in all of the tissues, enabling them to serve their various purposes. Working through the tissues, they build up the body and carry on its different activities. They are recognized on this account as *the units of structure and of function,* and are the "individuals" in the body organization. Among the most important and interesting of the activities of the cells are those by which they build up the body, or cause it to grow.

How the Cells enable the Body to Grow.—Every cell is able [016] to take new material into itself and to add this to the protoplasm. This tends to increase the amount of the protoplasm, thereby causing the cells to increase in size. A general increase in the size of the cells has the effect of increasing the size of the entire body, and this is one way by which they cause it to grow. There is, however, a fixed limit, varying with different cells, to the size which they attain, and this is quite low. (The largest cells are scarcely visible to the naked eye.) Any marked increase in the size of the body must, therefore, be brought about by other means. Such a means is found in the formation of new cells, or *cell reproduction*. The new cells are always formed *by* and *from* the old cells, the essential process being known as *cell-division*.

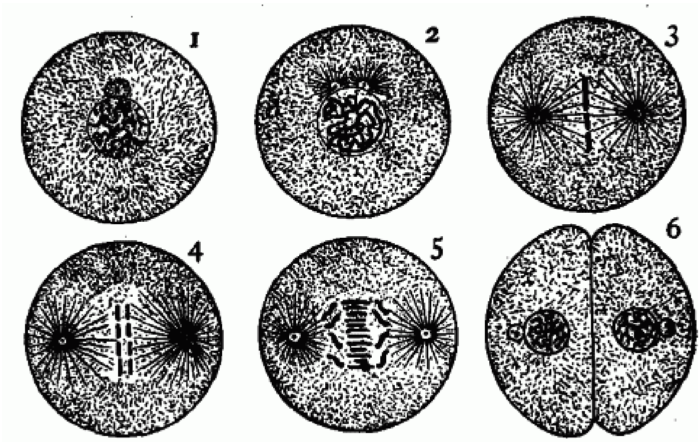

Fig. 5—Steps in cell-division (after Wilson). Note that the process begins with the division of the attraction sphere, then involves the nucleus, and finally separates the main body.

Cell-Division.—By dividing, a single cell will, on attaining its growth, separate into two or more new cells. The process is quite complex and is imperfectly understood. It is known, however, that the act of separation is preceded by a series of
[017] changes in which the attraction sphere and the nucleus actively participate, and that, as a result of these changes, the contents of the old cell are rearranged to form the new cells. Some of the different stages in the process, as they have been studied under the microscope, are indicated in Fig. 5.

Gradually, through the formation of new cells and by the growth of these cells after they have been formed, the body attains its full size. When growth is complete, cell reproduction is supposed to cease except where the tissues are injured, as in the breaking of a bone, or where cells, like those at the surface of the skin, are subject to wear. Then new material continues to be added to the protoplasm throughout life, but in amount only sufficient to replace that lost from the protoplasm as waste.

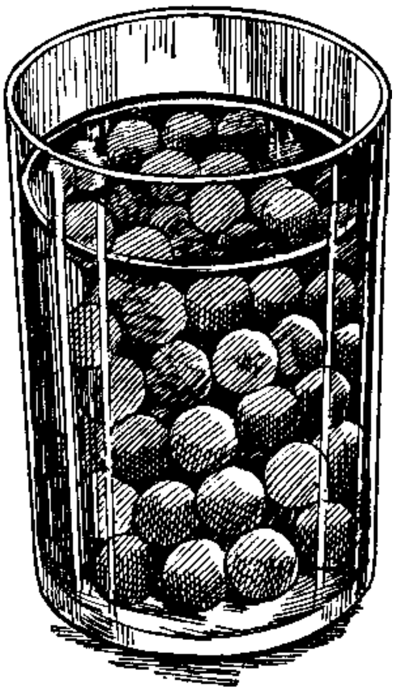

Fig. 6—A tumbler partly filled with marbles covered with water, suggesting the relations of the cells to the lymph.

Cell Surroundings.—All cells are said to be *aquatic*. This means simply that they require water for carrying on their various activities. The cells, in order to live, must take in and give out materials, and water is necessary to both processes. It is also an essential part of the protoplasm. Deprived of water, cells become inactive and usually die. Aquatic surroundings are provided for the cells of the body through a liquid known as the *lymph*, which is distributed throughout the intercellular material (Fig. 6). This consists of water containing oxygen and food substances in solution. Besides supplying these to the cells, the lymph also receives their wastes. Through the lymph the necessary conditions for cell life are provided in the body.

[018] **The General Work of Cells.**—In handling the materials derived from the lymph, the cells carry on three well-defined processes, known as absorption, assimilation, and excretion.

Absorption is the process of taking water, food, and oxygen into the cells.

Assimilation is a complex process which results in the addition of the absorbed materials to the protoplasm. Through assimilation the protoplasm is built up or renewed.

Excretion is the throwing off of such waste materials as have been formed in the cells. These are passed into the lymph and thence to the surface of the body.

Absorption, assimilation, excretion, and also reproduction are performed by all classes of cells. They are, on this account, referred to as the *general work of cells*.

The Special Work of Cells.—In addition to the general work which all cells do in common, each class of cells in the body is able to do some particular kind of work—a work which the others cannot do or which they can do only to a limited extent. This is spoken of as the *special work of cells*. Examples of the special work of cells are found in the production of motion by muscle cells and in the secretion of liquids by gland cells. It may be noted that while the general work of cells benefits them individually, their special work benefits the body as a whole. Another example of the special work of cells is found in the

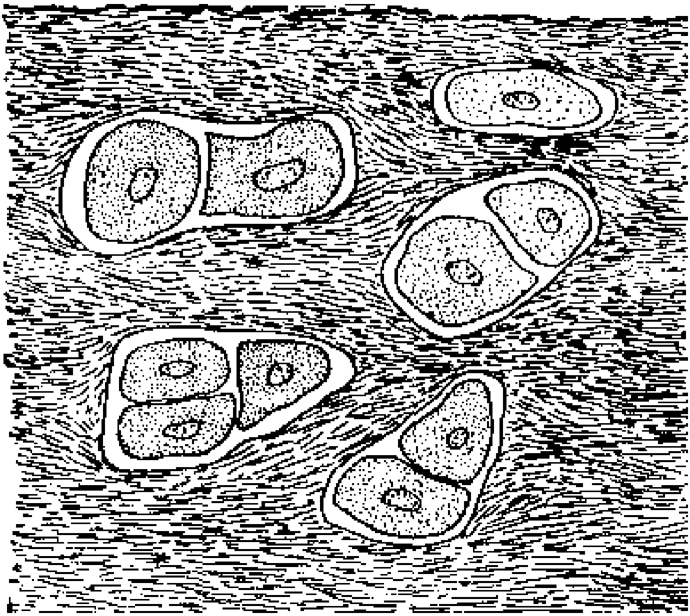

Fig. 7—Cartilage cells, surrounded by the intercellular material which they have deposited.

Production of the Intercellular Material.—Though most of the cells of the body deposit to a slight extent this material, the greater part of it is produced by a single class of cells found in bone, cartilage, and connective tissue. Cartilage, bone, and connective tissue differ greatly from the other tissues in the amount of intercellular material which they contain, the
[019] difference being due to these cells. In the connective tissue they deposit the fibrous material so important in holding the different parts of the body together. In the cartilage they produce the gristly substance which forms by far its larger portion (Fig. 7). In the bones they deposit a material similar to that in the cartilage, except that with it is mixed a mineral substance which gives the bones their hardness and stiffness.[4] The intercellular material, in addition to connecting the cells, supplies to certain tissues important properties, such as the elasticity of cartilage and the stiffness of the bones.

Nature of the Body Organization.—The division of labor carried on by the different organs, as shown in the preceding chapter, is in reality carried on by the cells that form the organs. To see that this is true we have only to observe the relation of cells to tissues and of tissues to organs. The cells form the tissues and the tissues form the organs. This arrangement enables the special work of different kinds of cells to be combined in the work of the organ as a whole. This is seen in the hand which, in grasping, uses motion supplied by the muscle cells, a controlling influence supplied by the nerve cells, a framework supplied by the bone cells, and so on. The cells supply the basis for the body organization and, properly speaking, the body is *an organization*
[020] *of cells*[5] (Recall the definition of an organization, page 10.) In

[4] Certain of these cells also form deposits of fat, giving rise to the adipose, or fatty, tissue.

[5] Any organized structure, such as the body, whose parts are pervaded by a common life, is known as an *organism*. The term "organism" is frequently applied to the body.

this organization there are to be observed:

1. A definite arrangement of the cells to form the tissues. A tissue is a group of like cells.

2. A definite arrangement of the tissues in the organ. Each organ contains the tissues needed for its work.

3. In several instances there is a definite arrangement of organs to form systems.

4. The body as a whole is made up of organs and systems, together with the structures necessary for their support and protection.

There now remains a further question for consideration. What is the one supreme end, or purpose, toward which all the activities of the body organization are directed? This purpose will naturally have some relation to the maintenance, or preservation, of the cell group which we call the body.

The Maintenance of Life.—The preservation of any cell group in its natural condition, whether it be plant or animal, is accomplished through keeping it alive. If life ceases, the group quickly disintegrates and its elements become scattered, a fact which is verified through everyday observation. Though the nature of life is unknown, it may be looked upon as the organizer and preserver of the protoplasm. But in preserving the protoplasm it also preserves the entire cell group, or body. Life is thus the most essential condition of the body. *With life all portions of the body are concerned, and toward its maintenance all the activities of the body organization are directed*.

The Nutrient Fluid in its Relations to the Cells.—The maintenance of life within the cells requires, as we have seen, that they be supplied with water, food, and oxygen, and that they be relieved of such wastes as they form. This double purpose is [021]
accomplished through the agency of an internal nutrient fluid, a portion of which has already been referred to as the lymph. Not only does this fluid supply the means for keeping the cells alive,

but, through the cells, it is also the means of preserving the life of the body as a whole.

The cells, however, rapidly exhaust the nutrient fluid. They take from it food and oxygen and they put into it their wastes. To prevent its becoming unfit for supplying their needs, food and oxygen must be continually added to this fluid, and waste materials must be continually removed. This is not an easy task. As a matter of fact, the preparation, distribution, and purification of the nutrient fluid requires the direct or indirect aid of practically all parts of the body. It supplies for this reason a broad basis for the division of labor on the part of the cells.

Relation of the Body to its Environment.—While life is directly dependent upon the internal nutrient fluid, it is indirectly dependent upon the physical surroundings of the body. Herein lies the need of the *external* organs—the feet and legs for moving about, the hands for handling things, the eyes for directing movements, etc. That the great needs of the body are supplied from its surroundings are facts of common experience. Food, shelter, air, clothing, water, and the means of protection are external to the body and form a part of its environment. In making the things about him contribute to his needs, man encounters a problem which taxes all his powers. Only by toil and hardship, "by the sweat of his brow," has he been able to wrest from his surroundings the means of his sustenance.

The Main Physiological Problems.—The study of the body is thus seen to resolve itself naturally into the consideration of two main problems:

[022] 1. *That of maintaining in the body a nutrient fluid for the cells.*

2. *That of bringing the body into such relations with its surroundings as will enable it to secure materials for the nutrient fluid and satisfy its other needs.*

The first problem is *internal* and includes the so-called vital processes, known as digestion, circulation, respiration, and excretion. The second problem is *external*, as it were, and includes the work of the external organs—the organs of motion and of locomotion and the organs of special sense. These problems are closely related, since they are the two divisions of the one problem of maintaining life. Neither can be considered independently of the other. In the chapter following is taken up the first of these problems.

Summary.—The individual parts, or units, that form the body organization are known as cells. These consist of minute but definitely arranged portions of protoplasm and are held together by the intercellular material. They build up the body and carry on its different activities. The tissues are groups of like cells. By certain general activities the cells maintain their existence in the tissues and by the exercise of certain special activities they adapt the tissues to their purposes in the body. The body, as a cell organization, has its activities directed under normal conditions toward a single purpose—that of maintaining life. In the accomplishment of this purpose a nutrient fluid is provided for the cells and proper relations between the body and its surroundings are established.

Exercises.—1. If a tissue be compared to a brick wall, to what do the separate bricks correspond? To what the mortar between the bricks?

2. Draw an outline of a typical cell, locating and naming the main divisions.

3. How do the cells enable the body to grow? Describe the process of cell-division.

4. How does the general work of cells differ from their special [023]
work? Define absorption, excretion, and assimilation as applied to the cells.

5. Compare the conditions surrounding a one-celled animal, living in water, to the conditions surrounding the cells in the body.

6. What is meant by the term "environment"? How does man's environment differ from that of a fish?

7. What is the necessity for a nutrient fluid in the body?

8. Why is the maintenance of life necessarily the chief aim of all the activities of the body?

9. State the two main problems in the study of the body.

PRACTICAL WORK

Observations.—1. Make some scrapings from the inside of the cheek with a dull knife and mix these with a little water on a glass slide. Place a cover-glass on the same and examine with a compound microscope. The large pale cells that can be seen in this way are a variety of epithelial cells.

2. Mount in water on a glass slide some thin slices of cartilage and examine first with a low and then with a high power of microscope. (Suitable slices may be cut, with a sharp razor, from the cartilage found at the end of the rib of a young animal.) Note the small groups of cells surrounded by, and imbedded in, the intercellular material.

3. Mount and examine with the microscope thin slices of elder pith, potato, and the stems of growing plants. Make drawings of the cells thus observed.

4. Examine with the microscope a small piece of the freshly sloughed off epidermis of a frog's skin. Examine it first in its natural condition, and then after soaking for an hour or two in a solution of carmine. Make drawings.

5. Mount on a glass slide some of the scum found on stagnant water and examine it with a compound microscope. Note the variety and relative size of the different things moving about. The forms most frequently seen by such an examination are one-celled plants. Many of these have the power of motion.

6. Examine tissues of the body, such as nervous, muscular, and glandular tissues, which have been suitably prepared and mounted for microscopic study, using low and high powers of

the microscope. Make drawings of the cells in the different tissues thus observed.

[024]

CHAPTER IV - THE BLOOD

Two liquids of similar nature are found in the body, known as the blood and the lymph. These are closely related in function and together they form the nutrient fluid referred to in the preceding chapter. The blood is the more familiar of the two liquids, and the one which can best be considered at this time.

The Blood: where Found.—The blood occupies and moves through a system of closed tubes, known as the blood vessels. By means of these vessels the blood is made to circulate through all parts of the body, but from them it does not escape under normal conditions. Though provisions exist whereby liquid materials may both enter and leave the blood stream, it is only when the blood vessels are cut or broken that the blood, as blood, is able to escape from its inclosures.

Physical Properties of the Blood.—Experiments such as those described at the close of this chapter reveal the more important physical properties of the blood. It may be shown to be heavier and denser than water; to have a faint odor and a slightly salty taste; to have a bright red color when it contains oxygen and a dark red color when oxygen is absent; and to undergo, when exposed to certain conditions, a change called coagulation. These properties are all accounted for through the different materials that enter into the formation of the blood.

[025] **Composition of the Blood.**—To the naked eye the blood appears as a thick but simple liquid; but when examined with a compound microscope, it is seen to be complex in nature, consisting of at least two distinct portions. One of these is a clear, transparent liquid; while the other is made up of many

small, round bodies that float in the liquid. The liquid portion of the blood is called the *plasma*; the small bodies are known as *corpuscles*. Two varieties of corpuscles are described—the *red* corpuscles and the *white* corpuscles (Fig. 8). Other round particles, smaller than the corpuscles, may also be seen under favorable conditions. These latter are known as *blood platelets*.

Red Corpuscles.—The red corpuscles are classed as cells, although, as found in the blood of man and the other mammals (Fig. 9), they have no nuclei.[6] Each one consists of a little mass of protoplasm, called the *stroma*, which contains a substance having a red color, known as *hemoglobin*. The shape of the red corpuscle is that of a circular disk with concave sides. It has a width of about 1/3200 of an inch (7.9 microns[7]) and a thickness of about 1/13000 of an inch (1.9 microns). The red corpuscles [026]
are exceedingly numerous, there being as many as five millions in a small drop (one cubic millimeter) of healthy blood. But the number varies somewhat and is greatly diminished during certain forms of disease.

It is the *function* of the red corpuscles to serve as *oxygen carriers* for the cells. They take up oxygen at the lungs and release it at the cells in the different tissues.[8] The performance of this function depends upon the hemoglobin.

Hemoglobin.—This substance has the remarkable property

[6] In birds, reptiles, amphibians, and fishes the red corpuscles have nuclei (Fig. 9).

[7] The micron is the unit of microscopical measurements. It is equal to 1/1000 of a millimeter and is indicated by the symbol μ.

[8] The peculiar shape of the red corpuscle has no doubt some relation to its work. Its circular form is of advantage in getting through the small blood vessels, while its extreme thinness brings all of its contents very near the surface—a condition which aids the hemoglobin in taking up oxygen. If the corpuscles were spherical in shape, some of the hemoglobin could not, on account of the distance from the surface, so readily unite with the oxygen.

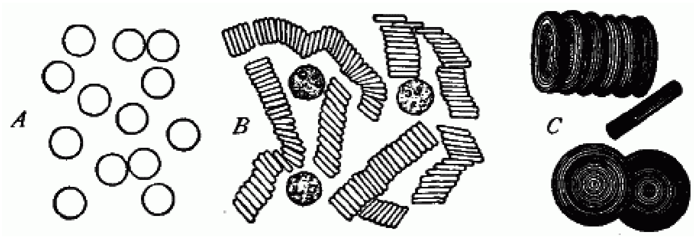

Fig. 8—Blood corpuscles, highly magnified. *A.* Red corpuscles as they appear in diluted blood. *B.* Arrangement of red corpuscles in rows between which are white corpuscles, as may be seen in undiluted blood. *C.* Red corpuscles much enlarged to show the form.

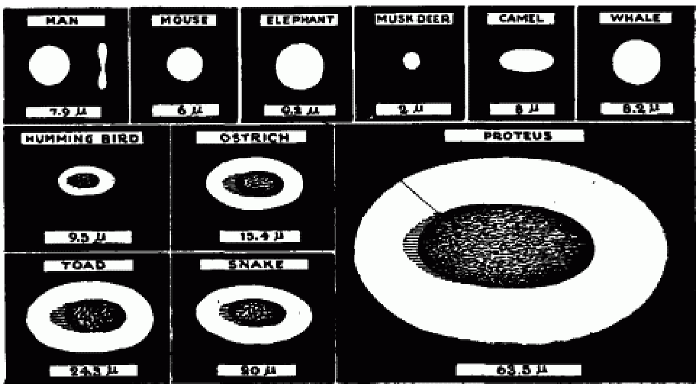

Fig. 9—Red corpuscles from various animals. Those from mammals are without nuclei, while those from birds and cold-blooded animals have nuclei.

of forming, under certain conditions, a weak chemical union with oxygen and, when the conditions are reversed, of separating from it. It forms about nine tenths of the solid matter of the red [027] corpuscles and to it is due the colors of the blood. When united with the oxygen it forms a compound, called *oxyhemoglobin*, which has a bright red color; the hemoglobin alone has a dark red color. These colors are the same as those of the blood as it takes on and gives off oxygen. The stroma, which forms only about one tenth of the solid matter of the corpuscles, serves as a contrivance for holding the hemoglobin. The conditions which cause the hemoglobin to unite with oxygen in the lungs and to separate from it in the tissues, will be considered later (Chapter VIII).

Disappearance and Origin of Red Corpuscles.—The red corpuscles, being cells without nuclei, are necessarily short-lived. It has been estimated that during a period of one to two months, all the red corpuscles in the body at a given time will have disappeared and their places taken by new ones. The origin of new corpuscles, however, and the manner of ridding the blood of old ones are problems that are not as yet fully solved. The removal of the products of broken down corpuscles is supposed to take place both in the liver and in the spleen.[9]

Regarding the origin of the red corpuscles, the evidence now seems conclusive that large numbers of them are formed in the red marrow of the bones. The red marrow is located in what is known as the spongy substance of the bones (Chapter XIV) and consists, to a large extent, of cells somewhat like the red corpuscles, but differing from them in having nuclei. These

[9] The coloring matter of the bile consists of compounds formed by the breaking down of the hemoglobin; the spleen contains many large cells that seem to have the power first of "engulfing" and later of decomposing red corpuscles. A further evidence that the spleen aids in the removal of worn-out corpuscles is found in the fact that during diseases that cause a destruction of the red corpuscles, such as the different forms of malaria, the spleen becomes enlarged.

appear to be constantly in a state of reproduction. The blood, flowing through the minute cavities containing these cells, carries those that have been loosened out into the blood stream. Nuclei appear in the red corpuscles at the time of their formation, but these quickly separate and, according to some authorities, form the blood platelets.

White Corpuscles.—The white corpuscles, or *leucocytes*, are cells of a general spherical shape, each containing one, two, or more nuclei. They are much less numerous than the red, there
[028] being on the average only one white corpuscle to about every five hundred of the red ones. On the other hand, the white corpuscles are larger than the red, one of the former being equal in volume to about three of the latter.

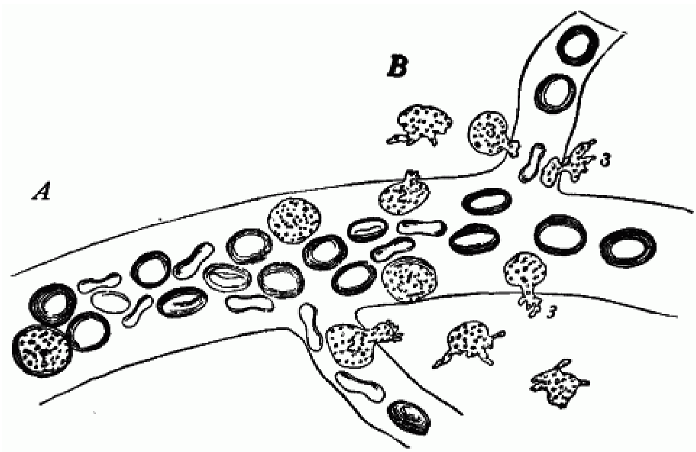

Fig. 10—**Escape of white corpuscles from a small blood vessel** (Hall). At *A* the conditions are normal, but at *B* some excitation in the surrounding tissue leads to a migration of corpuscles. 1, 2, and 3 show different stages of the passage.

The white corpuscles are found, when studied under favorable conditions, to possess the power of changing their shape and, by this means, of moving from place to place. This property enables them to penetrate the walls of capillaries and to pass with the lymph in between the cells of the tissues. The white corpuscles are, therefore, not confined to the blood vessels, as are the red corpuscles, but migrate through the intercellular spaces (Fig. 10). If any part of the body becomes inflamed, the white corpuscles collect there in large numbers; and, on breaking down, they form most of the white portion of the sore, called the *pus*.

New white corpuscles are formed from old ones, by cell- [029]
division. Their production may occur in almost any part of the body, but usually takes place in the lymphatic glands (Chapter VI) and in the spleen, where conditions for their development are especially favorable. In these places they are found in great abundance and in various stages of development.

Functions of White Corpuscles.—The main use of the white corpuscles appears to be that of a destroyer of disease germs. These consist of minute organisms that find their way into the body and, by living upon the tissues and fluids and by depositing toxins (poisons) in them, cause different forms of disease. Besides destroying germs that may be present in the blood, the white corpuscles also leave the blood and attack germs that have invaded the cells. By forming a kind of wall around any foreign substance, such as a splinter, that has penetrated the skin, they are able to prevent the spread of germs through the body. In a similar manner they also prevent the germs from boils, abscesses, and sore places in general from getting to and infecting other parts of the body.[10] Another function ascribed to

[10] An infected part of the body, such as a boil or abscess, should never be bruised or squeezed until the time of opening. Pressure tends to break down the wall of white corpuscles and to spread the infection. Pus from a sore contains germs and should not, on this account, come in contact with any part of the skin. (See treatment of skin wounds, Chapter XVI.)

the white corpuscles is that of aiding in the coagulation of the blood (page 31); and still another, of aiding in the healing of wounds.

Plasma.—The plasma is a complex liquid, being made up of water and of substances dissolved in the water. The dissolved substances consist mainly of foods for the cells and wastes from the cells.

1. *The foods* represent the same classes of materials as are
[030] taken in the daily fare, *i.e.*, proteids, carbohydrates, fats, and salts (Chapter IX). Three kinds of proteids are found in the plasma, called *serum albumin*, *serum globulin*, and *fibrinogen*. These resemble, in a general way, the white of raw egg, but differ from each other in the readiness with which they coagulate. Fibrinogen coagulates more readily than the others and is the only one that changes in the ordinary coagulation of the blood. The others remain dissolved during this process, but are coagulated by chemical agents and by heat. While all of the proteids probably serve as food for the cells, the fibrinogen, in addition, is a necessary factor in the coagulation of the blood (page 31).

The only representative of the carbohydrates in the plasma is *dextrose*. This is a variety of sugar, being derived from starch and the different sugars that are eaten. The *fat* in the plasma is in minute quantities and appears as fine droplets—the form in which it is found in milk. While several mineral salts are present in small quantities in the plasma, *sodium chloride*, or common salt, is the only one found in any considerable amount. The mineral salts serve various purposes, one of which is to cause the proteids to dissolve in the plasma.

2. *The wastes* are formed at the cells, whence they are passed by the lymph into the blood plasma. They are carried by the blood until removed by the organs of excretion. The two waste products found in greatest abundance in the plasma are carbon dioxide and urea.

The substances dissolved in the plasma form about 10 per cent of the whole amount. The remaining 90 per cent is water. Practically all the constituents of the plasma, except the wastes, enter the blood from the digestive organs.

Purposes of Water in the Blood.—Not only is water the most abundant constituent of the blood; it is, in some respects, the most important. It is the liquefying portion of the blood, holding in solution the constituents of the plasma and floating the corpuscles. Deprived of its water, the blood becomes a solid substance. Through the movements of the blood the water also serves the purpose of a transporting agent in the body. The cells in all parts of the body require water and this is supplied to them from the blood. Water is present in the corpuscles as well as in the plasma and forms about 80 per cent of the entire volume of the blood. [031]

Coagulation of the Blood.—If the blood is exposed to some unnatural condition, such as occurs when it escapes from the blood vessels, it undergoes a peculiar change known as *coagulation*.[11] In this change the corpuscles are collected into a solid mass, known as the *clot*, thereby separating from a liquid called the *serum*. The serum, which is similar in appearance to the blood plasma, differs from that liquid in one important respect as explained below.

Causes of Coagulation.—Although coagulation affects all parts of the blood, only one of its constituents is found in reality to coagulate. This is the fibrinogen. The formation of the clot and the separation of the serum is due almost entirely to the action of this substance. Fibrinogen is for this reason called the *coagulable constituent of the blood*. In the plasma the fibrinogen is in a liquid form; but during coagulation it changes into a white, stringy solid, called *fibrin*. This appears in the clot and is the cause of its formation. Forming as a network of exceedingly [032]

[11] Coagulation is not confined to the blood. The white of an egg coagulates when heated and when acted upon by certain chemicals, and the clabbering of milk also is a coagulation.

fine and very delicate threads (Fig. 11) *throughout the mass of blood* that is coagulating, the fibrin first entangles the corpuscles and then, by contracting, draws them into the solid mass or clot.[12] The contracting of the fibrin also squeezes out the serum. This liquid contains all the constituents of the plasma except the fibrinogen.

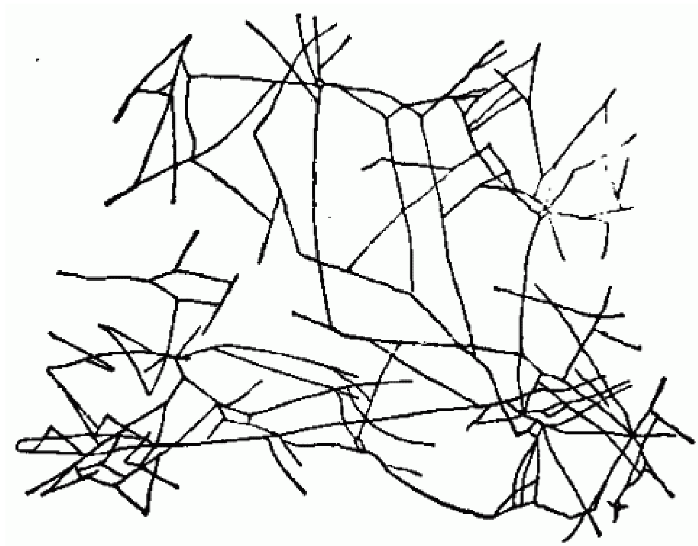

Fig. 11—**Fibrin threads** (after Ranvier). These by contracting draw the corpuscles together and form the clot.

Fibrin Ferment and Calcium.—Most difficult of all to answer have been the questions: What causes the blood to coagulate

[12] If the blood be stirred or "whipped" while it is coagulating, the clot may be broken up and the fibrin separated as fast as it forms. The blood which then remains consists of serum and corpuscles and will not coagulate. It is known as "defibrinated" blood.

outside of the blood vessels and what prevents its coagulation inside of these vessels? The best explanation offered as yet upon this point is as follows: Fibrinogen does not of itself change into fibrin, but is made to undergo this change by the presence of another substance, called *fibrin ferment*. This substance is not a regular constituent of the blood, but is formed as occasion requires. It is supposed to result from the breaking down of the white corpuscles, and perhaps also from the blood platelets, when the blood is exposed to unnatural conditions. The formation of the ferment leads in turn to the changing of the fibrinogen into fibrin.

Another substance which is necessary to the process of coagulation is the element calcium. If compounds of calcium are absent from the blood, coagulation does not take place. These are, however, regular constituents of healthy blood. Whether the presence of the calcium is necessary to the formation of the ferment or to the action of the ferment upon the fibrinogen is unknown.

Purpose of Coagulation.—The purpose of coagulation is to check the flow of blood from wounds. The fact that the blood
is contained in and kept flowing continuously through a system [033]
of *connected* vessels causes it to escape rapidly from the body whenever openings in these vessels are made. Clots form at such openings and close them up, stopping in this way the flow that would otherwise go on indefinitely. Coagulation, however, does not stop the flow of blood from the large vessels. From these the blood runs with too great force for the clot to form within the wound.

Time Required for Coagulation.—The rate at which coagulation takes place varies greatly under different conditions. It is influenced strongly by temperature; heat hastens and cold retards the process. It may be prevented entirely by lowering the temperature of the blood to near the freezing point. The presence of a foreign substance increases the rapidity of coagulation, and it has been observed that bleeding from small wounds is more quickly checked by covering them with linen or cotton fibers. The fibers in this case hasten the process of coagulation.

Quantity of Blood.—The quantity of blood is estimated to be about one thirteenth of the entire weight of the body. This for the average individual is an amount weighing nearly twelve pounds and having a volume of nearly one and one half gallons. About 46 per cent by volume of this amount is made up of corpuscles and 54 per cent of plasma. Of the plasma about 10 per cent consists of solids and 90 per cent of water, as already stated.

Functions of the Blood.—The blood is the great carrying, or distributing, agent in the body. Through its movements (considered in the next chapter) it carries food and oxygen to the cells and waste materials from the cells. Much of the blood may, therefore, be regarded as *freight* in the process of transportation. The blood also carries, or distributes, heat. Taking up heat in the warm parts of the body, it gives it off at places having a lower temperature. This enables all parts of the body to keep at about the same temperature.

In addition to serving as a carrier, the blood has antiseptic
[034] properties, i.e., it destroys disease germs. While this function is mainly due to the white corpuscles, it is due in part to the plasma.[13] Through its coagulation, the blood also closes leaks in the small blood vessels. The blood is thus seen to be a liquid of several functions.

Changes in the Blood.—In performing its functions in the body the blood must of necessity undergo rapid and continuous change. The red corpuscles, whose changes have already been

[13] Certain substances, called *opsonins*, have recently been shown to exist in the plasma, that aid the white corpuscles in their work of destroying germs. The opsonins appear to act in such a manner as to weaken the germs and make them more susceptible to the attacks of the white corpuscles.

noted, appear to be the most enduring constituents of the blood. The plasma is the portion that changes most rapidly. Yet in spite of these changes the quantity and character of the blood remain practically constant.[14] This is because there is a *balancing* of the forces that bring about the changes. The addition of various materials to the blood just equals the withdrawal of the same materials from the blood. Somewhat as a vessel of water (Fig. 12) having an inflow and an outflow which are equal in amount may keep always at the same level, the balancing of the intake and outgo of the blood keeps its composition about the same from time to time.

Hygiene of the Blood.—The blood, being a changeable liquid, is easily affected through our habits of living. Since it may be affected for ill as well as for good, one should cultivate those [035] habits that are beneficial and avoid those that are harmful in their effects. Most of the hygiene of the blood, however, is properly included in the hygiene of the organs that act upon the blood—a fact which makes it unnecessary to treat this subject fully at this time.

From a health standpoint, the most important constituents of the blood are, perhaps, the corpuscles. These are usually sufficient in number and vigor in the blood of those who take plenty of physical exercise, accustom themselves to outdoor air and sunlight, sleep sufficiently, and avoid the use of injurious drugs. On the other hand, they are deficient in quantity and inferior in quality in the bodies of those who pursue an opposite course. Impurities not infrequently find their way into the blood through the digestive organs. One should eat wholesome, well-cooked food, drink freely of *pure* water, and limit the quantity of food *to what can be properly digested*. The natural purifiers of

[14] Some of the changes in the blood are very closely related to our everyday habits and inclinations. For example, a lack of nourishment in the blood causes hunger and this leads to the taking of food. If the fluids of the body become too dense, a feeling of thirst is aroused which prompts one to drink water.

the blood are the organs of excretion. The skin is one of these and its power to throw off impurities depends upon its being clean and active.

Effect of Drugs.—Certain drugs and medicines, including alcohol and quinine,[15] have recently been shown to destroy the white corpuscles. The effect of such substances, if introduced in considerable amount in the body, is to render one less able to withstand attacks of disease. Many patent medicines are widely advertised for purifying the blood. While these may possibly do good in particular cases, the habit of doctoring one's self with them is open to serious objection. Instead of taking drugs and patent medicines for purifying the blood, one should study to live
[036] more hygienically. We may safely rely upon wholesome food, pure water, outdoor exercise and sunlight, plenty of sleep, and a clean skin for keeping the blood in good condition. If these natural remedies fail, a physician should be consulted.

Summary.—The blood is the carrying or transporting agent of the body. It consists in part of constituents, such as the red corpuscles, that enable it to carry different substances; and in part of the materials that are being carried. The latter, which include food and oxygen for the cells and wastes from the cells, may be classed as freight. Certain constituents in the blood destroy disease germs, and other constituents, by coagulating, close small leaks in the blood vessels. Although subject to rapid and continuous change, the blood is able—by reason of the balancing of materials added to and withdrawn from it—to remain about the same in quantity and composition.

Exercises.—1. Compare blood and water with reference to weight, density, color, odor, and complexity of composition.

2. Show by an outline the different constituents of the blood.

3. Compare the red and white corpuscles with reference to size, shape, number, origin, and function.

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[15] Metchnikoff, *The New Hygiene*.

4. Name some use or purpose for each constituent of the blood.

5. What constituents of the blood may be regarded as freight and what as agents for carrying this freight?

6. After coagulation, what portions of the blood are found in the clot? What portions are found in the serum?

7. What purposes are served by water in the blood?

8. Show how the blood, though constantly changing, is kept about the same in quantity, density, and composition.

9. In the lungs the blood changes from a dark to a bright red color and in the tissues it changes back to dark red. What is the cause of these changes?

10. If the oxygen and hemoglobin formed a strong instead of a weak chemical union, could the hemoglobin then act as an oxygen carrier? Why?

11. What habits of living favor the development of corpuscles [037] in the blood?

12. Why will keeping the skin clean and active improve the quality of one's blood?

PRACTICAL WORK

To demonstrate the Physical Properties of Blood (Optional).—Since blood is needed in considerable quantity in the following experiments, it is best obtained from the butcher. To be sure of securing the blood in the manner desired, take to the butcher three good-sized bottles bearing labels as follows:

1 Fill two thirds full. While the blood is cooling, stir rapidly with the hand or a bunch of switches to remove the clot.

2 Fill two thirds full and set aside without shaking or stirring.

3 Fill two thirds full and thoroughly mix with the liquid in the bottle.

Label 3 must be pasted on a bottle, having a tight-fitting stopper, which is filled one fifth full of a saturated solution of

Epsom salts. The purpose of the salts is to prevent coagulation until the blood is diluted with water as in the experiments which follow.

Experiments.—1. Let some of the defibrinated blood (bottle 1) flow (not fall) on the surface of water in a glass vessel. Does it remain on the surface or sink to the bottom? What does the experiment show with reference to the relative weight of blood and water?

2. Fill a large test tube or a small bottle one fourth full of the defibrinated blood and thin it by adding an equal amount of water. Then place the hand over the mouth and shake until the blood is thoroughly mixed with the air. Compare with a portion of the blood not mixed with the air, noting any difference in color. What substance in the air has acted on the blood to change its color?

3. Fill three tumblers each two thirds full of water and set them in a warm place. Pour into one of the tumblers, and thoroughly mix with the water, two tablespoonfuls of the blood containing the Epsom salts. After an interval of half an hour add blood to
[038] the second tumbler in the same manner, and after another half hour add blood to the third. The water dilutes the salts so that coagulation is no longer prevented. Jar the vessel occasionally as coagulation proceeds; and if the clot is slow in forming, add a trace of some salt of calcium (calcium chloride). After the blood has been added to the last tumbler make a comparative study of all. Note that coagulation begins in all parts of the liquid at the same time and that, as the process goes on, the clot shrinks and is drawn toward the center.

4. Place a clot from one of the tumblers in experiment 3 in a large vessel of water. Thoroughly wash, adding fresh water, until a white, stringy solid remains. This substance is fibrin.

5. Examine the coagulated blood obtained from the butcher (bottle 2). Observe the dark central mass (the clot) surrounded by a clear liquid (the serum). Sketch the vessel and its contents,

showing and naming the parts into which the blood separates by coagulation.

To examine the Red Corpuscles.—Blood for this purpose is easily obtained from the finger. With a handkerchief, wrap one of the fingers of the left hand from the knuckle down to the first joint. Bend this joint and give it a sharp prick with the point of a sterilized 'needle just above the root of the nail. Pressure applied to the under side of the finger will force plenty of blood through a very small opening. (To prevent any possibility of blood poisoning the needle should be sterilized. This may be done by dipping it in alcohol or by holding it for an instant in a hot flame. It is well also to wash the finger with soap and water, or with alcohol, before the operation.) Place a small drop of the blood in the middle of a glass slide, protect the same with a cover glass, and examine with a compound microscope. At least two specimens should be examined, one of which should be diluted with a little saliva or a physiological salt solution.[16] In the diluted specimen the red corpuscles appear as amber-colored, circular, disk-shaped bodies. In the undiluted specimen they show a decided tendency to arrange themselves in rows, resembling rows of coins. (Singly, the corpuscles do not appear red when highly magnified.)

A few white corpuscles may generally be found among the red ones in the undiluted specimen. These become separated by the formation of the red corpuscles into rows. They are easily [039]
recognized by their larger size and by their silvery appearance, due to the light shining through them.

To examine White Corpuscles.—Obtain from the butcher a small piece of the neck sweetbread of a calf. Press it between the fingers to squeeze out a whitish, semi-liquid substance. Dilute

[16] A physiological salt solution is prepared by dissolving .6 of a gram of common salt in 100 cc. of distilled water or pure cistern water. This solution, having the same density as the plasma of the blood, does not act injuriously upon the corpuscles.

with physiological salt solution on a glass slide and examine with a compound microscope. Numerous white corpuscles of different kinds and sizes will be found. Make sketches.

To prepare Models of Red Corpuscles.—Several models of red corpuscles should be prepared for the use of the class. Clay and putty may be pressed into the form of red corpuscles and allowed to harden, and small models may be cut out of blackboard crayon. Excellent models can be molded from plaster of Paris as follows: Coat the inside of the lid of a baking powder can with oil or vaseline and fill it even full of a thick mixture of plaster of Paris and water. After the plaster has set, remove it from the lid and with a pocket-knife round off the edges and hollow out the sides until the general form of the corpuscle is obtained. The models may be colored red if it is desired to match the color as well as the form of the corpuscle.

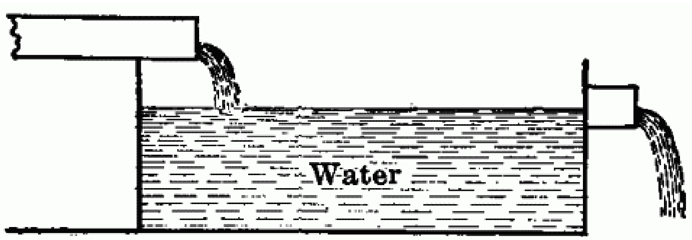

Fig. 12—**A balanced change** in water. The level remains constant although the water is continually changing; suggestive of the changes in the blood.

[040]

CHAPTER V - THE CIRCULATION

A Carrier must move. To enable the blood to carry food and oxygen *to* the cells and waste materials *from* the cells, and also to distribute heat, it is necessary to keep it moving, or circulating, in all parts of the body. So closely related to the welfare of the body is the circulation[17] of the blood, that its stoppage for only a brief interval of time results in death.

Discovery of the Circulation.—The discovery of the circulation of the blood was made about 1616 by an English physician named Harvey. In 1619 he announced it in his public lectures and in 1628 he published a treatise in Latin on the circulation. The chief arguments advanced in support of his views were the presence of valves in the heart and veins, the continuous movement of the blood in the same direction through the blood vessels, and the fact that the blood comes from a cut artery in jets, or spurts, that correspond to the contractions of the heart.

No other single discovery with reference to the human body has proved of such great importance. A knowledge of the nature and purpose of the circulation was the necessary first step in understanding the plan of the body and the method of maintaining life, and physiology as a science dates from the time of Harvey's discovery.

Organs of Circulation.—The organs of circulation, or blood vessels, are of four kinds, named the heart, the arteries, the
[041] capillaries, and the veins. They serve as contrivances both for holding the blood and for keeping it in motion through the body.

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[17] The term "circulation" literally means moving in a circle. While the blood does not move through the body in a circle, the term is justified by the fact that the blood flows out continually from a single point, the heart, and to this point is continually returning.

The heart, which is the chief organ for propelling the blood, acts as a force pump, while the arteries and veins serve as tubes for conveying the blood from place to place. Moreover, the blood vessels are so connected that the blood moves through them in a regular order, performing two well-defined circuits.

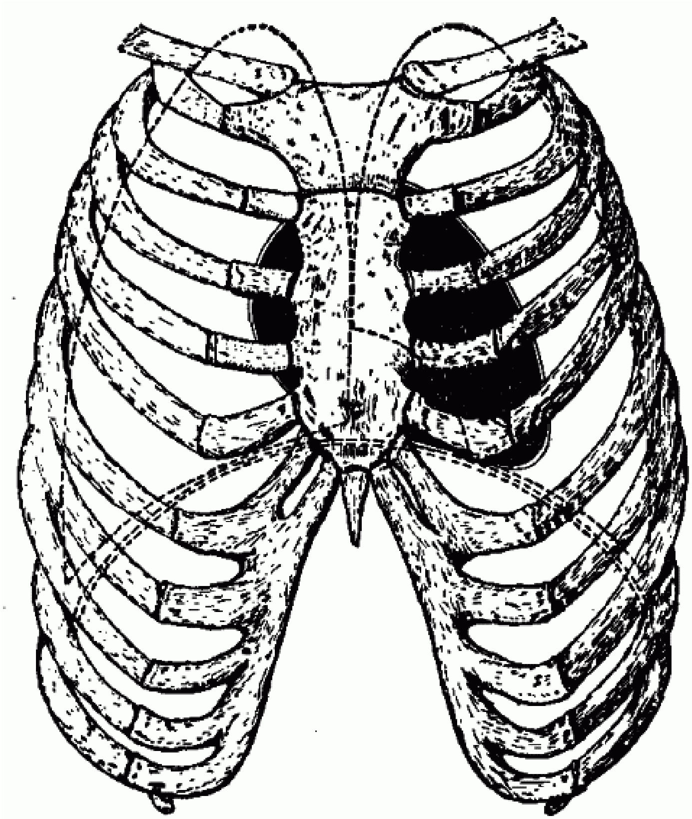

Fig. 13—**Heart** in position in thoracic cavity. Dotted lines show positin of diaphragm and of margins of lungs.

The Heart.—The human heart, roughly speaking, is about the size of the clenched fist of the individual owner. It is situated very near the center of the thoracic cavity and is almost completely surrounded by the lungs. It is cone-shaped and is so suspended that the small end hangs downward, forward, and a little to the left. When from excitement, or other cause, one becomes conscious of the movements of the heart, these appear to be in the left portion of the chest, a fact which accounts for the erroneous impression that the heart is on the left side. The position of the heart in the cavity of the chest is shown in Fig. 13.

The Pericardium.—Surrounding the heart is a protective covering, called the pericardium. This consists of a closed membranous sac so arranged as to form a double covering
[042] around the heart. The heart does not lie inside of the pericardial sac, as seems at first glance to be the case, but its relation to this space is like that of the hand to the inside of an empty sack which is laid around it (Fig. 14). The inner layer of the pericardium is closely attached to the heart muscle, forming for it an outside covering. The outer layer hangs loosely around the heart and is continuous with the inner layer at the top. The outer layer also connects at certain places with the membranes surrounding the lungs and is attached below to the diaphragm. Between the two layers of the pericardium is secreted a liquid which prevents friction from the movements of the heart.

Cavities of the Heart.—The heart is a hollow, muscular organ which has its interior divided by partitions into four distinct cavities. The main partition extends from top to bottom and divides the heart into two similar portions, named from their positions the right side and the left side. On each side are two cavities, the one being directly above the other. The upper cavities are called *auricles* and the lower ones *ventricles*. To distinguish these cavities further, they are named from their

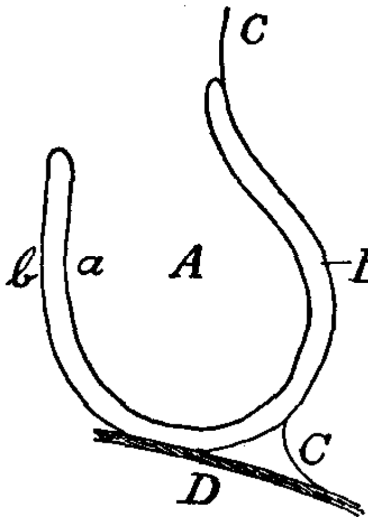

Fig. 14—**Diagram of section of the pericardial sac**, heart removed. *A.* Place occupied by the heart. *B.* Space inside of pericardial sac. *a*. Inner layer of pericardium and outer lining of heart. *b.* Outer layer of pericardium. *C*. Covering of lung. *D.* Diaphragm.

positions the right auricle and the left auricle, and the right ventricle and the left ventricle (Fig. 15). The auricles on each side communicate with the ventricles below; but after birth there is no communication between the cavities on the opposite sides of the heart. All the cavities of the heart are lined with a smooth, delicate membrane, called the *endocardium*.

[043] **Valves of the Heart.**—Located at suitable places in the heart are four gate-like contrivances, called valves. The purpose of these is *to give the blood a definite direction* in its movements. They consist of tough, inelastic sheets of connective tissue, and are so placed that pressure on one side causes them to come together and shut up the passageway, while pressure on the opposite side causes them to open. A valve is found at the opening of each auricle into the ventricle, and at the opening of each ventricle into the artery with which it is connected.

The valve between the right auricle and the right ventricle is called the *tricuspid* valve. It is suspended from a thin ring of connective tissue which surrounds the opening, and its free margins extend into the ventricle (Fig. 16). It consists of three parts, as its name implies, which are thrown together in closing the opening. Joined to the free edges of this valve are many small, tendinous cords which connect at their lower ends with muscular pillars in the walls of the ventricle. These are known as the *chordæ tendineæ*, or heart tendons. Their purpose is to serve as *valve stops*, to prevent the valve from being thrown, by the force of the blood stream, back into the auricle.

The *mitral*, or bicuspid, valve is suspended around the opening
[044] between the left auricle and the left ventricle, with the free margins extending into the ventricle. It is exactly similar in structure and arrangement to the tricuspid valve, except that it is stronger and is composed of two parts instead of three.

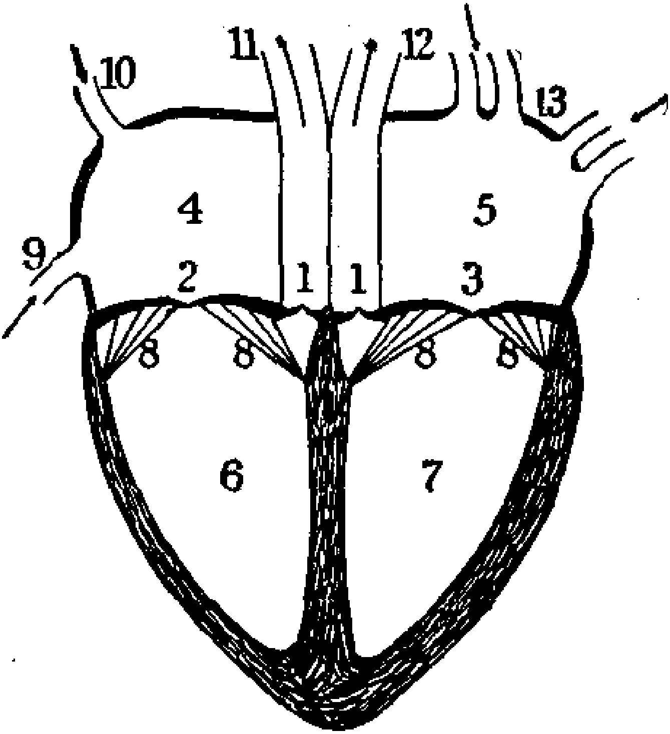

Fig. 15—**Diagram showing plan of the heart.** 1. Semilunar valves. 2. Tricuspid valve. 3. Mitral valve. 4. Right auricle. 5. Left auricle. 6. Right ventricle. 7. Left ventricle. 8. Chordæ tendineæ. 9. Inferior vena cava. 10. Superior vena cava. 11. Pulmonary artery. 12. Aorta. 13. Pulmonary veins.

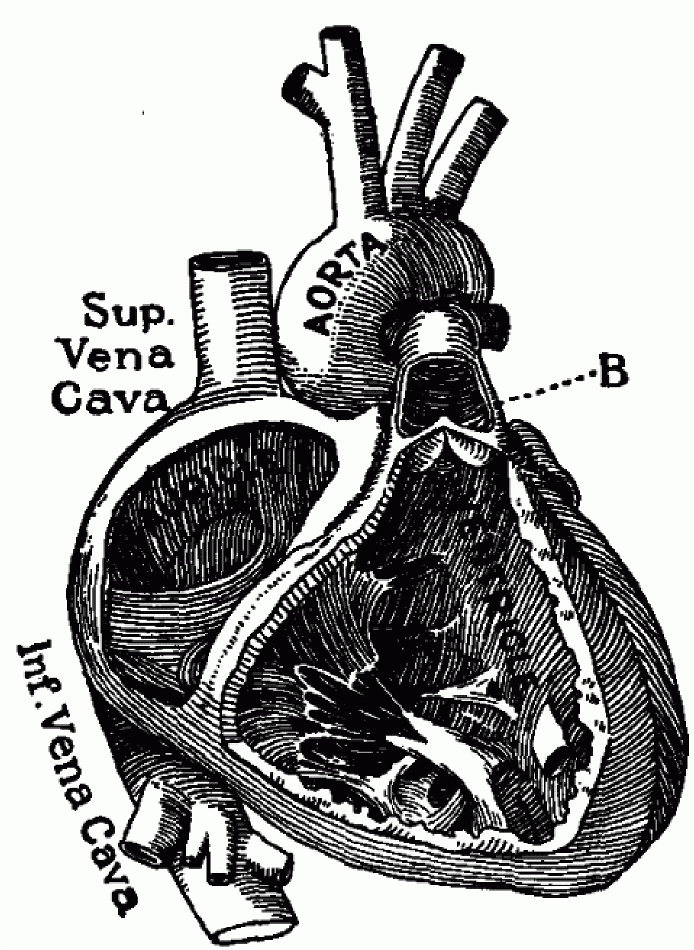

Fig. 16—**Right side of heart** dissected to show cavities and valves. *B.* Right semilunar valve. The tricuspid valve and the chordæ tendineæ shown in the ventricle.

The *right semilunar* valve is situated around the opening of the right ventricle into the pulmonary artery. It consists of three pocket-shaped strips of connective tissue which hang loosely from the walls when there is no pressure from above; but upon receiving pressure, the pockets fill and project into the opening, closing it completely (Fig. 16). The *left semilunar* valve is around the opening of the left ventricle into the aorta, and is similar in all respects to the right semilunar valve.

Differences in the Parts of the Heart.—Marked differences are found in the walls surrounding the different cavities of the heart. The walls of the ventricles are much thicker and stronger than those of the auricles, while the walls of the left ventricle are two or three times thicker than those of the right. A less marked but similar difference exists between the auricles and also between the valves on the two sides of the heart. These differences in structure are all accounted for by the work done by the different portions of the heart. The greater the work, the heavier the structures that perform the work.

Connection with Arteries and Veins.—Though the heart is [045]
in communication with all parts of the circulatory system, it makes actual connection with only a few of the blood tubes. These enter the heart at its upper portion (Fig. 15), but connect with its different cavities as follows:

1. *With the right auricle,* the superior and the inferior venæ cavæ and the coronary veins. The superior vena cava receives blood from the head and the upper extremities; the inferior vena cava, from the trunk and the lower extremities; and the coronary veins, from the heart itself.

2. *With the left auricle,* the four pulmonary veins. These receive blood from the lungs and empty it into the left auricle.

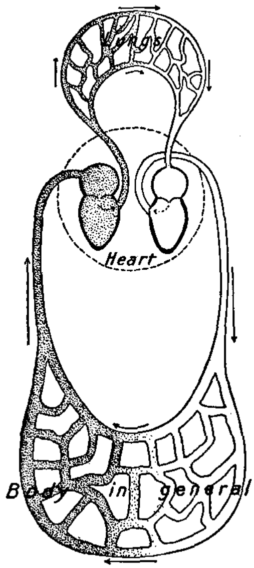

Fig. 17—**Diagram of the circulation**, showing in general the work done by each part of the heart. The right ventricle forces the blood through the lungs and into the left auricle. The left ventricle forces blood through all parts of the body and back to the auricle. The auricles force blood into the ventricles.

3. *With the right ventricle*, the pulmonary artery. This receives blood from the heart and by its branches distributes it to all parts of the lungs.

4. *With the left ventricle*, the aorta. The aorta receives blood from the heart and through its branches delivers it to all parts of the body.

How the Heart does its Work.—The heart is a muscular pump[18] and does its work through the contracting and relaxing [046] of its walls. During contraction the cavities are closed and the blood is forced out of them. During relaxation the cavities open and are refilled. The valves direct the flow of the blood, being so arranged as to keep it moving always in the same direction (Fig. 17).

The heart, however, is not a single or a simple pump, but consists in reality of *four* pumps which correspond to its different cavities. These connect with each other and with the blood vessels over the body in such a manner that each aids in the general movement of the blood.

Work of Auricles and Ventricles Compared.—In the work of the heart the two auricles contract at the same time—their contraction being followed immediately by the contraction of both ventricles. After the contraction of the ventricles comes a period of rest, or relaxation, about equal in time to the period of contraction of both the auricles and the ventricles.[19] On

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[18] The heart at first glance seems to bear little resemblance to the pumps in common use. When it is remembered, however, that any contrivance which moves a fluid by varying the size of a cavity is a pump, it is seen that not only the heart, but the chest in breathing and also the mouth in sucking a liquid through a tube, are pumps in principle. The ordinary syringe bulb illustrates the class of pumps to which the heart belongs. (See Practical Work.)

[19] The contraction of the heart is known as the *systole* and its relaxation as the *diastole*. The systole plus the diastole forms the so-called "cardiac cycle" (Fig. 18). This consists of (1) the contraction of the auricles, (2) the contraction

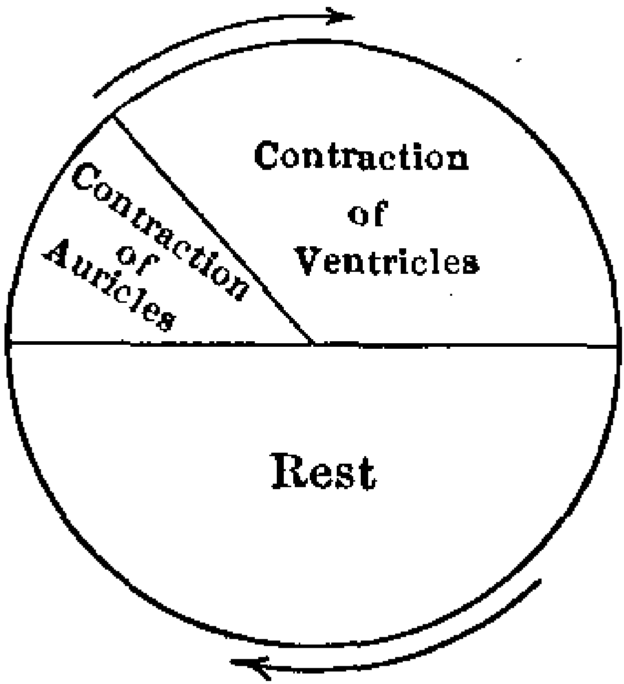

Fig. 18—Diagram illustrating the "cardiac cycle."

account of the work which they perform, the auricles have been called the "feed pumps" of the heart; and the ventricles, the "force pumps."[20] It is the function of the auricles to collect the blood from the veins, to let this run slowly into the ventricles when both the auricles and ventricles are relaxed, and finally, [047]
by contracting, *to force an excess of blood into the ventricles*, thereby distending their walls. The ventricles, having in this way been fully charged by the auricles, now contract and force their contents into the large arteries.

Sounds of the Heart.—Two distinct sounds are given out by the heart as it pumps the blood. One of them is a dull and rather heavy sound, while the other is a short, sharp sound. The short sound follows quickly after the dull sound and the two are fairly imitated by the words "lūbb, dŭp." While the cause of the first sound is not fully understood, most authorities believe it to be due to the contraction of the heart muscle and the sudden tension on the valve flaps. The second sound is due to the closing of the semilunar valves. These sounds are easily heard by placing an ear against the chest wall. They are of great value to the physician in determining the condition of the heart.

Arteries and Veins.—These form two systems of tubes which reach from the heart to all parts of the body. The arteries receive blood from the heart and distribute it to the capillaries. The veins receive the blood from the capillaries and return it to the heart. The arteries and veins are similar in structure, both having the form of tubes and both having three distinct layers, or coats, in their walls. The corresponding coats in the arteries and veins are made up of similar materials, as follows:

1. *The inner coat* consists of a delicate lining of flat cells resting upon a thin layer of connective tissue. The inner coat is continuous with the lining of the heart and provides a smooth

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of the ventricles, and (3) the period of rest. The heart systole includes the contraction of both the auricles and the ventricles.

[20] Martin, *The Human Body*.

surface over which the blood glides with little friction.

2. *The middle coat* consists mainly of non-striated, or involuntary, muscular fibers. This coat is quite thin in the veins, but in the arteries it is rather thick and strong.

[048] 3. *The outer coat* is made up of a variety of connective tissue and is also much thicker and stronger in the arteries than in the veins.

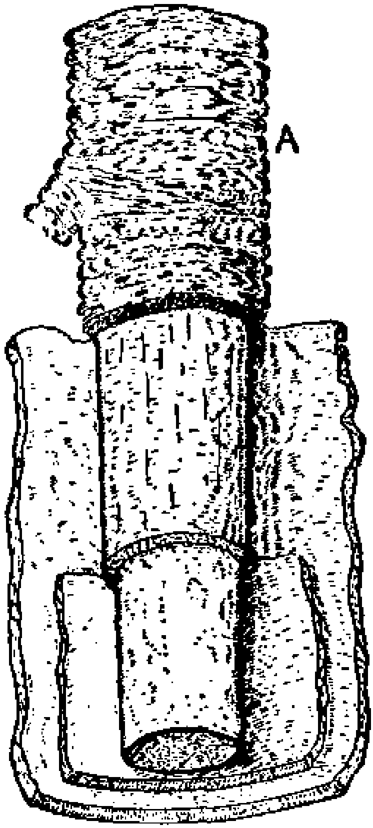

Fig. 19—Artery dissected to show the coats.

Marked differences exist between the arteries and the veins, and these vessels are readily distinguished from each other. The walls of the arteries are much thicker and heavier than those of the veins (Fig. 19). As a result these tubes stand open when empty, whereas the veins collapse. The arteries also are highly elastic, while the veins are but slightly elastic. On the other hand, many of the veins contain valves, formed by folds in the inner coat (Fig. 20), while the arteries have no valves. The blood flows more rapidly through the arteries than through the veins, the difference being due to the fact that the system of veins has a greater capacity than the system of arteries.

Why the Arteries are Elastic.—The elasticity of the arteries serves a twofold purpose. It keeps the arteries from bursting when the blood is forced into them from the ventricles, and it is a means of *supplying pressure to the blood while the ventricles are in a condition of relaxation.* The latter purpose is accomplished as follows:

Contraction of the ventricles fills the arteries overfull, causing them to swell out and make room for the excess of blood. Then while the ventricles are resting and filling, the stretched arteries press upon the blood to keep it flowing into the capillaries. In this [049]
way *they cause the intermittent flow from, the heart to become a steady stream in the capillaries*.

The swelling of the arteries at each contraction of the ventricle is easily felt at certain places in the body, such as the wrist. This expansion, known as the "pulse," is the chief means employed by the physician in determining the force and rapidity of the heart's action.

Purpose of the Valves in the Veins.—The valves in the veins are not used for directing the *general* flow of the blood, the valves of the heart being sufficient for this purpose. Their

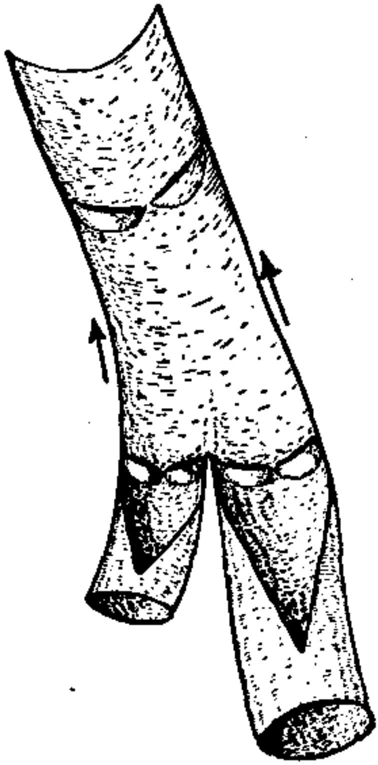

Fig. 20—Vein split open to show the valves.

presence is necessary because of the pressure to which the veins are subjected in different parts of the body. The contraction of a muscle will, for example, close the small veins in its vicinity and diminish the capacity of the larger ones. The natural tendency of such pressure is to empty the veins in two directions—one in the same direction as the regular movement of the blood, but the other in the opposite direction. The valves by closing cause the contracting muscle to push the blood in one direction only—toward the heart. The valves in the veins are, therefore, an economical device for *enabling variable pressure* in different parts of the body *to assist in the circulation*. Veins like the inferior vena cava and the veins of the brain, which are not compressed by movements of the body, do not have valves.

Purposes of the Muscular Coat.—The muscular coat, which is thicker in the arteries than in the veins and is more marked in small arteries than in large ones, serves two important purposes. In the first place it, together with the elastic tissue, keeps the capacity of the blood vessels *equal to the volume of the blood*. Since the blood vessels are capable of holding more blood than may be present at a given time in the body, there is a liability [050]
of empty spaces occurring in these tubes. Such spaces would seriously interfere with the circulation, since the heart pressure could not then reach all parts of the blood stream. This is prevented by the contracted state, or "tone," of the blood vessels, due to the muscular coat.

In the second place, the muscular coat serves the purpose of *regulating* the amount of blood which any given organ or part of the body receives. This it does by varying the caliber of the arteries going to the organ in question. To increase the blood supply, the muscular coat relaxes. The arteries are then dilated by the blood pressure from within so as to let through a larger quantity of blood. To diminish the supply, the muscle contracts, making the caliber of the arteries less, so that less blood can flow to this part of the body. Since the need of organs for blood varies with their activity, the muscular coat serves in this way a very necessary purpose.

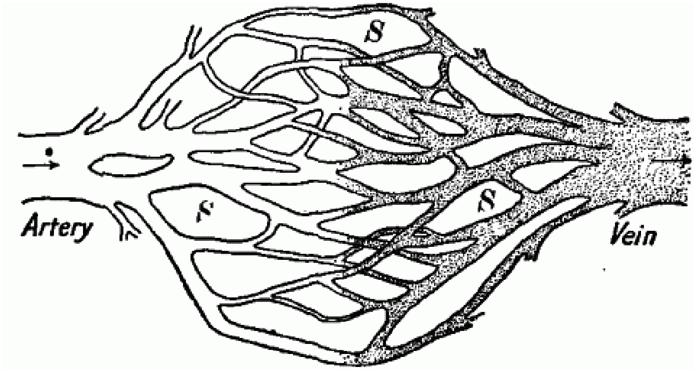

Fig. 21—Diagram of network of capillaries between a very small artery and a very small vein. Shading indicates the change of color of the blood as it passes through the capillaries. *S.* Places between capillaries occupied by the cells.

Capillaries.—The capillaries consist of a network of minute blood vessels which connect the terminations of the smallest arteries with the beginnings of the smallest veins (Fig. 21). They have an average diameter of less than one two-thousandth of an inch (12) and an average length of less than one twenty-fifth of
[051] an inch (1 millimeter). Their walls consist of a single coat which is continuous with the lining of the arteries and veins. This coat is formed of a single layer of thin, flat cells placed edge to edge (Fig. 22). With a few exceptions, the capillaries are found in great abundance in all parts of the body.

Functions of the Capillaries.—On account of the thinness of their walls, the capillaries are able to serve a twofold purpose in the body:

1. They admit materials into the blood vessels.

2. They allow materials to pass from the blood vessels to the surrounding tissues.

When it is remembered that the blood, as blood, does not escape from the blood vessels under normal conditions, the importance of the work of the capillaries is apparent. To serve its purpose as a carrier, there must be places where the blood can load up with the materials which it is to carry, and places also where these can be unloaded. Such places are supplied by the capillaries.

The capillaries also serve the purpose of spreading the blood out and of bringing it very near the individual cells in all parts of the body (Fig. 21).

Functions of Arteries and Veins.—While the capillaries provide the means whereby materials may both enter and leave the blood, the arteries and veins serve the general purpose of passing the blood from one set of capillaries to another. Since pressure is necessary for moving the blood, these tubes must connect with the source of the pressure, which is the heart. In the arteries and veins the blood neither receives nor gives up material, but having received or given up material at one set of capillaries, it is then pushed through these tubes to where it can serve a similar purpose in another set of capillaries (Fig. 23).

Divisions of the Circulation.—Man, in common with all warm-blooded animals, has a double circulation, a fact which [052]
explains the double structure of his heart. The two divisions are known as the *pulmonary* and the *systemic* circulations. By the former the blood passes from the right ventricle through the lungs, and is then returned to the left auricle; by the latter it passes from the left ventricle through all parts of the body, returning to the right auricle.

The general plan of the circulation is indicated in Fig. 23. All the blood flows continuously through both circulations and passes the various parts in the following order: right auricle, tricuspid valve, right ventricle, right semilunar valve, pulmonary artery and its branches, capillaries of the lungs, pulmonary veins, left auricle, mitral valve, left ventricle, left semilunar valve, aorta and its branches, systemic capillaries, the smaller veins, superior and inferior venæ cavæ, and then again into the right auricle.

In the pulmonary capillaries the blood gives up carbon dioxide and receives oxygen, changing from a dark red to a bright red color. In the systemic capillaries it gives up oxygen, receives carbon dioxide and other impurities, and changes back to a dark red color.

In addition to the two main divisions of the circulation, special circuits are found in various places. Such a circuit in the liver is called the *portal* circulation, and another in the kidneys is termed the *renal* circulation. To some extent the blood supply to the walls of the heart is also outside of the general movement; it is called the *coronary* circulation.

Blood Pressure and Velocity.—The blood, in obedience to physical laws, passes continuously through the blood vessels, moving always from a place of greater to one of less pressure. Through the contraction of the ventricles, a relatively high pressure is maintained in the arteries nearest the heart.[21] This pressure
[054] diminishes rapidly in the small arteries, becomes comparatively slight in the capillaries, and falls practically to nothing in the veins. Near the heart in the superior and inferior venæ cavæ, the

[21] The pressure maintained by the left ventricle has been estimated to be nearly three and one half pounds to the square inch—a pressure sufficient to sustain a column of water eight feet high. The pressure maintained by the right ventricle is about one third as great. In maintaining this pressure the heart does a work equal to about one two-hundredth of a horse power.

pressure at intervals is said to be *negative*. This means that the blood from these veins is actually drawn into the right auricle by the expansion of the chest walls in breathing.[22]

The velocity of the blood is greatest in the arteries, less in the veins, and *much* less in the capillaries than in either the arteries or the veins. The slower flow of the blood through the capillaries is accounted for by the fact that their united area is many times greater than that of the arteries which supply, or the veins which relieve, them. This allows the same quantity of blood, flowing through them in a given time, a wider channel and causes it to move more slowly. The time required for a complete circulation is less than one minute.

Summary of Causes of Circulation.—The chief factor in the circulation of the blood is, of course, the heart. The ventricles keep a pressure on the blood which is sufficient to force it through all the blood tubes and back to the auricles. The heart is aided in its work by the elasticity of the arteries, which keeps the blood under pressure while the ventricles are in a state of relaxation. It is also aided by the muscles and elastic tissue in all of the blood vessels. These, by keeping the blood vessels in a state of "tone," or so contracted that their capacity just equals the volume of the blood, enable pressure from the heart to be transmitted to all parts of the blood stream. A further aid to the circulation is found in the valves in the veins, which enable muscular contraction within the body, and variable pressure upon its surface, to drive the blood toward the heart. The heart is also aided to some extent by the movements of the chest walls in breathing. The organs Of circulation are under the control of the nervous system (Chapter XVIII).

[055]

[22] The location of the heart in the thoracic cavity causes movements of the chest walls to draw blood into the right auricle for the same reason that they "draw" air into the lungs.

HYGIENE OF THE CIRCULATION

Care of the Heart.—The heart, consisting largely of muscle, is subject to the laws of muscular exercise. It may be injured by over-exertion, but is strengthened by a moderate increase in its usual work.[23] It may even be subjected to great exertion without danger, if it be trained by gradually increasing its work. Such training, by giving the heart time to gain in size and strength, prepares it for tasks that could not at first be accomplished.

In taking up a new exercise requiring considerable exertion, precautions should be observed to prevent an overstrain of the heart. The heart of the amateur athlete, bicyclist, or mountain climber is frequently injured by attempting more than the previous training warrants. The new work should be taken up gradually, and feats requiring a large outlay of physical energy should be attempted only after long periods of training.

Since the heart is controlled by the nervous system, it frequently becomes irregular in its action through conditions that exhaust the nervous energy. Palpitations of the heart, the missing of beats, and pains in the heart region frequently arise from this cause. It is through their effect upon the nervous system that worry, overstudy, undue excitement, and dissipation cause disturbances of the heart. In all such cases the remedy lies in the removal of the cause. The nervous system should also be "toned up" through rest, plenty of sleep, and moderate exercise in the open air.

Effect of Drugs.—A number of substances classed as drugs,
[056] mainly by their action on the nervous system, produce undesirable effects upon the organs of circulation. Unfortunately some of these are extensively used, alcohol being one of them. If taken in any but small quantities, alcohol is a disturbing factor in the

[23] Active exercise through short intervals, followed by periods of rest, such as the exercise furnished by climbing stairs, or by short runs, is considered the best means of strengthening the heart.

circulation. It increases the rate of the heart beat and dilates the capillaries. Its effect upon the capillaries is shown by the "bloodshot" eye and the "red nose" of the hard drinker. Another bad effect from the use of much alcohol is the weakening of the heart through the accumulation of fat around this organ and within the heart muscle. The use of alcohol also leads in many cases to a hardening of the walls of the arteries, such as occurs in old age. This effect makes the use of alcohol especially dangerous for those in advanced years.

Tobacco contains a drug, called nicotine, which has a bad effect upon the heart in at least two ways: 1. When the use of tobacco is begun in early life, it interferes with the growth of the heart, leading to its weakness in the adult. 2. When used in considerable quantity, by young or old, it causes a nervous condition both distressing and dangerous, known as "tobacco heart."

Tea and coffee contain a drug, called caffeine, which acts upon the nervous system and which may, on this account, interfere with the proper control of the heart. In some individuals the taking of a very small amount of either tea or coffee is sufficient to cause irregularities in the action of the heart. Tea is considered the milder of the two liquids and the one less liable to injure.

Effect of Rheumatism.—The disease which affects the heart more frequently than any other is rheumatism. This attacks the lining membrane, or endocardium, and causes, not infrequently, a shrinkage of the heart valves. The heart is thus rendered defective and, to perform its function in the body, must work harder than [057]
if it were in a normal condition. Rheumatic attacks of the heart do most harm when they occur in early life—the period when the valves are the most easily affected. Any tendency toward rheumatism in children has, therefore, a serious significance and should receive the attention of the physician. Any one having a defective heart should avoid all forms of exercise that demand great exertion.

Strengthening of the Blood Vessels.—Disturbances of the circulation, causing too much blood to be sent to certain parts of the body and an insufficient amount to others, when resulting from slight causes, are usually due to weakness of the walls of the blood vessels, particularly of the muscular coat. Such weakness is frequently indicated by extreme sensitiveness to heat or cold and by a tendency to "catch cold." From a health standpoint the preservation of the normal muscular "tone" of the blood vessels is a problem of great importance. Though the muscles of the blood vessels cannot be exercised in the same manner as the voluntary muscles, they may be called actively into play through all the conditions that induce changes in the blood supply to different parts of the body. The usual forms of physical exercise necessitate such changes and indirectly exercise the muscular coat. The exposure of the body to cold for short intervals, because of the changes in the circulation which this induces, also serves the same purpose. A cold bath taken with proper precautions is beneficial to the circulation of many and so also is a brisk walk on a frosty morning. Both indirectly exercise and strengthen the muscular coat of the blood vessels. On the other hand, too much time spent indoors, especially in overheated rooms, leads to a weakening of the muscular coat and should be avoided.

[058] **Checking of Flow of Blood from Wounds.**—The loss of any considerable quantity of blood is such a serious matter that every one should know the simpler methods of checking its flow from wounds. In small wounds the flow is easily checked by binding cotton or linen fiber over the place. The absorbent cotton, sold in small packages at drug stores, is excellent for this purpose and should be kept in every home. A simple method of checking "nosebleed" is that of drawing air through the bleeding nostril, while the other nostril is compressed with the finger.[24] Another

[24] Nosebleed in connection with any kind of severe sickness should receive prompt attention, since a considerable loss of blood when the body is already

method is to "press with the finger (or insert a small roll of paper) under the lip against the base of the nose." [25] Where the bleeding is persistent, the nostril should be plugged with a small roll of clean cotton or paper. When this is done, the plug should not be removed too soon because of the likelihood of starting the flow afresh.

In dealing with large wounds the services of a physician are indispensable. But in waiting for the physician to arrive temporary aid must be rendered. The one who gives such aid should first decide whether an artery or a vein has been injured. This is easily determined by the nature of the blood stream, which is in jets, or spurts, from an artery, but flows steadily from a vein. If an artery is injured, the limb should be tightly bandaged on the side of the wound nearest the heart; if a vein, on the side farthest from the heart. In addition to this, the edges of the wound should be closed and covered with cotton fiber and the limb should be placed on a support above the level of the rest of the body. A large handkerchief makes a convenient bandage if properly applied. This should be folded diagonally and a knot tied in the middle. [059]
Opposite ends are then tied, making a loose-fitting loop around the limb. The knot is placed directly over the blood vessel to be compressed and a short stick inserted in the loop. The necessary pressure is then applied by twisting the handkerchief with the stick. Time must not be lost, however, in the preparation of a suitable bandage. The blood vessel should be compressed with the fingers while the bandage is being prepared.

Summary.—The blood, to serve as a transporting agent, must be kept continually moving through all parts of the body. The blood vessels hold the blood, supply the channels and force necessary for its circulation, and provide conditions which enable materials both to enter and to leave the blood stream. The heart is the chief factor in propelling the blood, although the muscles

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weak may seriously delay recovery.

[25] Newton, *Practical Hygiene*.

and the elastic tissue in the walls of the arteries and the valves in the veins are necessary aids in the process. In the capillaries the blood takes on and gives off materials, while the arteries and veins serve chiefly as tubes for conveying the blood from one system of capillaries to another.

Exercises.—1. Of what special value in the study of the body was the discovery of the circulation of the blood?

2. State the necessity for a circulating liquid in the body.

3. Show by a drawing the general plan of the heart, locating and naming the essential parts. Show also the connection of the large blood vessels with the cavities of the heart.

4. Compare the purpose served by the chordæ tendineæ to that served by doorstops (the strips against which the door strikes in closing).

5. Explain how the heart propels the blood. To what class of pumps does it belong? What special work is performed by each of its divisions?

6. Define a valve. Of what use are the valves in the heart? In the veins?

[060] 7. By what means is pressure from contracting muscles in different parts of the body made to assist in the circulation?

8. Of what advantage is the elasticity of the arteries?

9. How is blood forced from the capillaries back to the heart?

10. Why should there be a difference in structure between the two sides of the heart?

11. Following Fig. 23, trace the blood through a complete circulation, naming all the divisions of the system in the order of the flow of the blood.

12. If the period of rest following the period of contraction of the heart be as long as the period of contraction, how many hours is the heart able to rest out of every twenty-four?

13. State the functions of the capillaries. Show how their structure adapts them to their work.

14. What kind of physical exercise tends to strengthen the heart? What forms of exercise tend to injure it? State the effects of alcohol and tobacco on the heart.

15. How may rheumatism injure the heart?

16. Give directions for checking the flow of blood from small and from large blood vessels.

PRACTICAL WORK

In showing the relations of the different parts of the heart, a large dissectible model is of great service (Fig. 24). Indeed, where the time of the class is limited, the practical work may be confined to the study of the heart model, diagrams of the heart and the circulation, and a few simple experiments. However, where the course is more extended, the dissection of the heart of some animal as described below is strongly advised.

Observations on the Heart.—Procure, by the assistance of a butcher, the heart of a sheep, calf, or hog. To insure the specimen against mutilation, the lungs and the diaphragm must be left attached to the heart. In studying the different parts, good results will be obtained by observing the following order:

1. Observe the connection of the heart to the lungs, diaphragm, and large blood vessels. Inflate the lungs and observe the position of the heart with reference to them.

2. Examine the sac surrounding the heart, called the *pericardium*. Pierce its lower portion and collect the pericardial fluid. Increase the opening thus made until it is large enough to [061] slip the heart out through it. Then slide back the pericardium until its connection with the large blood vessels above the heart is found. Observe that a thin layer of it continues down from this attachment, forming the outer covering of the heart.

3. Trace out for a short distance and study the veins and arteries connected with the heart. The arteries are to be distinguished by their thick walls. The heart may now be severed from the lungs

by cutting the large blood vessels, care being taken to leave a considerable length of each one attached to the heart.

4. Observe the outside of the heart. The thick, lower portion contains the cavities called *ventricles*; the thin, upper, ear-shaped portions are the *auricles*. The thicker and denser side lies toward the left of the animal's body and is called the *left* side of the heart; the other is the *right* side. Locate the right auricle and the right ventricle; the left auricle and the left ventricle.

5. Lay the heart on the table with the front side up and the apex pointing from the operator. This places the left side of the heart to his left and the right side to his right. Notice the groove between the ventricles, called the inter-ventricular groove. Make an incision half an inch to the right of this groove and cut toward the base of the heart until the pulmonary artery is laid open. Then, following within half an inch of the groove, cut down and around the right side of the heart. The wall of the right ventricle may now be raised and the cavity exposed. Observe the extent of the cavity, its shape, its lining, its columns of muscles, its half columns of muscles, its tendons (chordæ tendineæ), the tricuspid valve from the under side, etc. Also notice the valve at the beginning of the pulmonary artery (the right semilunar) and the sinuses, or depressions, in the artery immediately behind its divisions.

6. Now cut through the middle of the loosened ventricular wall from the apex to the middle of the right auricle, laying it open for
[062] observation. Observe the openings into the auricle, there being one each for the vena cava superior, the vena cava inferior, and the coronary vein. Compare the walls, lining, shape, size, etc., with the ventricle below.

7. Cut off the end of the left ventricle about an inch above the apex. This will show the extension of the cavity to the apex; it will also show the thickness of the walls and the shape of the

cavity. Split up the ventricular wall far enough to examine the mitral valve and the chordæ tendineæ from the lower side.

8. Make an incision in the left auricle. Examine its inner surface and find the places of entrance of the pulmonary veins. Examine the mitral valve from above. Compare the two sides of the heart, part for part.

9. Separate the aorta from the other blood vessels and cut it entirely free from the heart, care being taken to leave enough of the heart attached to the artery to insure the semilunar valve's being left in good condition. After tying or plugging up the holes in the sides of the artery, pour water into the small end and observe the closing of the semilunar valve. Repeat the experiment until the action of the valve is understood. Sketch the artery, showing the valve in a closed condition.

To illustrate the Action of a Ventricle.—Procure a syringe bulb with an opening at each end. Connect a rubber tube with each opening, letting the tubes reach into two tumblers containing water. By alternately compressing and releasing the bulb, water is pumped from one vessel into the other. The bulb may be taken to represent one of the ventricles. What action of the ventricle is represented by compressing the bulb? By releasing the pressure? Show by a sectional drawing the arrangement of the valves in the syringe bulb.

To show the Advantage of the Elasticity of Arteries.—Connect the syringe bulb used in the last experiment with a rubber tube three or four feet in length and having rather thin walls. In the opposite end of the rubber tube insert a short glass tube which has been drawn (by heating) to a fine point (Fig. 25). Pump water into the rubber tube, observing:

1. The swelling of the tube (pulse) as the water is forced into it. (This is best observed by placing the fingers on the tube.)

2. The forcing of water from the pointed tubs during the inter- [063]

val when no pressure is being applied from the bulb. Compare with the action of the arteries when blood is forced into them from the ventricles.

Repeat the experiment, using a long glass tube terminating in a point instead of the rubber tube. (In fitting the glass tube to the bulb use a very short rubber tube.) Observe and account for the differences in the flow of water through the inelastic tube.

To show the Advantage of Valves in the Veins.—Attach an open glass tube one foot in length to each end of the rubber tube used in the preceding experiment and fill with water (by sucking) to within about six inches of the end. Lay on the table with the glass tubes secured in an upright position (Fig. 26). Now compress the tube with the hand, noting that the water rises in both tubes, being pushed in both directions. This effect is similar to that produced on the blood when a vein having no valves is compressed.

Now imitate the action of a valve by clamping the tube at one point, or by closing it by pressure from the finger, and then compressing with the hand some portion of the tube on the table. Observe in this instance that the water is **all** pushed in the same direction. The movement of the water is now like the effect produced on the blood in veins having valves when the veins are compressed.

To show the Position of the Valves in the Veins.—Exercise the arm and hand for a moment to increase the blood supply. Expose the forearm and examine the veins on its surface. With a finger, stroke one of the veins toward the heart, noting that, as the blood is pushed along on one side of the finger the blood follows on the other side. Now stroke the vein toward the hand. Places are found beyond which the blood does not follow the finger. These mark the positions of valves.

To show Effect of Exercise upon the Circulation.—1. With a finger on the "pulse" at the wrist or temple, count the number of heart beats during a period of one minute under the following conditions: (*a*) when sitting; (*b*) when standing; (*c*) after active exercise, as running. What relation, if any, do these observations indicate between the general activity of the body and the work of the heart?

2. Compare the size of the veins on the backs of the hands when they are placed side by side on a table. Then exercise briskly the right hand and arm, clenching and unclenching the [064]
fist and flexing the arm at the elbow. Place the hands again side by side and, after waiting a minute, observe the increase in the size of the veins in the hand exercised. How is this accounted for?

To Show the Effect of Gravity on the Circulation.—Hold one hand high above the head, at the same time letting the other hand hang loosely by the side. Observe the difference in the color of the hands and the degree to which the large veins are filled. Repeat the experiment, reversing the position of the hands. What results are observed? In what parts of the body does gravity aid in the return of the blood to the heart? In what parts does it hinder? Where fainting is caused by lack of blood in the brain (the usual cause), is it better to let the patient lie down flat or to force him into a sitting posture?

To study the Circulation in a Frog's Foot (Optional).—A compound microscope is needed in this study and for extended examination it is best to destroy the frog's brain. This is done by inserting some blunt-pointed instrument into the skull cavity from the neck and moving it about. A small frog, on account of the thinness of its webs, gives the best results. It should be attached to a thin board which has an opening in one end over which the web of the foot may be stretched. Threads should extend from two of the toes to pins driven into the board to secure the necessary tension of the web, and the foot and lower leg should be kept moist. Using a two-thirds-inch objective, observe the branching of the small arteries into the capillaries and the union of the capillaries to form the small veins. The appearance is truly wonderful, but allowance must be made for the fact that the *motion* of the blood is magnified, as well as the different structures, and that it appears to move much faster than it really does. With a still higher power, the movements of the corpuscles through the capillaries may be studied.

NOTE.—To perform this experiment without destroying the brain, the frog is first carefully wrapped with strips of wet cloth and securely tied to the board. The wrapping, while preventing movements of the frog, must not interfere with the circulation.

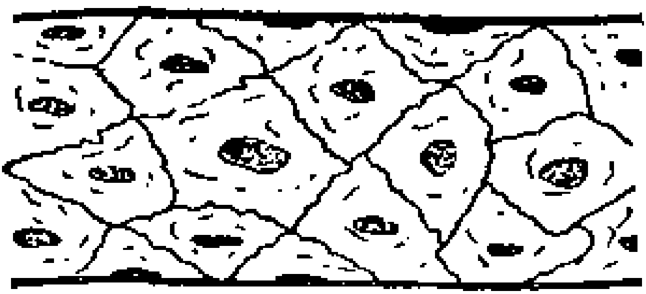

Fig. 22—**Surface of capillary** highly magnified, showing its coat of thin cells placed edge to edge.

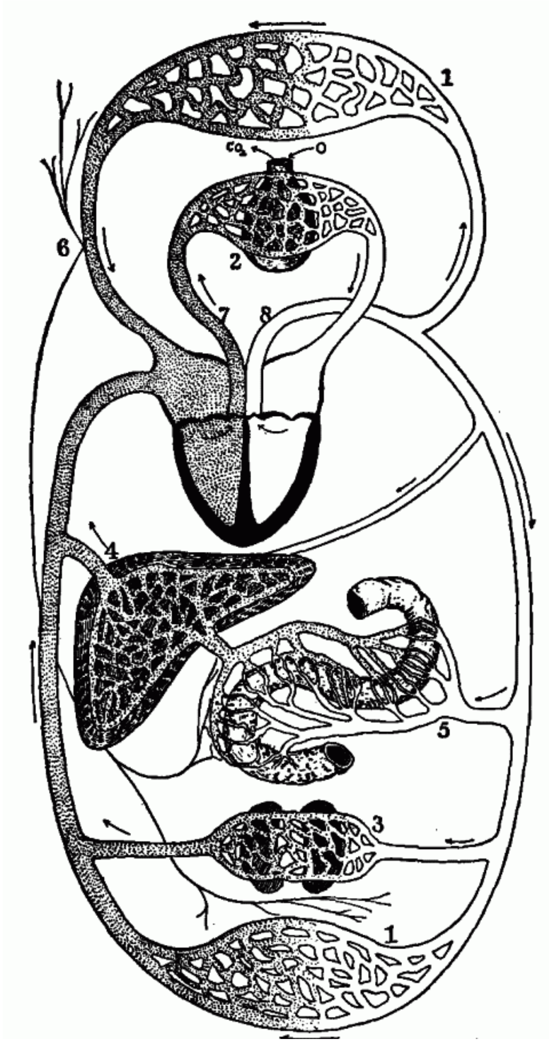

Fig. 23—**General scheme of the circulation**, showing places where the blood takes on and gives off materials. 1. Body in general. 2. Lungs. 3. Kidneys. 4. Liver. 5. Organs of digestion. 6. Lymph ducts. 7. Pulmonary artery. 8. Aorta.

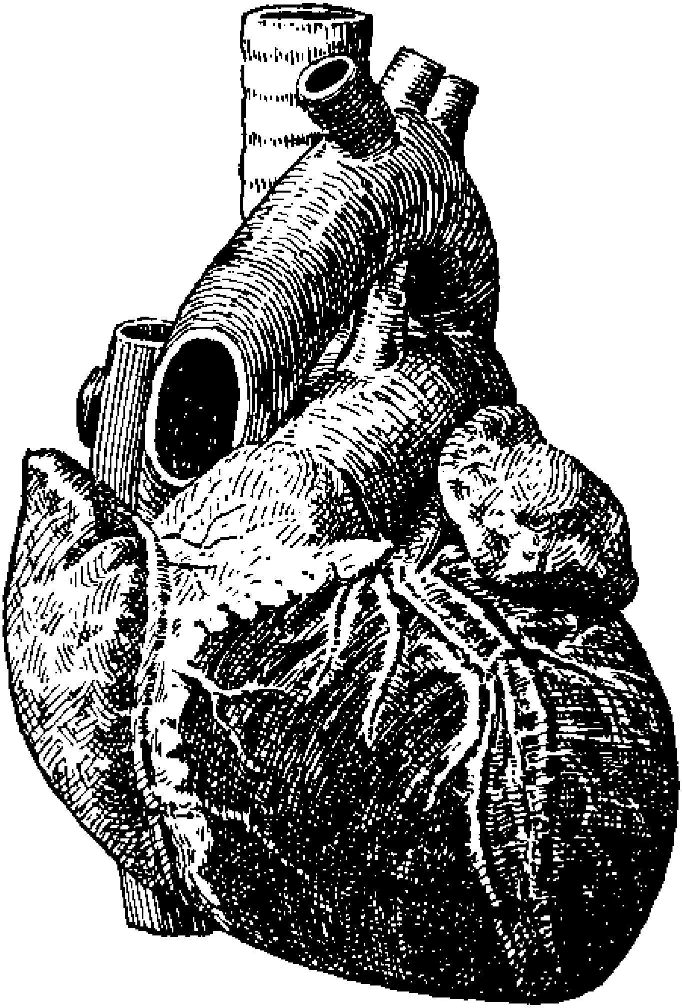

Fig. 24—Model for demonstrating the heart.

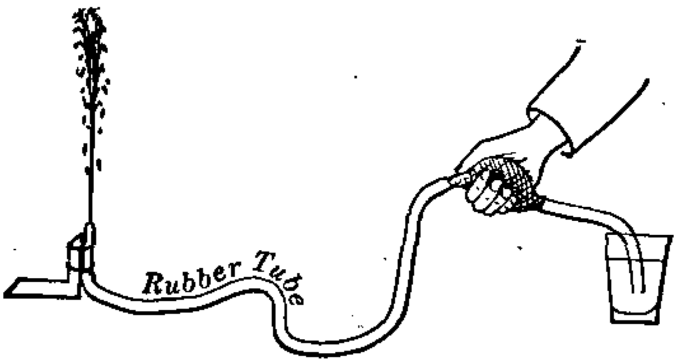

Fig. 25—Illustrating elasticity of arteries.

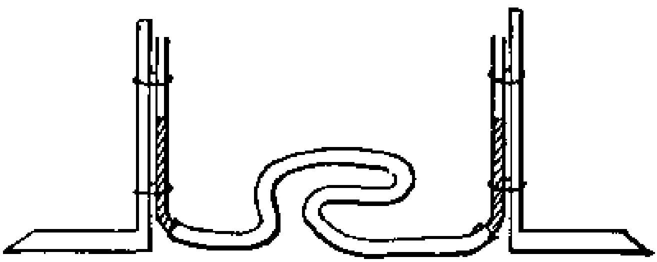

Fig. 26.—**Simple apparatus** for showing advantage of valves in veins.

[065]

CHAPTER VI - THE LYMPH AND ITS MOVEMENT THROUGH THE BODY

The blood, it will be remembered, moves everywhere through the body in a system of *closed* tubes. These keep it from coming in contact with any of the cells of the body except those lining the tubes themselves. The capillaries, to be sure, bring the blood very near the cells of the different tissues; still, there is need of a liquid to fill the space between the capillaries and the cells and to transfer materials from one to the other. The lymph occupies this position and does this work. The position of the lymph with reference to the capillaries and the cells is shown in Fig. 27.

Origin of the Lymph.—The chief source of the lymph is the plasma of the blood. As before described, the walls of the capillaries consist of a single layer of flat cells placed edge to edge. Partly on account of the pressure upon the blood and partly on account of the natural tendency of liquids to pass through animal membranes, a considerable portion of the plasma penetrates the thin walls and enters the spaces occupied by the lymph.

The cells themselves also help to form the lymph, since the [066] water and wastes leaving the cells add to its bulk. These mix with the plasma from the blood, forming the resultant liquid which is the lymph. A considerable amount of the material absorbed from the food canal also enters the lymph tubes, but this passes into the blood before reaching the cells.

Composition and Physical Properties of the Lymph.[26]—As

[26] On account of its position in the body, the lymph is not easily collected for examination. Still, nearly every one will recall some experience that has enabled him to see lymph. The liquid in a water blister is lymph, and so also is the liquid which oozes from the skin when it is scraped or slightly scratched.

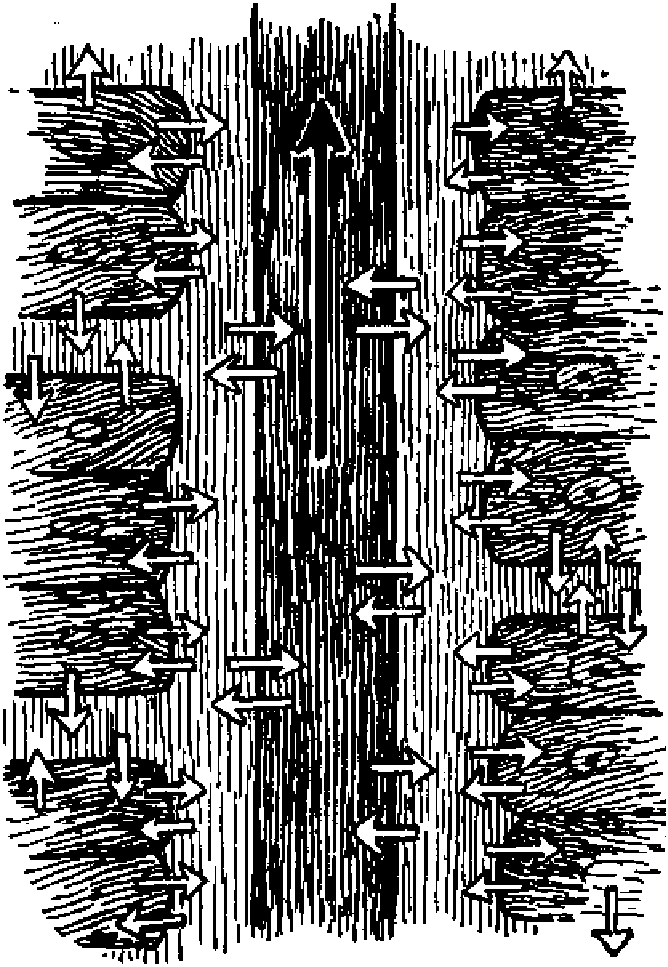

Fig. 27—**Diagram showing position of the lymph** with reference to the blood and the cells. The central tube is a capillary. The arrows indicate the direction of slight movements in the lymph.

would naturally be expected, the composition of the lymph is similar to that of the blood. In fact, nearly all the important constituents of the blood are found in the lymph, but in different proportions. Food materials for the cells are present in smaller amounts than in the blood, while impurities from the cells are in larger amounts. As a rule the red corpuscles are absent from the lymph, but the white corpuscles are present and in about the same numbers as in the blood.

The physical properties of the lymph are also similar to those of the blood. Like the blood, the lymph is denser than water and also coagulates, but it coagulates more slowly than does the blood. The most noticeable difference between these liquids is that of color, the lymph being colorless. This is due to the absence of red corpuscles. The quantity of lymph is estimated to be considerably greater than that of the blood.

Lymph Vessels.—Most of the lymph lies in minute cavities surrounding the cells and in close relations with the capillaries (Figs. 27 and 30). These are called *lymph spaces*. Connecting with the lymph spaces on the one hand, and with certain blood [067]
vessels on the other, is a system of tubes that return the lymph to the blood stream. The smallest of these, and the ones in greatest abundance, are called *lymphatics*. They consist of slender, thin-walled tubes, which resemble veins in structure, and, like the veins, have valves. They differ from veins, however, in being more uniform in size and in having thinner walls.

The lymphatics in different places gradually converge toward, and empty into, the two main lymph tubes of the body. The smaller of these tubes, called the *right lymphatic duct*, receives the lymph from the lymphatics in the right arm, the right side of the head, and the region of the right shoulder. It connects with,

Swelling in any part of the body is due to the accumulation of lymph at that place.

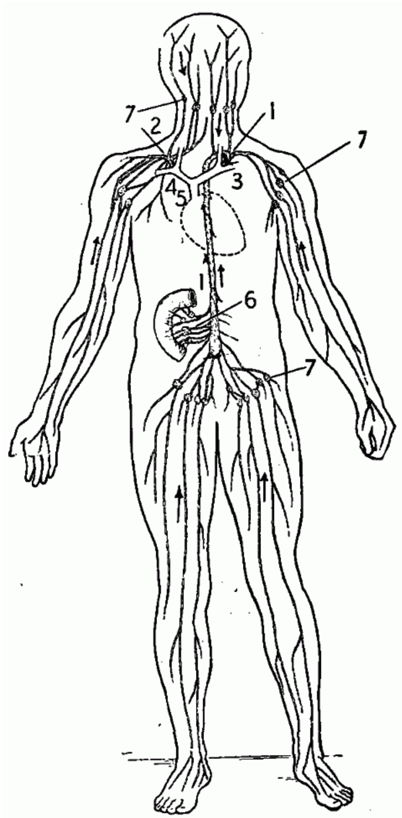

Fig. 28—**Diagram of drainage system for the lymph.** 1. Thoracic duct. 2. Right lymphatic duct. 3. Left subclavian vein. 4. Right subclavian vein. 5. Superior vena cava. 6. Lacteals. 7. Lymphatic glands. The small tubes connecting with the lymph spaces in all parts of the body are the lymphatics.

and empties its contents into, the right subclavian vein at the place where it is joined by the right jugular vein (Fig. 28).

The larger of the lymph tubes is called the *thoracic duct*. This receives lymph from all parts of the body not drained by the [068] right lymphatic duct, and empties it into the left subclavian vein. Connection is made with the subclavian vein on the upper side at the place where it is joined by the left jugular vein. The thoracic duct has a length of from sixteen to eighteen inches, and is about as large around as a goose quill. The lower end terminates in an enlargement in the abdominal cavity, called the *receptacle of the chyle*. It is provided with valves throughout its course, in addition to one of considerable size which guards the opening into the blood vessel.

The lymphatics which join the thoracic duct from the small intestine are called the *lacteals* (Fig. 28). These do not differ in structure from the lymphatics in other parts of the body, but they perform a special work in absorbing the digested fat (Chapter XI).

Lymphatic Glands.—The lymphatic glands, sometimes called lymph nodes, are small and somewhat rounded bodies situated along the course of the lymphatic tubes. They vary in size, some of them being an inch or more in length. The lymph vessels generally open into them on one side and leave them on the other (Figs. 28 and 30). They are not glands in function, but are so called because of their having the general form of glands. They provide favorable conditions for the development of white corpuscles (page 29). They also separate harmful germs and poisonous wastes from the lymph, thereby preventing their entrance into the blood.

Relations of the Lymph, the Blood, and the Cells.—While the blood is necessary as a carrying, or transporting, agent in the body, the lymph is necessary for transferring materials from the blood to the cells and *vice versa*. Serving as a physiological "go between," or medium of exchange, the lymph enables the

[069] blood to minister to the needs of the cells. But the lymph and the blood, everything considered, can hardly be looked upon as two separate and distinct liquids. Not only do they supplement each other in their work and possess striking similarities, but each is made in its movements to pass into the vessels occupied by the other, so that they are constantly mixing and mingling. For these and other reasons, they are more properly regarded as two divisions of a single liquid—one which, by adapting itself to different purposes,[27] supplies all the conditions of a nutrient fluid for the cells.

Movements of the Lymph.—As compared with the blood, the lymph must be classed as a quiet liquid. But, as already suggested, it has certain movements which are necessary to the purposes which it serves. A careful study shows it to have three well-defined movements as follows:

1. A movement from the capillaries toward the cells.
2. A movement from the cells toward the capillaries.
3. A movement of the entire body of lymph from the lymph spaces into the lymphatics and along these channels to the ducts through which it enters the blood.

By the first movement the cells receive their nourishment. By the second and third movements the lymph, more or less laden with impurities, is returned to the blood stream. (See Figs. 28 and 30.)

Causes of the Lymph Movements.—Let us consider first the movement through the lymph tubes. No pump, like the heart,
[070] is known to be connected with these tubes and to supply the

[27] In certain small animals of the lowest types a single liquid, serving as a medium of exchange between the cells and the body surface, supplies all the needs of the organism. In larger animals, however, where materials have to be moved from one part of the cell group to another, a portion of the nutrient fluid is used for purposes of transportation. This is confined in channels where it is set in motion by suitable organs. The portion which remains outside of the channels then transfers material between the cells, on the one hand, and the moving liquid, on the other.

pressure necessary for moving the lymph. There are, however, several forces that indirectly aid in its flow. The most important of these are as follows:

1. *Blood Pressure at the Capillaries.*—The plasma which is forced through the capillary walls by pressure from the heart makes room for itself by pushing a portion of the lymph out of the lymph spaces. This in turn presses upon the lymph in the tubes which it enters. In this way pressure from the heart is transmitted to the lymph, forcing it to move.

2. *Variable Pressure on the Walls of the Lymph Vessels.*—Pressure exerted on the sides of the lymph tubes by contracting muscles tends to close them up and to push the lymph past the valves, which, by closing, prevent its return (Fig. 29). Pressure at the surface of the body, provided that it is variable, also forces the lymph along. The valves in the lymph vessels serve the same purpose as those in the veins.

3. *The Inspiratory Force.*—When the thoracic cavity is enlarged in breathing, the unbalanced atmospheric pressure is exerted from all directions towards the thoracic space. This not only causes the air to flow into the lungs (Chapter VII), but also causes a movement of the blood and lymph in such of their tubes as enter this cavity. It will be noted that both of the large lymph ducts terminate where their contents may be influenced by the respiratory movements. (See Practical Work.)

Where the Lymph enters the Blood.—The fact that the lymph is poured into the blood at but two places, and these very close to each other, requires a word of explanation. As a matter [071]
of fact, it is impossible for the lymph to flow into blood vessels at most places on account of the blood pressure. This would force the blood into the lymph vessels, instead of allowing the lymph to enter the blood. The lymph can enter only at some place where the blood pressure is less than the pressure that moves the

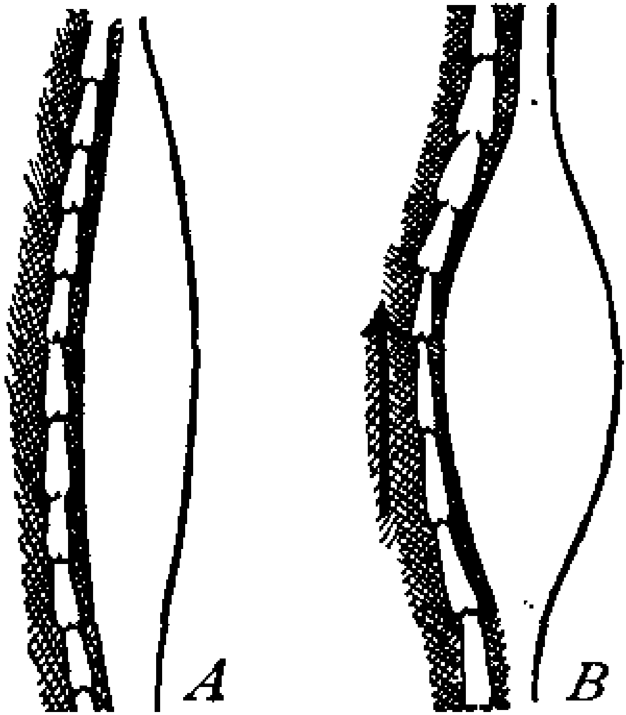

Fig. 29—**Diagram** to show how the muscles pump lymph. *A.* Relaxed muscle beside which is a lymphatic tube. *B.* Same muscle in state of contraction.

lymph. Such a place is found in the thoracic cavity. As already pointed out (page 54), the blood pressure in the veins entering this cavity becomes, with each expansion of the chest, negative, i.e., less than the pressure of the atmosphere on the outside of the body. This, as we have seen, aids in the flow of the blood into the right auricle. It also aids in the passage of lymph into the blood vessels. The lymph is said to be "sucked in," which means that it is forced in by the unbalanced pressure of the atmosphere.[28] Some advantage is also gained by the lymph duct's entering the subclavian vein on the upper side and at its union with the jugular vein. Everything considered, it is found that the lymph flows into the blood vessels where it can be "drawn in" by the movements of breathing and where it meets with no opposition from the blood stream itself (Fig. 30).

Lymph Movements at the Cells.—The double movement of the lymph from the capillaries toward the cells and from the cells [072] toward the capillaries is not entirely understood. Blood pressure in the capillaries undoubtedly has much to do in forcing the plasma through the capillary walls, but this tends to prevent the movement of the lymph in the opposite direction. Movements between the blood and the lymph are known to take place in part according to a general principle, known as *osmosis*, or dialysis.

Osmosis.—The term "osmosis" is used to designate the passage of liquids through some partition which separates them. Thus, if a vessel with an upright membranous partition be filled on the one side with pure water and on the other with water containing salt, an exchange of materials will take place through the membrane until the same proportion of salt exists on the

[28] Surgeons in opening veins near the thoracic cavity have to be on their guard to prevent air from being sucked into them, thereby causing death.

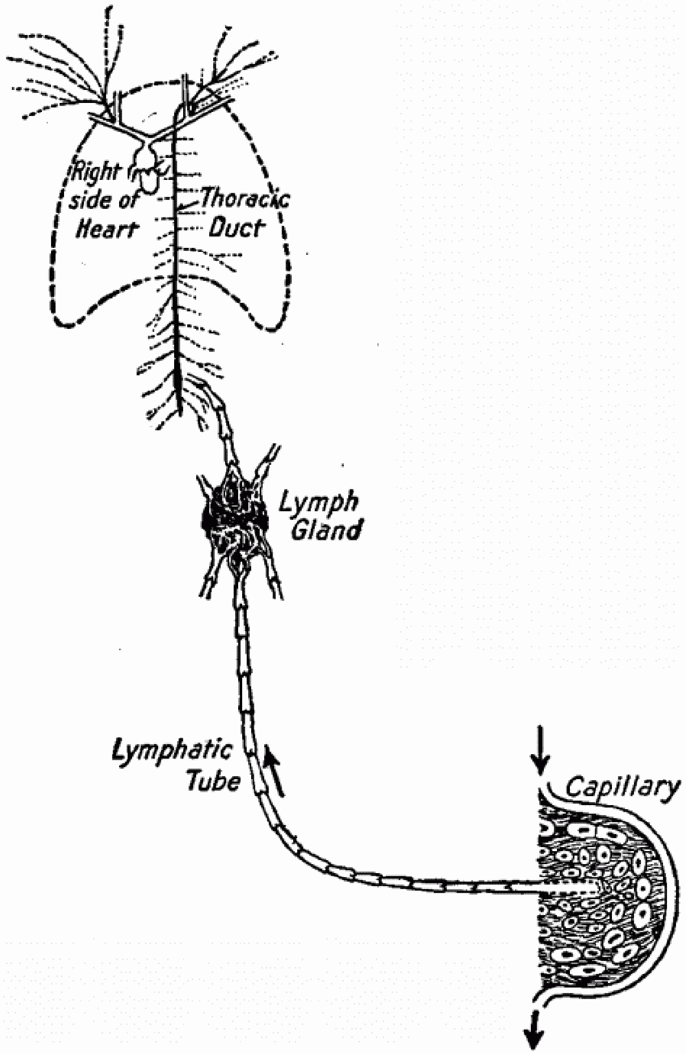

Fig. 30—**Diagram** showing general movement of lymph from the place of relatively high pressure at the lymph spaces to the place of relatively low pressure in the thoracic cavity.

two sides (Fig. 31). The cause of osmosis is the motion of the molecules, or minute particles, that make up the liquid substance. If the partition were not present, this motion would simply cause a mixing of the liquids.

Conditions under which Osmosis occurs.—Osmosis may be shown by suitable experiments (see Practical Work) to take place under the following conditions:

1. The liquids on the two sides of the partition must be *unlike* either in density or in composition. Since the effect of the movement is to reduce the liquids to the same condition, *a difference in density causes the flow to be greater from the less dense toward the denser liquid*, than in the opposite direction; while *a difference in composition causes the substances in solution to move from the place of greater abundance toward places of less abundance*.

2. The liquids must be capable of wetting, or penetrating, the partition. If but one of the liquids penetrates the partition, the flow will be in but one direction.

3. The liquids on the two sides of the partition must readily mix with each other.

Osmosis at the Cells.—In the body osmosis takes place between the blood and the lymph and between the lymph and [073] the cells, the movements being through the capillary walls and the membranes inclosing the cells (Fig. 27). Oxygen and food materials, which are found in great abundance in the blood, are less abundant in the lymph and still less abundant in the cells. According to the principle of osmosis, the main flow of oxygen and food is from the capillaries toward the cells. On the other hand, the wastes are most abundant in the cells where they are formed, less abundant in the lymph, and least abundant in the blood. Hence the wastes flow from the cells toward the capillaries.

Solutions.—Neither the blood plasma nor the lymph, as already shown, are simple liquids; but they consist of water and different substances dissolved in the water. They belong to a class of substances called *solutions*. The chief point of interest about substances in solution is that they are very finely divided and that their little particles are free to move about in the liquid that contains them. Both the motion and the finely divided condition of the dissolved substances are necessary to the process of osmosis. All substances, however, that appear to be in solution are not able to penetrate membranes, or take part in osmosis.

Kinds of Solutions in the Body.—The substances in solution in the body liquids are of two general kinds known as *colloids* and *crystalloids*. The crystalloids are able to pass through membranous partitions, while the colloids are not. An example of a colloid is found in the albumin of an egg, which is unable to penetrate the membrane which surrounds it. Examples of crystalloids are found in solutions of salt and sugar in water. The inability of a colloid to penetrate a membrane is due to the fact that it does not form a true solution. Its particles (molecules), instead of being completely separated, still cling together, forming little masses that are too large to penetrate the membrane. Since, however, it has the appearance, on being mixed with water, of being dissolved, it is called a *colloidal solution*. The crystalloid substance, on the other hand, completely separates in the water and forms a *true solution*—one which is able to penetrate the partition or membrane.

Osmosis not a Sufficient Cause.—The passage of materials through animal membranes, according to the principle of osmosis, is limited to crystalloid substances. But colloid substances are also known to pass through the various partitions of the body. An example of such is found in the proteids of the blood which, as a colloidal solution, pass through the capillary walls to become
[074] a part of the lymph. Perhaps the best explanation offered as yet for this passage is that the colloidal substances are changed by the cells lining the capillaries into substances that form true

solutions and that after the passage they are changed back again to the colloidal condition.

Summary.—Between the cells and the capillaries is a liquid, known as the lymph, which is similar in composition and physical properties to the blood. It consists chiefly of escaped plasma. The vessels that contain it are connected with the system for the circulation of the blood. By adding new material to the lymph and withdrawing waste material from it, the blood keeps this liquid in a suitable condition for supplying the needs of the cells. Supplementing each other in all respects, the blood and the lymph together form the nutrient cell fluid of the body. The interchange of material between the blood and the lymph, and the lymph and the cells, takes place in part according to the principle of osmosis.

Exercises.—1. Explain the necessity for the lymph in the body.

2. Compare lymph and water with reference to density, color, and complexity of composition.

3. Compare lymph and blood with reference to color, composition, and movement through the body.

4. Show how blood pressure in the capillaries causes a flow of the lymph.

5. Show how contracting muscles cause the lymph to move. Compare with the effect of muscular contraction upon the blood in the veins.

6. Trace the lymph in its flow from the right hand to where it enters the blood; from the feet to where it enters the blood.

7. What conditions prevail at the cells to cause a movement of food and oxygen in one direction and of waste materials in the opposite direction?

8. What part does water play in the exchanges at the cells?

9. Show that the blood and the lymph together fulfill all the requirements of a nutrient cell fluid in the body.

[075]

PRACTICAL WORK

To illustrate the Effect of Breathing upon the Flow of Lymph.—Tightly holding one end of a glass tube between the lips, let the other end extend into water in a tumbler on a table. In this position quickly inhale air through the nostrils, noting that with each inhalation there is a slight movement of the water up the tube. (No sucking action should be exerted by the mouth.) Apply to the movements in the large blood and lymph vessels entering the thoracic cavity.

To illustrate Osmosis.—1. Separate the shell from the lining membrane at one end of an egg, over an area about one inch in diameter. To do this without injuring the membrane, the shell must first be broken into small pieces and then picked off with a pair of forceps, or a small knife blade. Fit a small glass tube, eight or ten inches long, into the other end so that it will penetrate the membrane and pass down into the yolk. Securely fasten the tube to the shell by melting beeswax around it, and set the egg in a small tumbler partly filled with water. Examine in the course of half an hour. What evidence now exists that the water has passed through the membrane?

2. Tie over the large end of a "thistle tube" (used by chemists) a thin animal membrane, such as a piece of the pericardium or a strip of the membrane from around a sausage. Then fill the bulb and the lower end of the tube with a concentrated solution of some solid, such as sugar, salt, or copper sulphate. Suspend in a vessel of water so that the liquid which it contains is just on a level with the water in the vessel. Examine from time to time, looking for evidence of a movement in each direction through the membrane. Why should the movement of the water into the tube be greater than the movement in the opposite direction? (If the thistle tube has a very slender stem, it is better to fill the bulb before tying on the membrane. The opening in the stem may be plugged during the process of filling.)

NOTE.—With a special piece of apparatus, known as an *osmosometer*, the principle of osmosis may be more easily illustrated than by the method in either of the above experiments (Fig. 32). This apparatus may be obtained from supply houses.

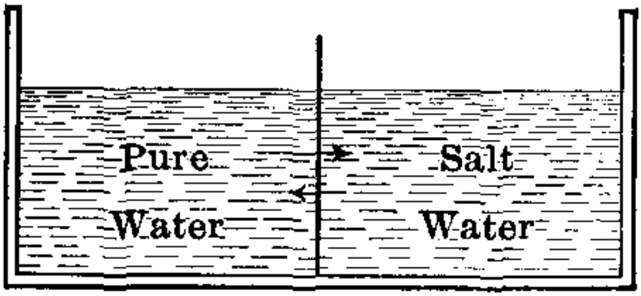

Fig. 31—**Vessel** with an upright membranous partition for illustrating osmosis.

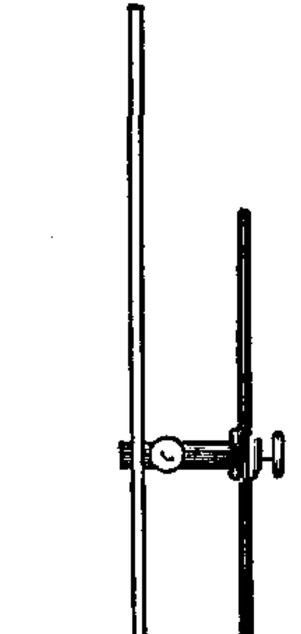

Fig. 32—An osmosometer.

[076]

CHAPTER VII - RESPIRATION

Through the movements of the blood and the lymph, materials entering the body are transported to the cells, and wastes formed at the cells are carried to the organs which remove them from the body. We are now to consider the passage of materials from outside the body to the cells and *vice versa*. One substance which the body constantly needs is oxygen, and one which it is constantly throwing off is carbon dioxide. Both of these are constituents of

The Atmosphere.—The atmosphere, or air, completely surrounds the earth as a kind of envelope, and comes in contact with everything upon its surface. It is composed chiefly of oxygen and nitrogen,[29] but it also contains a small per cent of other substances, such as water-vapor, carbon dioxide, and argon. All of the regular constituents of the atmosphere are gases, and these, as compared with liquids and solids, are very light. Nevertheless the atmosphere has weight and, on this account, exerts pressure upon everything on the earth. At the sea level, its pressure is nearly fifteen pounds to the square inch. The atmosphere forms an essential part of one's physical environment and serves various
[077] purposes. The process by which gaseous materials are made to pass between the body and the atmosphere is known as

Respiration.—As usually defined, respiration, or breathing, consists of two simple processes—that of taking air into special contrivances in the body, called the lungs, and that of expelling air from the lungs. The first process is known as *inspiration*;

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[29] Oxygen forms about 21 per cent of the atmosphere, nitrogen about 78 per cent, carbon dioxide about .03 per cent, and the recently discovered element argon about 1 per cent. The oxygen is in a *free*, or uncombined, condition—the form in which it can be used in the body.

the second as *expiration*. We must, however, distinguish between respiration by the lungs, called *external respiration*, and respiration by the cells, called *internal respiration*.

The purpose of respiration is indicated by the changes that take place in the air while it is in the lungs. Air entering the lungs in ordinary breathing parts with about five per cent of itself in the form of oxygen and receives about four and one half per cent of carbon dioxide, considerable water-vapor, and a small amount of other impurities. These changes suggest a twofold purpose for respiration:

1. To obtain from the atmosphere the supply of oxygen needed by the body.

2. To transfer to the atmosphere certain materials (wastes) which must be removed from the body.

The chief organs concerned in the work of respiration are

The Lungs.—The lungs consist of two sac-like bodies suspended in the thoracic cavity, and occupying all the space not taken up by the heart. They are not simple sacs, however, but are separated into numerous divisions, as follows:

1. The lung on the right side of the thorax, called the right lung, is made up of three divisions, or *lobes*, and the left lung is made up of two lobes.

2. The lobes on either side are separated into smaller divisions, [078] called *lobules* (Fig. 33). Each lobule receives a distinct division of an air tube and has in itself the structure of a miniature lung.

3. In the lobule the air tube divides into a number of smaller tubes, each ending in a thin-walled sac, called an *infundibulum*. The interior of the infundibulum is separated into many small spaces, known as the *alveoli*, or air cells.

The lungs are remarkable for their lightness and delicacy of

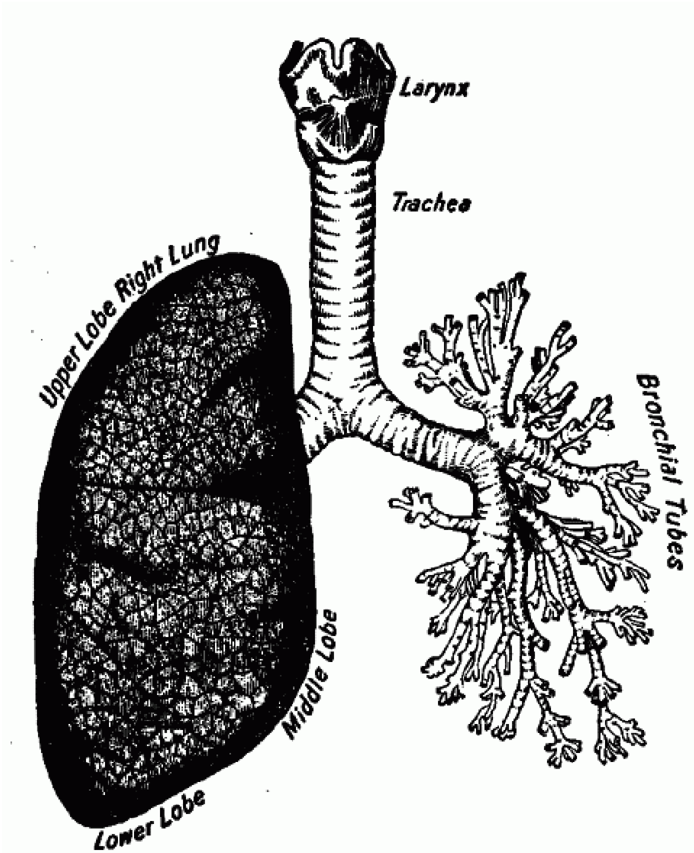

Fig. 33—**Lungs and air passages** seen from the front. The right lung shows the lobes and their divisions, the lobules. The tissue of the left lung has been dissected away to show the air tubes.

structure.[30] They consist chiefly of the tissues that form their sacs, air tubes, and blood vessels; the membranes that line their inner and outer surfaces; and the connective tissue that binds these parts together. All these tissues are more or less elastic. The relation of the different parts of the lungs to each other and [079]
to the outside atmosphere will be seen through a study of the

Air Passages.—The air passages consist of a system of tubes which form a continuous passageway between the outside atmosphere and the different divisions of the lungs. The air passes through them as it enters and leaves the lungs, a fact which accounts for the name.

The incoming air first enters the *nostrils*. These consist of two narrow passages lying side by side in the nose, and connecting with the pharynx behind. The lining of the nostrils, called *mucous membrane* is quite thick, and has its surface much extended by reason of being spread over some thin, scroll-shaped bones that project into the passage. This membrane is well supplied with blood vessels and secretes a considerable quantity of liquid. Because of the nature and arrangement of the membrane, the nostrils are able to *warm* and *moisten* the incoming air, and to *free it from dust particles*, preparing it, in this way, for entrance into the lungs (Fig. 34).

The nostrils are separated from the mouth by a thin layer of bone, and back of both the mouth and the nostrils is the pharynx. The *pharynx* and the *mouth* serve as parts of the food canal, as well as air passages, and are described in connection with [080]

[30] The peculiar work devolving upon the organs of respiration necessitates a special plan of construction—one adapted to the properties of the atmosphere. Being concerned in the movement of air, a gaseous substance, they will naturally have a structure different from the organs of circulation which move a liquid (the blood). All the organs of the body are adapted by their structure to the work which they perform.

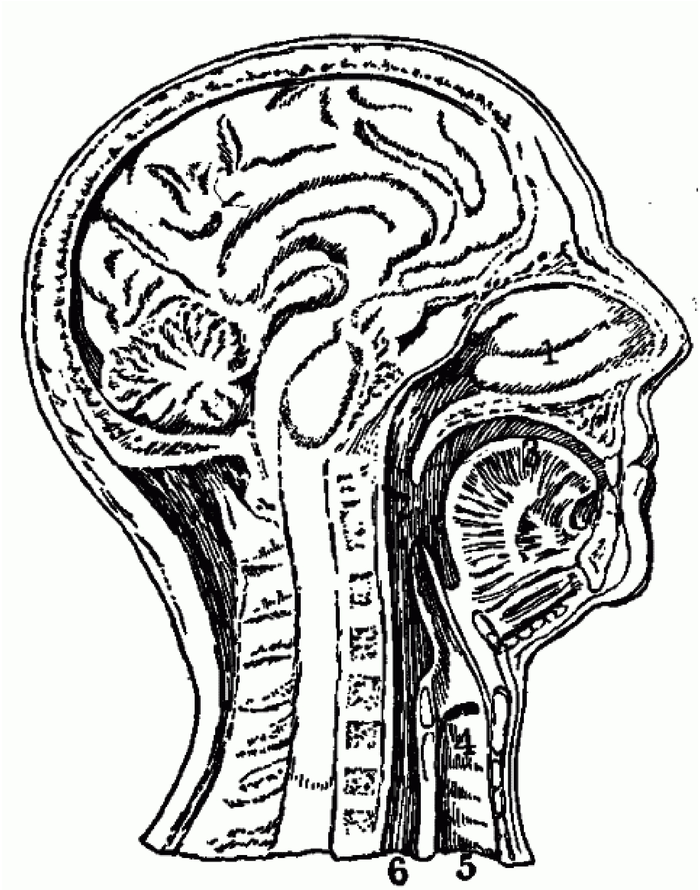

Fig. 34—**Model of section through the head**, showing upper air passages and other parts. 1. Left nostril. 2. Pharynx. 3. Tongue and cavity of mouth. 4. Larynx. 5. Trachea. 6. Esophagus.

the organs of digestion (Chapter X). Air entering the pharynx, either by the nostrils or by the mouth, passes through it into the *larynx*. The larynx, being the special organ for the production of the voice, is described later (Chapter XXI). The entrance into the larynx is guarded by a movable lid of cartilage, called the *epiglottis*, which prevents food particles and liquids, on being swallowed, from passing into the lower air tubes. The relations of the nostrils, mouth, pharynx, and larynx are shown in Fig. 34.

From the larynx the air enters the *trachea*, or windpipe. This is a straight and nearly round tube, slightly less than an inch in diameter and about four and one half inches in length. Its walls contain from sixteen to twenty C-shaped, cartilaginous rings, one above the other and encircling the tube. These incomplete rings, with their openings directed backward, are held in place by thin layers of connective and muscular tissue. At the lower end the trachea divides into two branches, called the bronchi, each of which closely resembles it in structure. Each *bronchus* separates into a number of smaller divisions, called the *bronchial tubes*, and these in turn divide into still smaller branches, known as the *lesser bronchial tubes* (Fig. 33). The lesser bronchial tubes, and the branches into which they separate, are the smallest of the air tubes. One of these joins, or expands into, each of the minute lung sacs, or infundibula. Mucous membrane lines all of the air passages.

General Condition of the Air Passages.—One necessary condition for the movement of the air into and from the lungs is an unobstructed passageway.[31] The air passages must be kept [081]
open and free from obstructions. They are *kept open* by special contrivances found in their walls, which, by supplying a degree

[31] In ordinary inspirations the force that causes the air to move through the passages is scarcely an ounce to the square inch, while in forced inspirations it does not exceed half a pound. On this account the closing of any of the air passages by pressure, or by the presence of foreign substances, would keep the air from reaching some part of the lungs.

of stiffness, cause the tubes to keep their form. In the trachea, bronchi, and larger bronchial tubes, the stiffness is supplied by rings of cartilage, while in the smaller tubes this is replaced by connective and muscular tissue. The walls of the larynx contain strips and plates of cartilage; while the nostrils and the pharynx are kept open by their bony surroundings.

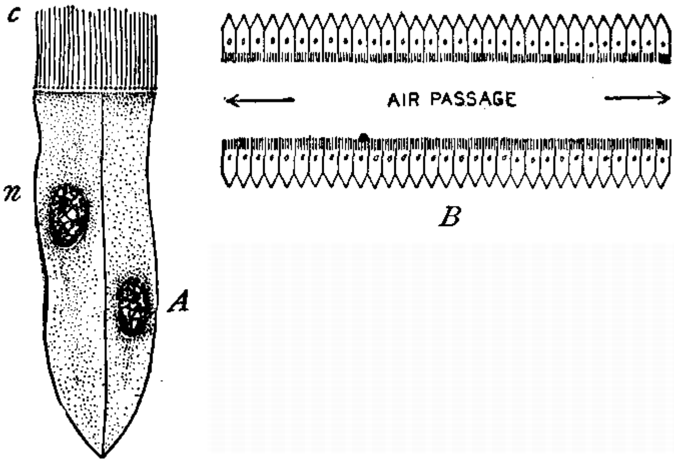

Fig. 35—**Ciliated epithelial cells.** *A.* Two cells highly magnified. *c.* Cilia, *n.* Nucleus. *B.* Diagram of a small air tube showing the lining of cilia.

The air passages are *kept clean* by cells especially adapted to this purpose, known as the *ciliated epithelial cells*. These are slender, wedge-shaped cells which have projecting from a free end many small, hair-like bodies, called *cilia* (Fig. 35). They line the mucous membrane in most of the air passages, and are so placed that the cilia project into the tubes. Here they keep up an inward and outward wave-like movement, which is quicker and has greater force in the *outward* direction. By this means the cilia are able to move small pieces of foreign matter, such as dust particles and bits of partly dried mucus, called phlegm, to places where they can be easily expelled from the lungs.[32]

The Alveoli.—The alveoli, or air cells, are the small divisions of the infundibula (Fig. 36). They are each about one one-hundredth of an inch (1/4 mm.) in diameter, being formed by the infolding of the infundibular wall. This wall, which has for its framework a thin layer of elastic connective tissue, supports a dense network of capillaries (Fig. 37), and is lined by a single layer of cells placed edge to edge. By this arrangement the air within the alveoli is brought very near a large surface of blood, and the exchange of gases between the air and the blood is made possible. It is at the alveoli that the oxygen passes from the air into the blood, and the carbon dioxide passes from the blood into the air. At no place in the lungs, however, do the air and the blood come in direct contact. Their exchanges must in all cases take place through the capillary walls and the layer of cells lining the alveoli. [082]

Blood Supply to the Lungs.—To accomplish the purposes of respiration, not only the air, but the blood also, must be

[32] Coughing, which is a forceful expulsion of air, has for its purpose the ejection of foreign substances from the throat and lungs. Sneezing, on the other hand, has for its purpose the cleansing of the nostrils. In coughing, the air is expelled through the mouth, while in sneezing it is expelled through the nostrils.

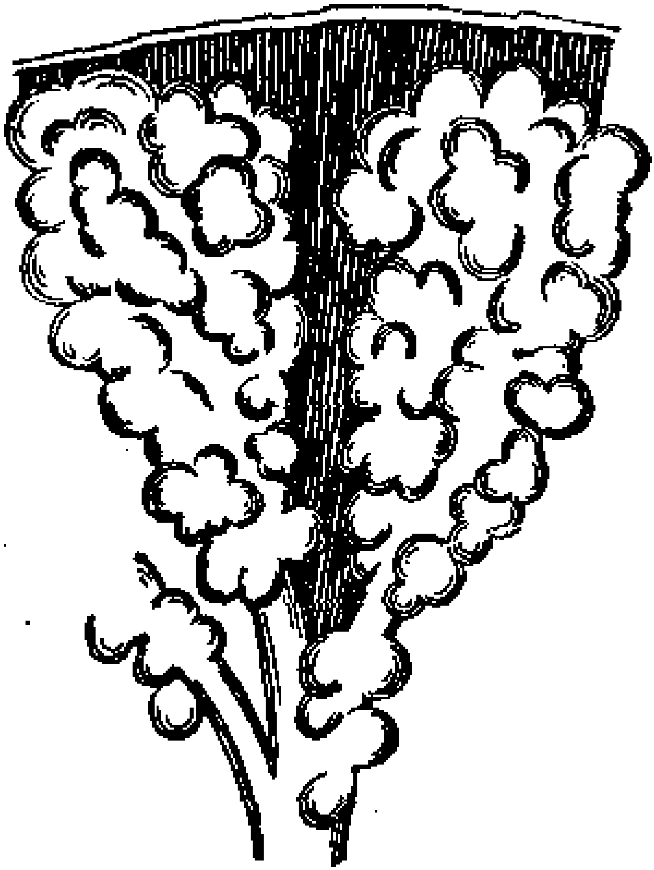

Fig. 36—**Terminal air sacs.** The two large sacs are infundibula; the small divisions are alveoli. (Enlarged.)

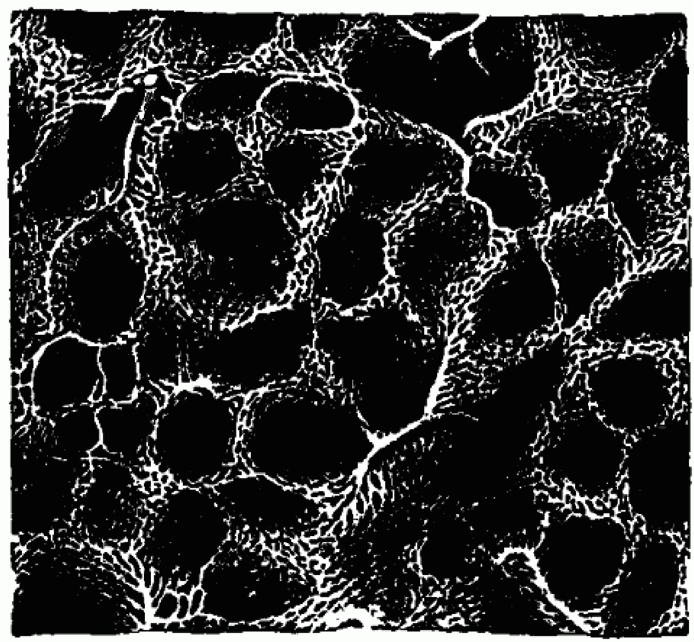

Fig. 37—**Inner lung surface (magnified)**, the blood vessels injected with coloring matter. The small pits are alveoli, and the vessels in their walls are chiefly capillaries.

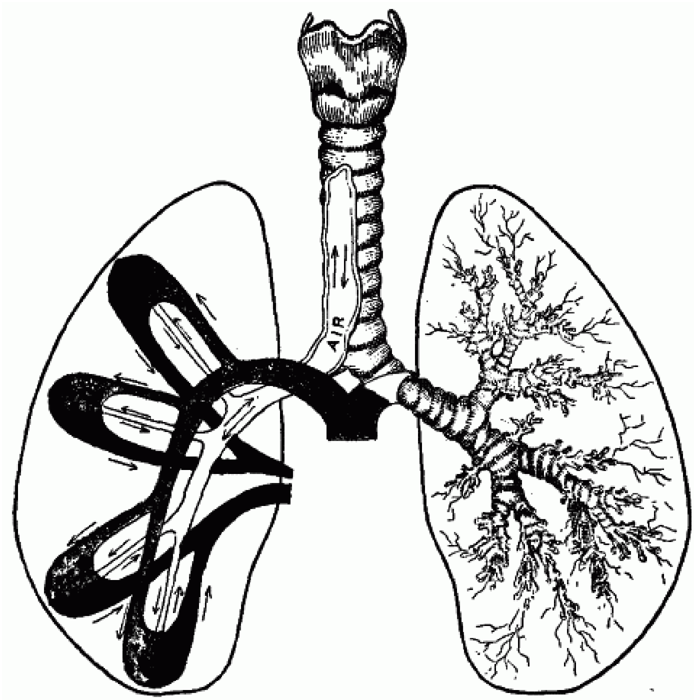

Fig. 38.—**Diagram to show the double movement of air and blood through the lungs.** The blood leaves the heart by the pulmonary artery and returns by the pulmonary veins. The air enters and leaves the lungs by the same system of tubes.

passed into and from the lungs. The chief artery conveying blood to the lungs is the *pulmonary artery*. This starts at the right ventricle and by its branches conveys blood to the capillaries surrounding the alveoli in all parts of the lungs. The branches of the pulmonary artery lie alongside of, and divide similarly to, the bronchial tubes. At the places where the finest divisions of the air tubes enter the infundibula, the little arteries branch into the capillaries that penetrate the infundibular walls (Figs. 38 and 39). From these capillaries the blood is conveyed by the pulmonary veins to the left auricle. [084]

The lungs also receive blood from two (in some individuals three) small arteries branching from the aorta, known as the *bronchial arteries*. These convey to the lungs blood that has already been supplied with oxygen, passing it into the capillaries in the walls of the bronchi, bronchial tubes, and large blood vessels, as well as the connective tissue between the lobes of the lungs. This blood leaves the lungs partly by the bronchial veins and partly by the pulmonary veins. No part of the body is so well supplied with blood as the lungs.

The Pleura.—The pleura is a thin, smooth, elastic, and tough membrane which covers the outside of the lungs and lines the inside of the chest walls. The covering of each lung is continuous with the lining of the chest wall on its respective side and forms with it a closed sac by which the lung is surrounded, the [085]
arrangement being similar to that of the pericardium. Properly speaking, there are two pleuræ, one for each lung, and these, besides inclosing the lungs, partition off a middle space which is occupied by the heart (Fig. 40). They also cover the upper surface of the diaphragm, from which they deflect upward, blending with the pericardium. A small amount of liquid is secreted by the pleura, which prevents friction as the surfaces glide over each other in breathing.

The Thorax.—The force required for breathing is supplied by the box-like portion of the body in which the lungs are placed. This is known as the thorax, or chest, and includes that part of the trunk between the neck and the abdomen. The space which it incloses, known as the thoracic cavity, is a *variable* space and the walls surrounding this space are *air-tight.* A framework for the thorax is supplied by the ribs which connect with the spinal column behind and with the sternum, or breast-bone, in front. They form joints with the spinal column, but connect with the sternum by strips of cartilage. The ribs do not encircle the cavity in a horizontal direction, but slope downward from the spinal column both toward the front and toward the sides, this being necessary to the service which they render in breathing.

How Air is Brought into and Expelled from the Lungs.—The principle involved in breathing is that air flows from a place of *greater* to a place of *less* pressure. The construction of the thorax and the arrangement of the lungs within it provide for the application of this principle in a most practical manner. The lungs are suspended from the upper portion of the thoracic cavity, and the trachea and the upper air passages provide the only opening to the outside atmosphere. Air entering
[086] the thorax must on this account pass into the lungs. As the thorax is enlarged the air in the lungs expands, and there is produced within them a place of *slightly less* air pressure than that of the atmosphere on the outside of the body. This difference causes the air to flow into the lungs.

When the thorax is diminished in size, the air within the lungs is slightly compressed. This causes it to become denser and to exert on this account a pressure *slightly greater* than that of the atmosphere on the outside. The air now flows out until the equality of the pressure is again restored. Thus the thorax, by making the pressure within the lungs first slightly less and then slightly greater than the atmospheric pressure, causes the air to move into and out of the lungs.

Breathing is well illustrated by means of the common hand bellows, its action being similar to that of the thorax. It will be observed that when the sides are spread apart air flows into the bellows. When they are pressed together the air flows out. If an air-tight sack were hung in the bellows with its mouth attached to the projecting tube, the arrangement would resemble closely the general plan of the breathing organs (Fig. 41). One respect, however, in which the bellows differs from the thorax should be noted. The thorax is never sufficiently compressed to drive out all the air. Air is always present in the lungs. This keeps them more or less distended and pressed against the thoracic walls.

How the Thoracic Space is Varied.—One means of varying the size of the thoracic cavity is through the movements of the ribs and their resultant effect upon the walls of the thorax. [087] In bringing about these movements the following muscles are employed:

1. The *scaleni* muscles, three in number on each side, which connect at one end with the vertebræ of the neck and at the other with the first and second ribs. Their contraction slightly raises the upper portion of the thorax.

2. The *elevators of the ribs*, twelve in number on each side, which are so distributed that each single muscle is attached, at one end, to the back portion of a rib and, at the other, to a projection of the vertebra a few inches above. The effect of their contraction is to' elevate the middle portion of the ribs and to turn them outward or spread them apart.

3. The *intercostal* muscles, which form two thin layers between the ribs, known as the *internal* and the *external* intercostal muscles. The external intercostals are attached between the outer lower margin of the rib above and the outer upper margin of the rib below, and extend obliquely downward and forward. The internal intercostals are attached between the inner margins of

adjacent ribs, and they extend obliquely downward and backward from the front. The contraction of the external intercostal muscles raises the ribs, and the contraction of the internal intercostals tends to lower them.

By slightly raising and spreading apart the ribs the thoracic space is increased in two directions—from front to back and from side to side. Lowering and converging the ribs has, of course, the opposite effect (Fig. 42). Except in forced expirations the ribs are lowered and converged by their own weight and by the elastic reaction of the surrounding parts.

[088] **The Diaphragm.**—Another means of varying the thoracic space is found in an organ known as the diaphragm. This is the dome-shaped, *movable partition* which separates the thoracic cavity from the cavity of the abdomen. The edges of the diaphragm are firmly attached to the walls of the trunk, and the center is supported by the pericardium and the pleura. The outer margin is muscular, but the central portion consists of a strong sheet of connective tissue. By the contraction of its muscles the diaphragm is pulled down, thereby increasing the thoracic cavity. By raising the diaphragm the thoracic cavity is diminished.

The diaphragm, however, is not raised by the contraction of its own muscles, but *is pushed up* by the organs beneath. By the elastic reaction of the abdominal walls (after their having been pushed out by the lowering of the diaphragm), pressure is exerted on the organs of the abdomen and these in turn press against the diaphragm. This crowds it into the thoracic space. In forced expirations the muscles in the abdominal walls contract to push up the diaphragm.

Interchange of Gases in the Lungs.—During each inspiration the air from the outside fills the entire system of bronchial tubes, but the alveoli are largely filled, at the same time, by the air which the last expiratory effort has left in the passages. By the action of currents and eddies and by the rapid diffusion of gas particles, the air from the outside mixes with that in the alveoli and comes in contact with the membranous walls. Here the oxygen, after being dissolved by the moisture in the membrane, diffuses into the blood. The carbon dioxide, on the other hand, being in excess in the blood, diffuses toward the air in the alveoli. The interchange of gases at the lungs, however, is not fully understood, and it is possible that other forces than osmosis play a part.

Capacity of the Lungs.—The air which passes into and from the lungs in ordinary breathing, called the *tidal* air, is but a small
part of the whole amount of air which the lungs contain. Even [089]
after a forced expiration the lungs are almost half full; the air which remains is called the *residual* air. The air which is expelled from the lungs by a forced expiration, less the tidal air, is called the *reserve*, or supplemental, air. These several quantities are easily estimated. (See Practical Work.) In the average individual the total capacity of the lungs (with the chest in repose) is about one gallon. In forced inspirations this capacity may be increased about one third, the excess being known as the *complemental* air (Fig. 43).

Internal, or Cell, Respiration.—The oxygen which enters the blood in the lungs leaves it in the tissues, passing through the lymph into the cells (Fig. 44). At the same time the carbon dioxide which is being formed at the cells passes into the blood. An exchange of gases is thus taking place between the cells and
the blood, similar to that taking place between the blood and the [090]
air. This exchange is known as *internal*, or cell, respiration. By internal respiration the oxygen reaches the place where it is to serve its purpose, and the carbon dioxide begins its movement toward the exterior of the body. This "breathing by the cells" is,

therefore, *the final and essential act of respiration*. Breathing by the lungs is simply the means by which the taking up of oxygen and **the** giving off of carbon dioxide by the cells is made possible.

HYGIENE OF RESPIRATORY ORGANS

The liability of the lungs to attacks from such dread diseases as consumption and pneumonia makes questions touching their hygiene of first importance. Consumption does not as a rule attack sound lung tissue, but usually has its beginning in some weak or enfeebled spot in the lungs which has lost its "power of resistance." Though consumption is not inherited, as some suppose, lung weaknesses may be transmitted from parents to children. This, together with the fact, now generally recognized, that consumption is contagious, accounts for the frequent appearance of this disease in the same family. Consumption as well as other respiratory affections can in the majority of cases be *prevented*, and in many cases cured, by an intelligent observation of well-known laws of health.

Breathe through the Nostrils.—Pure air and plenty of it is the main condition in the hygiene of the lungs. One necessary provision for obtaining *pure air* is that of breathing through the nostrils. Air is the carrier of dust particles and not infrequently of
[091] disease germs.[33] Partly through the small hairs in the nose, but mainly through the moist membrane that lines the passages, the nostrils serve as filters for removing the minute solid particles (Fig. 45). While it is important that nose breathing be observed at all times, it is especially important when one is surrounded by a dusty or smoky atmosphere. Otherwise the small particles that are breathed in through the mouth may find a lodging place in the lungs.

[33] The amount of dust suspended in what we ordinarily think of as pure air is shown when a beam of direct sunlight enters an otherwise darkened room.

In addition to removing dust particles and germs, other purposes are served by breathing through the nostrils. The warmth and moisture which the air receives in this way, prepare it for entering the lungs. Mouth breathing, on the other hand, looks bad and during sleep causes snoring. The habit of nose breathing should be established early in life.[34]

Cultivate Full Breathing.—Many people, while apparently taking in sufficient air to supply their need for oxygen, do not breathe deeply enough to "freely ventilate the lungs." "Shallow breathing," as this is called, is objectionable because it fails to [092] keep up a healthy condition of the entire lung surface. Portions of the lungs to which air does not easily penetrate fail to get the fresh air and exercise which they need. As a consequence, they become weak and, by losing their "power of resistance," become points of attack in diseases of the lungs.[35] The breathing of each individual should receive attention, and where from some cause it is not sufficiently full and deep, the means should be found for remedying the defect.

Causes of Shallow Breathing.—Anything that impedes the free movement of air into the lungs tends to cause shallow breathing A drooping of the back or shoulders and a curved condition of the spinal column, such as is caused by an improper position in sitting, interfere with the free movements of the

[34] Some children find it difficult to breathe through the nostrils on account of growths (called adenoids) in the upper pharynx. Such children should have medical attention. The removal of these growths not only improves the method of breathing, but in many instances causes a marked improvement in the general health and personal appearance.

[35] The weakest portions of the lungs appear to be the tiny lobes at the top. As they occupy the part of the thorax most difficult to expand, air penetrates them much less freely than it does the lobes below. In most cases of consumption (some authorities give as high as eighty per cent), the upper lobes are the first to be affected. Flat chests and round shoulders, by increasing this natural difficulty in breathing, have long been recognized as causes which predispose to consumption.

ribs and are recognized causes. Clothing also may impede the respiratory movements and lead to shallow breathing. If too tight around the chest, clothing interferes with the elevation of the ribs; and if too tight around the waist, it prevents the depression of the diaphragm. Other causes of shallow breathing are found in the absence of vigorous exercise, in the leading of an indoor and inactive life, in obstructions in the nostrils and upper pharynx, and in the lack of attention to proper methods of breathing.

To prevent shallow breathing one should have the habit of sitting and standing erect. The clothing must not be allowed to interfere with the respiratory movements. The taking of exercise
[093] sufficiently vigorous to cause deep and rapid breathing should be a common practice and one should spend considerable time out of doors. If one has a flat chest or round shoulders, he should strive by suitable exercises to overcome these defects. Obstructions in the nostrils or pharynx should be removed.

Breathing Exercises.—In overcoming the habit of shallow breathing and in strengthening the lungs generally, the practicing of occasional deep breathing has been found most valuable and is widely recommended. With the hands on the hips, the shoulders drawn back and *down*, the chest pushed upward and forward, and the chin slightly depressed, draw the air slowly through the nostrils until the lungs are *completely* full. After holding this long enough to count three slowly, expel it quickly from the lungs. Avoid straining. To get the benefit of pure air, it is generally better to practice deep breathing out of doors or before an open window.

By combining deep breathing with simple exercises of the arms, shoulders, and trunk much may be done towards straightening the spine, squaring the shoulders, and overcoming flatness of the chest. Though such movements are best carried on by the aid of a physical director, one can do much to help himself. One may safely proceed on the principle that slight deformities of the chest, spine, and shoulders are corrected by gaining and keeping the natural positions, and may employ any movements which will loosen up the parts and bring them where they naturally belong.[36]

Serious Nature of Colds.—That many cases of consumption have their beginning in severe colds (on the lungs) is not only a matter of popular belief, but the judgment also of physicians. Though the cold is a different affection from that of consumption, it may so lower the vitality of the body and weaken the lung surfaces that the germs of consumption find it easy to get a start. On this account a cold on the chest which does not disappear in a few days, but which persists, causing more or less coughing and pain in the lungs, must be given serious consideration.[37] The usual home remedies failing to give relief, a physician should be consulted. It should also be noted that certain diseases of a serious nature (pneumonia, diphtheria, measles, etc.) have in their beginning the appearance of colds. On this account it is [094]

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[36] The following exercise, from Dudley A. Sargent's *Health, Strength, and Power*, will be found most beneficial: "Stand with the feet together, face downward, arms extended downward, and backs of the hands touching. Raise the hands, arms, and elbows, keeping the backs of the hands together until they pass the chest and face. Then continue the movement upward, until the hands separate above the head with the face turned upward, when they should be brought downward and outward in a large circle to the starting point. Begin to inhale as the arms are raised and take in as much air as possible by the time the hands are above the head, then allow the breath to go out slowly as the arms descend."

[37] Colds may frequently be broken up at their beginning by taking a prolonged *hot* bath and going to bed. After getting a start, however, they run a course of a few days, a week, or longer, depending upon the natural vigor of the individual and the care which he gives his body during the time. In throwing off a cold, the following suggestions will be found helpful:

1. Dress warmly (without overdoing it) and avoid getting chilled. 2. Diminish the usual amount of work and increase the period for sleep. If very weak, stay in bed. Save the energy for throwing off the cold. 3. If able to be about, spend considerable time in light exercise out of doors, but avoid getting chilled. 4. Keep the bowels active, taking a cathartic if necessary. 5. To relieve pain in the chest, apply a mustard plaster or a flannel cloth moistened

wise not only to call a physician, but to call him early, in severe attacks of the lungs. Especially if the attack be attended by difficult breathing, fever, and a rapid pulse is the case serious and medical advice necessary.

Ventilation.—The process by which the air in a room is [095] kept fresh and pure is known as ventilation. It is a double process—that of bringing fresh air into the room and that of getting rid of air that has been rendered impure by breathing [38] or by lamps. Outdoor air is usually of a different temperature (colder in winter, warmer in summer) from that indoors, and as a consequence differs from it slightly in weight. On account of this difference, suitable openings in the walls of buildings induce currents which pass between the rooms and the outside atmosphere even when there is no wind. In winter care must be taken to prevent drafts and to avoid too great a loss of heat from the room. A cold draft may even cause more harm to one in delicate health than the breathing of air which is impure. To ventilate a room successfully the problem of preventing drafts must be considered along with that of admitting the fresh air.

The method of ventilation must also be adapted to the construction of the building, the plan of heating, and the condition of the weather. Specific directions cannot be given, but the following suggestions will be found helpful in ventilating rooms where the air is not warmed before being admitted:

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with some irritating substance, such as turpentine or a mixture of equal parts of kerosene and lard. Keep up a mild irritation until the pain is relieved, but avoid blistering.

[38] Not only do the lungs remove oxygen from the air and add carbon dioxide to it, but they separate from the body considerable moisture and, according to some authorities, a small amount of an impurity referred to as "animal matter." Odors also arise from the skin, teeth, and clothing which, if not dangerous to the health, are offensive to the nostrils. If on going into a room such odors are detected, the ventilation is not sufficient. This is said to be a reliable test.

1. *Introduce, the air through many small openings* rather than a few large ones. If the windows are used for this purpose, raise the lower sash and drop the upper one *slightly* for *several* windows, varying the width to suit the conditions (Fig. 46). By this means sufficient air may be introduced without causing drafts.

2. *Introduce the air at the warmest portions of the room.* The air should, if possible, be warmed before reaching the occupants. [096]

3. If the wind is blowing, *ventilate principally on the sheltered side of the house*.

Ample provision should be made for fresh air in sleeping rooms, and here again drafts must be avoided. Especially should the bed be so placed that strong air currents do not pass over the sleeper. In schoolhouses and halls for public gatherings the means for efficient ventilation should, if possible, be provided in the general plan of construction and method of heating.

Artificial Respiration.—When natural breathing is temporarily suspended, as in partial drowning, or when one has been overcome by breathing some poisonous gas, the saving of life often depends upon the prompt application of artificial respiration. This is accomplished by alternately compressing and enlarging the thorax by means of variable pressure on the outside, imitating the natural process as nearly as possible. Following is the method proposed by Professor E.A. Schaffer of England, and called by him "the *prone-posture* method of artificial respiration":

The patient is laid face downward with an arm bent under the head, and *intermittent* pressure applied vertically over the shortest ribs. The pressure drives the air from the lungs, both by compressing the lower portions of the chest and by forcing the abdominal contents against the diaphragm, while the elastic reaction of the parts causes fresh air to enter (Figs. 47 and 48). "The operator kneels or squats by the side of, or across the [097] patient, places his hands over the lowest ribs and swings his body backward and forward so as to allow his weight to fall vertically on the wrists and then to be removed; in this way hardly any muscular exertion is required.... The pressure is applied gradually and slowly, occupying some three seconds; it is then withdrawn during two seconds and again applied; and so on some twelve times per minute."[39]

The special advantages of the prone-posture method over others that have been employed are: I. It may be applied by a single individual and fora long period of time without exhaustion. 2. It allows the mucus and water (in case of drowning) to run out of the mouth, and causes the tongue to fall forward so as not to obstruct the passageway. 3. It brings a sufficient amount of air into the lungs.[40]

[098] While applying artificial respiration, the heat of the body should not be allowed to escape any more than can possibly be helped. In case of drowning, the patient should be wrapped in dry blankets or clothing, while bottles of hot water may be placed in contact with the body. The circulation should be stimulated, as may be done by rubbing the hands, feet, or limbs in the direction of the flow of the blood in the veins.

Tobacco Smoke and the Air Passages.—Smoke consists of minute particles of unburnt carbon, or soot, such as collect in the chimneys of fireplaces and furnaces. If much smoke is taken into the lungs, it irritates the delicate linings and tends to clog them up. Tobacco smoke also contains the poison nicotine, which is

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[39] E.A. Schaffer, "Artificial Respiration in its Physiologic Aspects," *The Journal of the American Medical Association*, September, 1908.

[40] Testing the prone-posture method by suitable apparatus, Professor Schaffer has found it capable of introducing more air per minute into the lungs than any of the other methods of artificial respiration, and more even than is introduced by ordinary breathing.

absorbed into the blood. For these reasons the cigarette user who inhales the smoke does himself great harm, injuring his nervous system and laying the foundation for diseases of the air passages. The practice of smoking indoors is likewise objectionable, since every one in a room containing the smoke is compelled to breathe it.

Alcohol and Diseases of the Lungs.—Pneumonia is a serious disease of the lungs caused by germs. The attacks occur as a result of exposure, especially when the body is in a weakened condition. A noted authority states that "alcoholism is perhaps the most potent predisposing cause" of pneumonia.[41] A person addicted to the use of alcohol is also less likely to recover from the disease than one who has avoided its use, a result due in part to the weakening effect of alcohol upon the heart. The congestion of the lungs in pneumonia makes it very difficult for the heart to force the blood through them. The weakened heart of the drunkard gives way under the task.

The statement sometimes made that alcohol is beneficial in [099]
pulmonary tuberculosis is without foundation in fact. On the other hand, alcoholism is a recognized cause of consumption. Some authorities claim that this disease is more frequent in heavy drinkers than in those of temperate habits, in the proportion of about three to one, and that possibly half of the cases of tuberculosis are traceable to alcoholism.[42]

The Outdoor Cure for Lung Diseases—Among the many remedies proposed for consumption and kindred diseases, none have proved more beneficial, according to reports, than the so-called "outdoor" cure. The person having consumption is fed plentifully upon the most nourishing food, and is made to spend practically his entire time, including the sleeping hours, *out of doors*. Not only is this done during the pleasant months of summer, but also during the winter when the temperature

[41] Osier, *The Principles and Practice of Medicine*.
[42] Huber, *Consumption and Civilization*.

is below freezing. Severe exposure is prevented by overhead protection at night and by sufficient clothing to keep the body warm. The abundant supply of pure, cold air toughens the lungs and invigorates the entire body, thereby enabling it to throw off the disease.

The success attending this method of treating consumptives suggests the proper mode of strengthening lungs that are not diseased, but simply weak. The person having weak lungs should spend as much time as he conveniently can out of doors. He should provide the most ample ventilation at night and have a sleeping room to himself. He should practice deep breathing exercises and partake of a nourishing diet. While avoiding prolonged chilling and other conditions liable to induce colds, he should take advantage of every opportunity of exposing himself fully and freely to the outside atmosphere.

Summary.—The purpose of respiration is to bring about an exchange of gases between the body and the atmosphere. The organs employed for this purpose, called the respiratory organs, are adapted to handling materials in the *gaseous* state, and are operated in accordance with principles governing the movements
[100] of the atmosphere. By alternately increasing and diminishing the thoracic space, air is made to pass between the outside atmosphere and the interior of the lungs. Finding its way into the smallest divisions of the lungs, called the alveoli, the air comes very near a large surface of blood. By this means the carbon dioxide diffuses out of the blood, and the free oxygen enters. Through the combined action of the organs of respiration and the organs that move the blood and the lymph, the cells in all parts of the body are enabled to exchange certain gaseous materials with the outside atmosphere.

Exercises.—1. How does air entering the lungs differ in composition from air leaving the lungs? What purposes of respiration are indicated by these differences?

2. Name the divisions of the lungs.

3. Trace air from the outside atmosphere into the alveoli. Trace the blood from the right ventricle to the alveoli and back again to the left auricle.

4. How does the movement of air into and from the lungs differ from that of the blood through the lungs with respect to (*a*) the direction of the motion. (*b*) the causes of the motion, and (*c*) the tubes through which the motion takes place?

5. How are the air passages kept clean and open?

6. Describe the pleura. Into what divisions does it separate the thoracic cavity?

7. Describe and name uses of the diaphragm.

8. If 30 cubic inches of air are passed into the lungs at each inspiration and .05 of this is retained as oxygen, calculate the number of cubic feet of oxygen consumed each day, if the number of inspirations be 18 per minute.

9. Find the *weight* of a day's supply of oxygen, as found in the above problem, allowing 1.3 ounces as the weight of a cubic foot.

10. Make a study of the hygienic ventilation of the schoolroom.

11. Give advantages of full breathing over shallow breathing. [101]

12. How may a flat chest and round shoulders be a cause of consumption? How may these deformities be corrected?

13. Give general directions for applying artificial respiration.

PRACTICAL WORK

Examine a dissectible model of the chest and its contents (Fig. 49). Note the relative size of the two lungs and their position with reference to the heart and diaphragm. Compare the side to side and vertical diameters of the cavity. Trace the air tubes from the trachea to their smallest divisions.

Observation of Lungs (Optional).—Secure from a butcher the lungs of a sheep, calf, or hog. The windpipe and heart should be left attached and the specimen kept in a moist condition until used. Demonstrate the trachea, bronchi, and the bronchial tubes, and the general arrangement of pulmonary arteries and veins. Examine the pleura and show lightness of lung tissue by floating a piece on water.

To show the Changes that Air undergoes in the Lungs.—1. Fill a quart jar even full of water. Place a piece of cardboard over its mouth and invert, without spilling, in a pan of water. Inserting a tube under the jar, blow into it air that has been held as long as possible in the lungs. When filled with air, remove the jar from the pan, keeping the top well covered. Slipping the cover slightly to one side, insert a burning splinter and observe that the flame is extinguished. This proves the absence of sufficient oxygen to support combustion. Pour in a little limewater[43] and shake to mix with the air. The change of the limewater to a milky white color proves the presence of carbon dioxide.

2. The effects illustrated in experiment 1 may be shown in a somewhat more striking manner as follows: Fill two bottles of
[102] the same size each one fourth full of limewater and fit each with a two-holed rubber stopper (Fig. 50). Fit into each stopper one short and one long glass tube, the long tube extending below the limewater. Connect the short tube of one bottle and the long tube of the other bottle with a Y-tube. Now breathe slowly three or four times through the Y-tube. It will be found that the inspired air passes through one bottle and the expired air through the

[43] To prepare limewater some small lumps of *fresh* lime (either slacked or unslacked) are added to a large bottle of water and thoroughly shaken. This is put aside until the lime all settles to the bottom and the water above is perfectly clear. This is now ready for use and may be poured off as needed. When the supply is exhausted add more water and shake again.

other. Compare the effect upon the limewater in the two bottles. Insert a small burning splinter into the top of each bottle and note result. What differences between inspired and expired air are thus shown?

3. Blow the breath against a cold window pane. Note and account for the collection of moisture.

4. Note the temperature of the room as shown by a thermometer. Now breathe several times upon the bulb, noting the rise in the mercury. What does this experiment show the body to be losing through the breath?

To show Changes in the Thoracic Cavity.—1. To a yard- or meter-stick, attach two vertical strips, each about eight inches long, as shown in Fig. 51. The piece at the end should be secured firmly in place by screws or nails. The other should be movable. With this contrivance measure the sideward and forward expansion of a boy's thorax. Take the diameter first during a complete inspiration and then during a complete expiration, reading the difference. Compare the forward with the sideward expansion.

2. With a tape-line take the circumference of the chest when all the air possible has been expelled from the lungs. Take it again when the lungs have been fully inflated. The difference is now read as the chest expansion.

To illustrate the Action of the Diaphragm.—Remove the bottom from a large bottle having a small neck. (Scratch a deep mark with a file and hold on the end of this mark a hot [103]
poker. When the glass cracks, lead the crack around the bottle by heating about one half inch in advance of it.) Place the bottle in a large glass jar filled two thirds full of water (Fig. 52). Let the space above the water represent the chest cavity and the water

surface represent the diaphragm. Raise the bottle, noting that the water falls, thereby increasing the space and causing air to enter. Then lower the bottle, noting the opposite effect. To show the movement of the air in and out of the bottle, hold with the hand (or arrange a support for) a burning splinter over the mouth of the bottle.

To estimate the Capacity of the Lungs.—Breathing as naturally as possible, expel the air into a spirometer (lung tester) during a period, say of ten respirations (Fig. 53). Note the total amount of air exhaled and the number of "breaths" and calculate the amount of air exhaled at each breath. This is called the *tidal* air.

2. After an ordinary inspiration empty the lungs as completely as possible into the spirometer, noting the quantity exhaled. This amount, less the tidal air, is known as the *reserve* air. The air which is now left in the lungs is called the *residual* air. On the theory that this is equal in amount to the reserve air, calculate the capacity of the lungs in an ordinary inspiration.

3. Now fill the lungs to the full expansion of the chest and empty them as completely as possible into the spirometer, noting the amount expelled. This, less the tidal air and the reserve air, is called the *complemental* air. Now calculate the total capacity of the lungs.

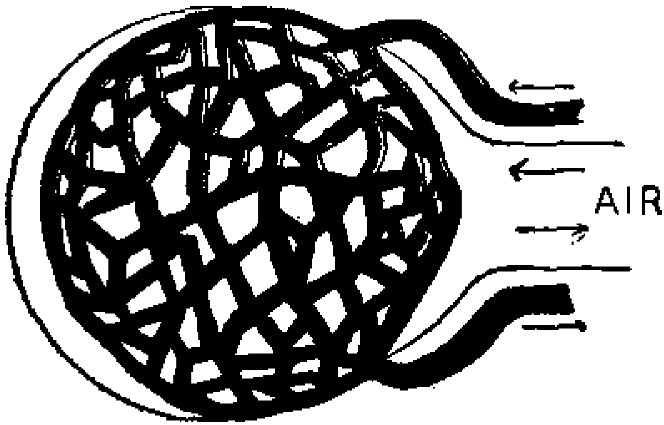

Fig. 39—**Diagram to show air and blood movements in a terminal air sac.** While the air moves into and from the space within the sac, the blood circulates through the sac walls.

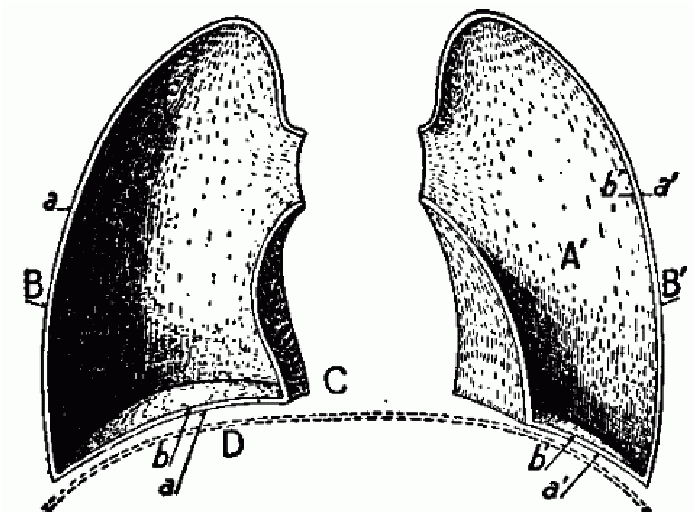

Fig. 40—**The pleuræ.** Diagram showing the general form of the pleural sacs as they surround the lungs and line the inner surfaces of the chest (other parts removed). *A, A'.* Places occupied by the lungs. *B, B'.* Slight space within the pleural sacs containing the pleural secretion, *a, a'.* Outer layer of pleura and lining of chest walls and upper surface of diaphragm. *b, b'.* Inner layer of pleura and outer lining of lungs. *C.* Space occupied by the heart. *D.* Diaphragm.

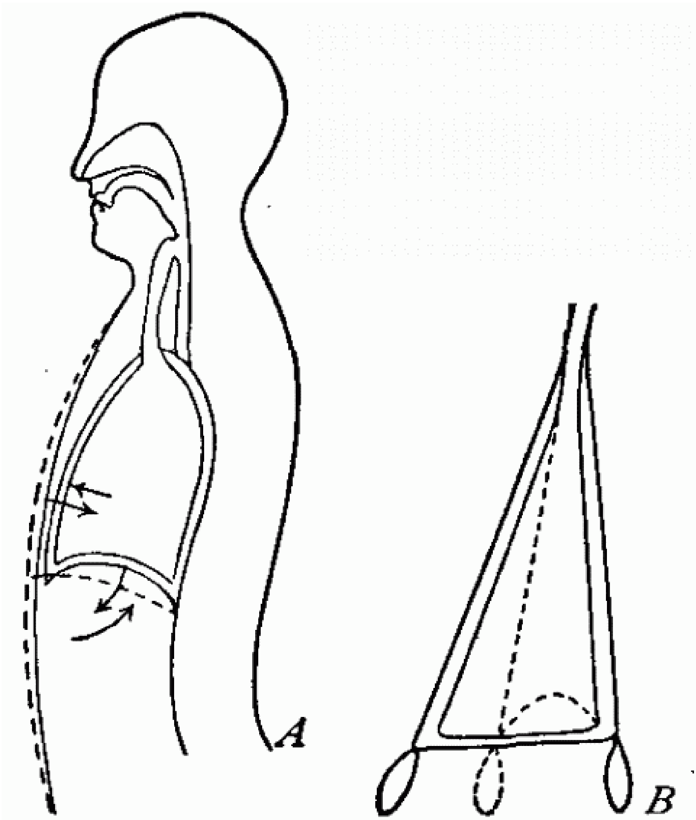

Fig. 41—**Diagram illustrating the bellows principle in breathing.** *A.* The human bellows. *B.* The hand bellows. Compare part for part.

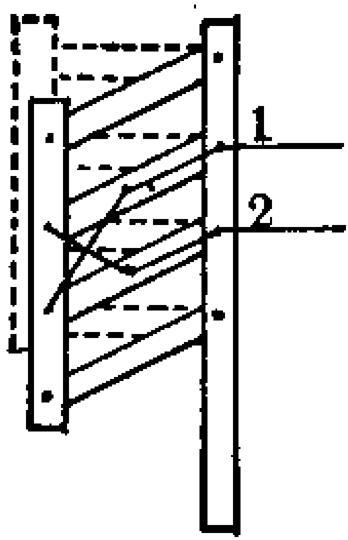

Fig. 42—**Simple apparatus** for illustrating effect of movements of the ribs upon the thoracic space; strips of cardboard held together by pins, the front part being raised or lowered by threads moving through attachments at 1 and 2. As the front is raised the space between the uprights is increased. The front upright corresponds to the breastbone, the back one to the spinal column, the connecting strips to the ribs, and the threads to the intercostal muscles.

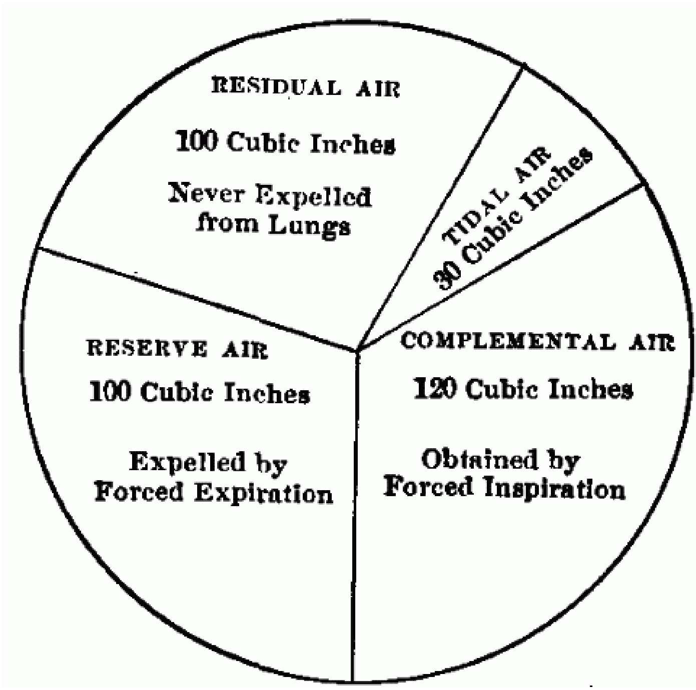

Fig. 43—**Diagram** illustrating lung capacity.

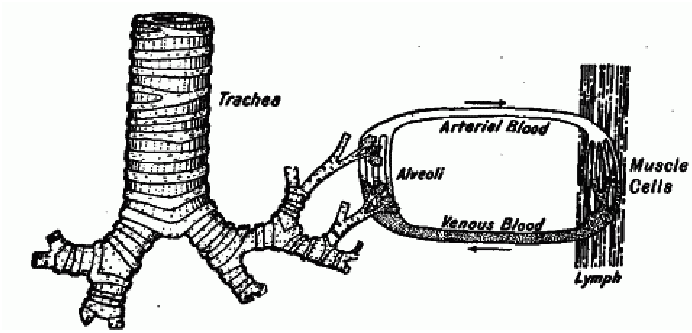

Fig. 44—**Diagram** illustrating internal respiration and its dependence on external respiration. (Modified from Hall.) (See text.)

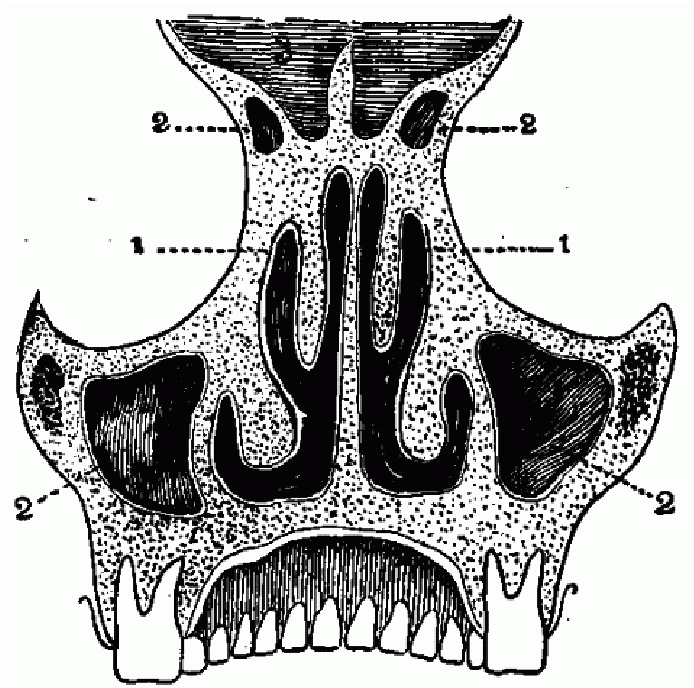

Fig. 45—**Human air filter.** Diagram of a section through the nostrils; shows projecting bones covered with moist membrane against which the air is made to strike by the narrow passages. 1. Air passages. 2. Cavities in the bones. 3. Front lower portion of the cranial cavity.

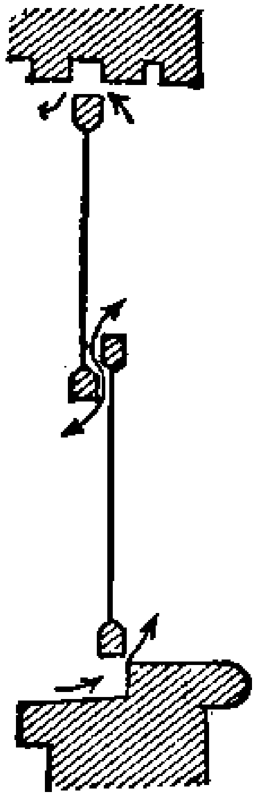

Fig. 46—Window adjusted for ventilation without drafts.

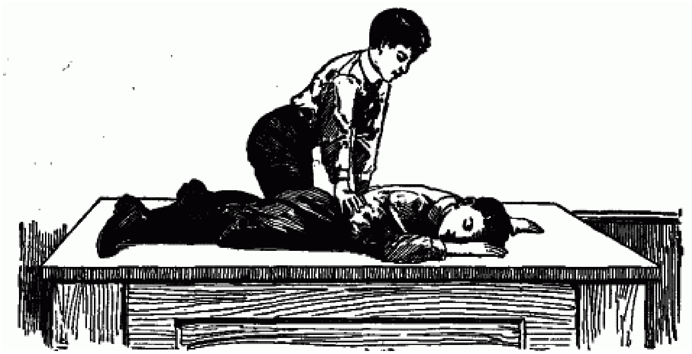

Fig. 47—**Artificial respiration** as a laboratory experiment. Expiration. Prone-posture method of Schaffer.

Fig. 48—Artificial respiration. Inspiration.

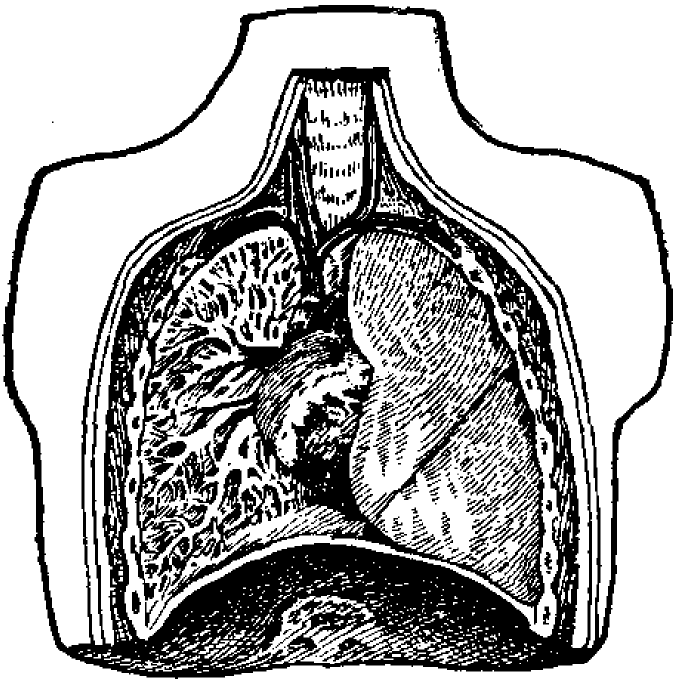

Fig. 49—Model for demonstrating the lungs.

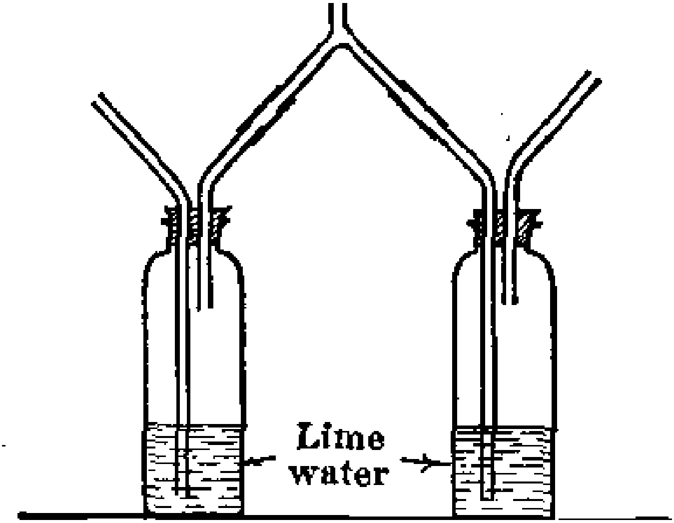

Fig. 50—**Apparatus** for showing changes which air undergoes while in the lungs.

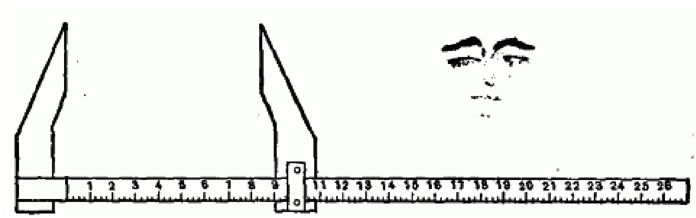

Fig. 51—**Apparatus** for measuring chest expansion.

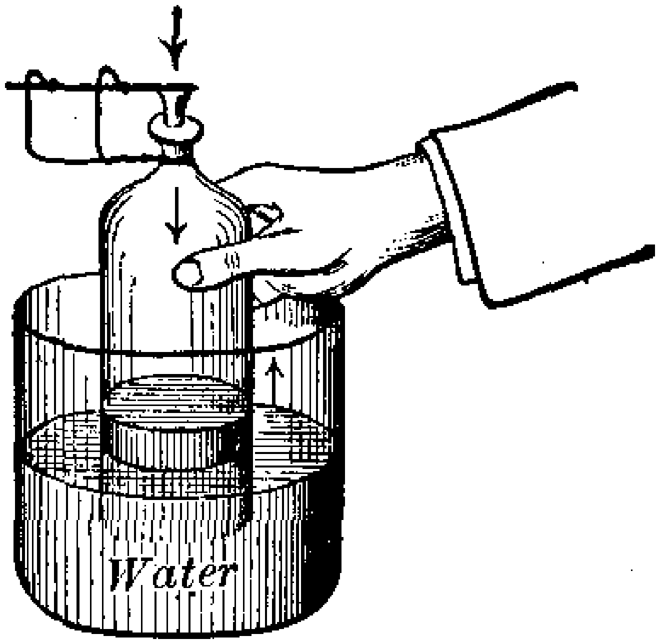

Fig. 52—**Simple apparatus** for illustrating the action of the diaphragm.

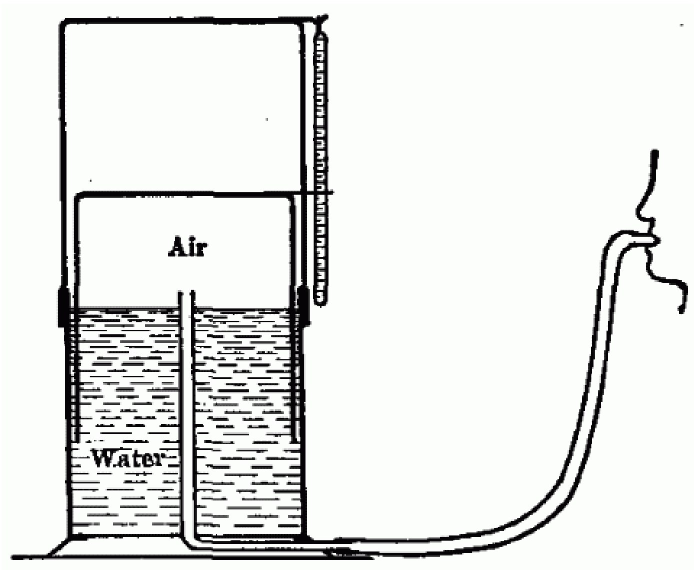

Fig. 53—**Apparatus** (spirometer) for measuring the capacity of the lungs.

[104]

CHAPTER VIII - PASSAGE OF OXYGEN THROUGH THE BODY

What is the nature of oxygen? What is its purpose in the body and how does it serve this purpose? How is the blood able to take it up at the lungs and give it off at the cells? What becomes of it after being used? These are questions touching the maintenance of life and they deserve careful consideration.

Nature of Oxygen.—To understand the relation which oxygen sustains to the body we must acquaint ourselves with certain of its chemical properties. It is an element[44] of intense affinity, or combining power, and is one of the most active of all chemical agents. It is able to combine with most of the other elements to form chemical compounds. A familiar example of its combining action is found in ordinary combustion, or burning. On account of the part it plays in this process, oxygen is called the *supporter of combustion*; but it supports combustion by the simple method of uniting. The ashes that are left and the invisible gases that escape into the atmosphere are the compounds formed by the uniting process. It thus appears that oxygen, in common with the other elements, may exist in either of two forms:

[105] 1. That in which it is in a *free*, or uncombined, condition—the form in which it exists in the atmosphere.

2. That in which it is a part of compounds, such as the compounds formed in combustion.

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[44] An *element* is a single kind of matter. Those substances are classed as elements which cannot be separated into different kinds of matter. Two or more elements combined in definite proportions by weight form a *compound*. The elements are few in number, only about eighty being known. Compounds, on the other hand, are exceedingly numerous.

Oxygen manifests its activity to the best advantage when it is in a free state, or, more accurately speaking, when it is passing from the free state into one of combination. It is separated from its compounds and brought again into a free state by overcoming with heat, or some other force, the affinity which causes it to unite.

How Oxygen unites.—The chemist believes oxygen, as well as all other substances, to be made up of exceedingly small particles, called *atoms*. The atoms do not exist singly in either elements or compounds, but are united with each other to form groups of atoms that are called *molecules*. In an element the molecules are made up of one kind of atoms, but in a compound the molecules are made up of as many kinds of atoms as there are elements in the compound. Changes in the composition of substances (called chemical changes) are due to rearrangements of the atoms and the formation of new molecules. The atoms, therefore, are the units of chemical combination. In the formation of new compounds they unite, and in the breaking up of existing compounds they separate.

The uniting of oxygen is no exception to this general law. All of its combinations are brought about by the uniting of its atoms. In the burning of carbon, for example, the atoms of oxygen and the atoms of carbon unite, forming molecules of the compound known as carbon dioxide. The chemical formula of this compound, which is CO_2, shows the proportion in which the atoms unite—one atom of carbon uniting with two atoms of oxygen in each of the molecules. The affinity of oxygen for other [106] elements, and the affinity of other elements for oxygen, and for each other, resides in their atoms.

Oxidation.—The uniting of oxygen with other elements is termed *oxidation*. This may take place slowly or rapidly, the two rates being designated as *slow* oxidation and *rapid* oxidation. Examples of slow oxidation are found in certain kinds of decay and in the rusting of iron. Combustion is an example of rapid oxidation. Slow and rapid oxidation, while differing widely in their effects upon surrounding objects, are alike in that both produce heat and form compounds of oxygen. In slow oxidation, however, the heat may come off so gradually that it is not observed.

Movement of Oxygen through the Body.—Oxygen has been shown in the preceding chapters to pass from the lungs into the blood and later to leave the blood and, passing through the lymph, to enter the cells. That oxygen does not become a permanent constituent of the cells is shown by the constancy of the body weight. Nearly two pounds of oxygen per day are known to enter the cells of the average-sized person. If this became a permanent part of the cells, the body would increase in weight from day to day. Since the body weight remains constant, or nearly so, we must conclude that oxygen leaves the body about as fast as it enters. Oxygen enters the body as a *free* element. The form in which it leaves the body will be understood when we realize the purpose which it serves and the method by which it serves this purpose.

Purpose of Oxygen in the Body.—The question may be raised: Is it possible for oxygen to serve a purpose in the body without remaining in it? This, of course, depends upon what the purpose is. That it is possible for oxygen to serve a purpose and
[107] at the same time pass on through the place where it serves that purpose, is seen by studying the combustion in an ordinary stove (Fig. 54). Oxygen enters at the draft and for the most part passes out at the flue, but in passing through the stove it unites with, or oxidizes, the fuel, causing the combustion which produces the heat.

Now it is found that certain chemical processes, mainly oxidations, are taking place in the body. These produce the heat

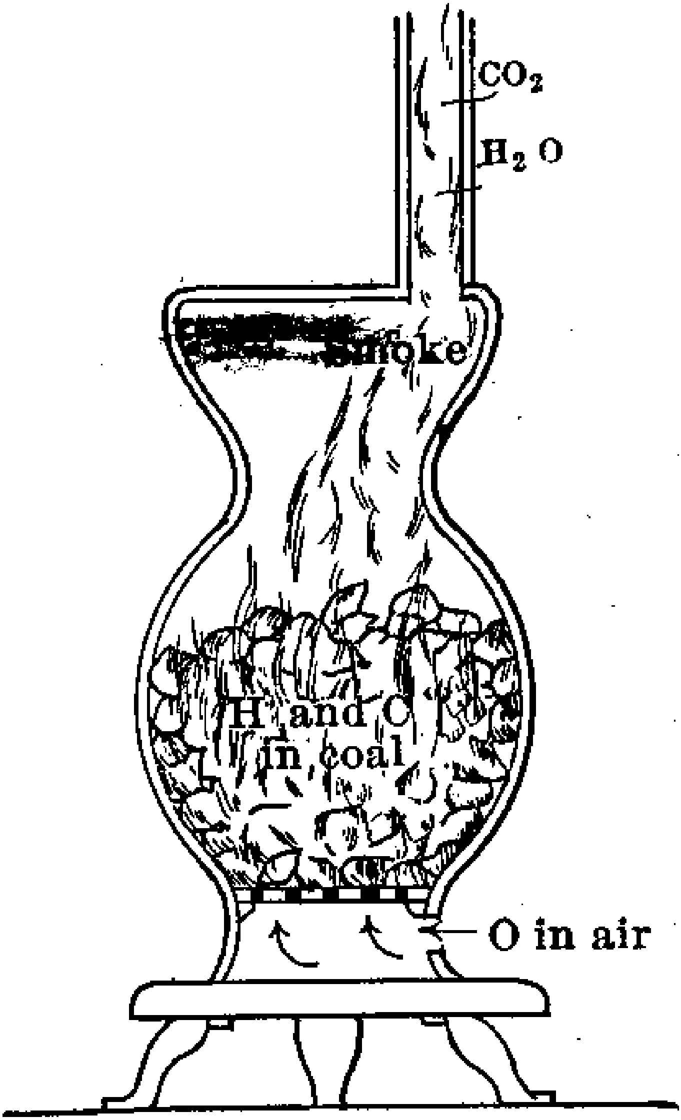

Fig. 54—**Coal stove** illustrating rapid oxidation.

for keeping it warm and also supply other forms of energy,[45] including motion. It is the purpose of oxygen to keep up these oxidations and, by so doing, to aid in supplying the body with energy. It serves this purpose in much the same way that it supports combustion, *i.e.*, by uniting with, or oxidizing, materials derived from foods that are present in the cells.

Does Oxygen serve Other Purposes?—It has been suggested that oxygen may serve the purpose of oxidizing, or destroying, substances that are injurious and of acting, in this way, as a purifying agent in the body. In support of this view is the natural tendency of oxygen to unite with substances and the well-known fact that oxygen is an important natural agent in purifying water. It seems probable, therefore, that it may to a slight extent serve this purpose in the body. It is probable also that oxygen aids
[108] through its chemical activity in the formation of compounds which are to become a part of the cells. Both of these uses, however, are of minor importance when compared with *the main use of oxygen*, which *is that of an aid in supplying energy to the body*.

Oxygen and the Maintenance of Life.—In the supplying of energy to the body, one of the conditions necessary to the maintenance of life is provided. Because oxygen is necessary to this process, and because death quickly results when the supply of it is cut off, oxygen is frequently called the supporter of life. This idea is misleading, for oxygen has no more to do with the maintenance of life than have the food materials with which it unites. Life appears to be more dependent upon oxygen than upon food, simply because the supply of it in the body at any time is exceedingly small. Being continually surrounded by an atmosphere containing free oxygen, the body depends upon this as a constant source of supply, and does not store it up. Food, on the other hand, is taken in excess of the body's needs and

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[45] The term *energy*, as used here, has the same general meaning as the word *power*. See Chapter XII.

stored in the various tissues, the supply being sufficient to last for several days. When the supply of either oxygen or food is exhausted in the body, life must cease.

The Oxygen Movement a Necessity.—Since *free* oxygen is required for keeping up the chemical changes in the cells, and since it ceases to be free as soon as it goes into combination, its continuous movement through the body is a necessity. The oxygen compounds must be removed as fast as formed in order to make room for more free oxygen. This movement has already been studied in connection with the blood and the organs of respiration, but the consideration of certain details has been deferred till now. By what means and in what form is the oxygen passed *to* and *from* the cells?

Passage of Oxygen through the Blood.—In serving its [109] purpose at the cells, the oxygen passes twice through the blood—once as it goes toward the cells and again as it passes from the cells to the exterior of the body:

Passage toward the Cells.—This is effected mainly through the hemoglobin of the red corpuscles. At the lungs the oxygen and the hemoglobin form a weak chemical compound that breaks up and liberates the oxygen when it reaches the capillaries in the tissues. The separation of the oxygen from the hemoglobin at the tissues appears to be due to two causes: first, to the weakness of the chemical attraction between the atoms of oxygen and the atoms that make up the hemoglobin molecule; and second, to a difference in the so-called *oxygen pressure* at the lungs and at the tissues.[46]

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[46] The oxygen pressure of the atmosphere is that portion of the total atmospheric pressure which is due to the weight of the oxygen. Since oxygen comprises about one fifth of the atmosphere, the pressure which it exerts is about one fifth of the total atmospheric pressure, or, at the sea level, about three pounds to the square inch (15 x 1/5 = 3). This is the oxygen pressure of the atmosphere. The low oxygen pressure in the tissues is due to its scarcity, and this scarcity is due to its entering into combination at the cells.

The attraction of the oxygen and the hemoglobin is sufficient to cause them to unite where the oxygen pressure is more than one half pound to the square inch, but it is not sufficiently strong to cause them to unite or to prevent their separation, if already united, where the oxygen pressure is less than one half pound to the square inch. The oxygen pressure at the lungs, which amounts to nearly three pounds to the square inch, easily causes the oxygen and the hemoglobin to unite, while the almost complete absence of any oxygen pressure at the tissues, permits their separation. The blood in its circulation constantly flows
[110] from the place of high oxygen pressure at the lungs to the place of low oxygen pressure at the tissues and, in so doing, loads up with oxygen at one place and unloads it at the other (Fig. 55).

Passage from the Cells.—Since oxygen leaves the free state at the cells and becomes a part of compounds, we are able to trace it from the body only by following the course of these compounds. Three waste compounds of importance are formed at the cells—carbon dioxide (CO_2), water (H_2O), and urea (N_2H_4CO). The first is formed by the union of oxygen with carbon, the second by its union with hydrogen, and the third by its union with nitrogen, hydrogen, and carbon. These compounds are carried by the blood to the organs of excretion, where they are removed from the body. The water leaves the body chiefly as a liquid, the urea as a solid dissolved in water, and the carbon dioxide as a gas. The passage of carbon dioxide through the blood requires special consideration.

Passage of Carbon Dioxide through the Blood.—Part of the carbon dioxide is dissolved in the plasma of the blood, and part of it is in weak chemical combination with substances found in the plasma and in the corpuscles. Its passage through the
[111] blood is accounted for in the same way as the passage of the oxygen. Its ability to dissolve in liquids and to enter into chemical

combination varies as the *carbon dioxide pressure*[47] This in turn varies with the amount of the carbon dioxide, which is greatest at the cells (where it is formed), less in the blood, and still less in the lungs. Because of these differences, the blood is able to take it up at the cells and release it at the lungs (Fig. 55).

Properties of Carbon Dioxide.—Carbon dioxide is a colorless gas with little or no odor. It is classed as a heavy gas, being about one third heavier than air[48] (Fig. 56). It does not support combustion, but on the contrary is used to some extent to extinguish fires. It is formed by the oxidation of carbon in the body, and by the combustion of carbon outside of the body. It is also formed by the decay of animal and vegetable matter. From these sources it is continually finding its way into the atmosphere. Although not a poisonous gas, carbon dioxide may, if it surround the body, shut out the supply of oxygen and cause death.[49]

Final Disposition of Carbon Dioxide.—It is readily seen that the union of carbon and oxygen, which is continually removing oxygen from the air and replacing it with carbon dioxide, tends to make the whole atmosphere deficient in the one and to have [112]

[47] See footnote on oxygen pressure, page 109.

[48] The impression prevails to some extent that carbon dioxide, on account of its weight, settles out of the atmosphere, collecting in old wells and at the floor in crowded rooms. Any such settling of the carbon dioxide is prevented by the rapid motion of its molecules. This motion not only prevents a separation of carbon dioxide and air after they are mixed, but causes them to mix rapidly when they are separated, if they still have surface contact. The carbon dioxide found in old wells is formed there by decaying vegetable or animal matter. In rooms it is no more abundant at the floor than in other parts.

[49] On account of the formation of carbon dioxide in places containing decaying material, the descent into an old well or other opening into the earth is often a hazardous undertaking. Before making such a descent the air should always be tested by lowering a lighted lantern or candle. Artificial respiration is the only means of restoring one who has been overcome by this gas (page 97).

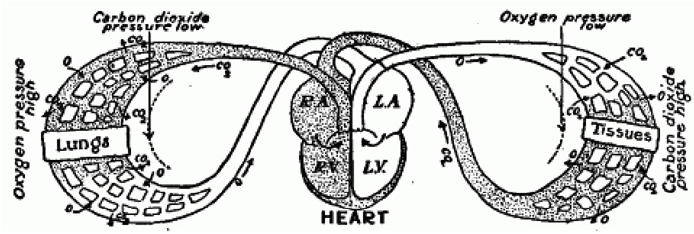

Fig. 55—**Diagram illustrating movement, of oxygen and carbon dioxide through the body** (S.D. Magers). Each moves from a place of relatively high to a place of relatively low pressure. (See text.)

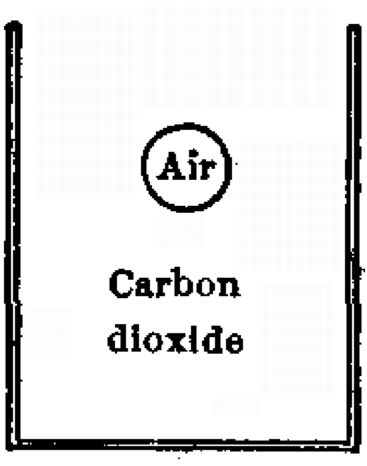

Fig. 56—**Soap bubble** floating in a vessel of carbon dioxide, illustrating the difference in weight between air and carbon dioxide gas.

an excess of the other. This tendency is counteracted through the agency of vegetation. Green plants absorb the carbon dioxide from the air, decompose it, build the carbon into compounds (starch, etc.) that become a part of the plant, and return the free oxygen to the air (Fig. 57). In doing this, they not only preserve the necessary proportion of oxygen and carbon dioxide in the atmosphere, but also put the carbon and oxygen in such a condition that they can again unite. The force which enables the plant cells to decompose the carbon dioxide is supplied by the sunlight (Chapter XII).

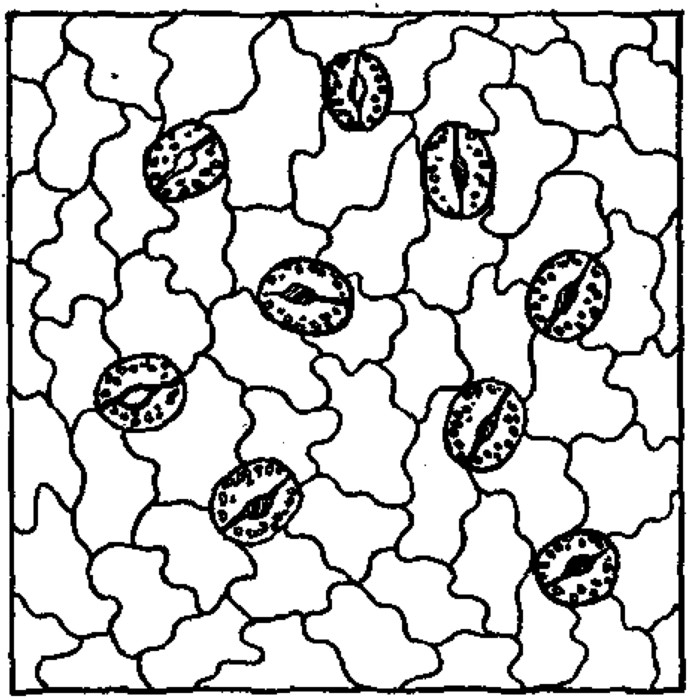

Fig. 57—**Under surface** of a geranium leaf showing breathing pores, highly magnified (O.H.).

Summary.—Oxygen, by uniting with materials at the cells, keeps up a condition of chemical activity (oxidation) in the body. This supplies heat and the other forms of bodily energy. Entering as a free element, oxygen leaves the body as a part of the waste compounds which it helps to form. The free oxygen is transported from the lungs to the cells by means of the hemoglobin of the red corpuscles, while the combined oxygen in carbon dioxide and other compounds from the cells is carried mainly by the plasma. The limited supply of free oxygen in the body at any time makes necessary its continuous introduction into the body.

[113] **Exercises.**—1. Describe the properties of oxygen. How does it unite with other elements? How does it support combustion?

2. State the purpose of oxygen in the body. What properties enable it to fulfill this purpose?

3. What is the proof that oxygen does not remain permanently in the body? How does the oxygen entering the body differ from the same oxygen as it leaves the body?

4. What is the necessity for the *continuous* introduction of oxygen into the body, while food is introduced only at intervals?

5. How are the red corpuscles able to take up and give off oxygen? How is the plasma able to take up and give off carbon dioxide?

6. If thirty cubic inches of air pass from the lungs at each expiration and 4.5 per cent of this is carbon dioxide, calculate the number of cubic feet of the gas expelled in twenty-four hours, estimating the number of respirations at eighteen per minute.

7. What is the weight of this volume of carbon dioxide, if one cubic foot weigh 1.79 ounces?

8. What portion of this weight is oxygen and what carbon, the ratio by weight of carbon to oxygen in carbon dioxide being twelve to thirty-two?

9. What is the final disposition of carbon dioxide in the atmosphere?

PRACTICAL WORK

To show the Difference between Free Oxygen and Oxygen in Combination.—Examine some crystals of potassium chlorate (KC_lO_3). They contain oxygen *in combination* with potassium and chlorine. Place a few of these in a small test tube and heat strongly in a gas or alcohol flame. The crystals first melt, and the liquid which they form soon appears to boil. If a splinter, having a spark on the end, is now inserted in the tube, it is kindled into a flame. This shows the presence of *free* oxygen, the heat having caused the potassium chlorate to decompose. The difference between free and combined oxygen may also be shown by decomposing other compounds of oxygen, such as water and mercuric oxide.

Preparation and Properties of Oxygen.—Intimately mix 3 grams (1/2 teaspoonful) of potassium chlorate with half its bulk of manganese dioxide, and place the mixture in a large test tube. Close the test tube with a tight-fitting stopper which bears a glass tube of sufficient length and of the right shape to convey the [114] escaping gas to a small trough or pan partly filled with water, on the table. Fill four large-mouthed bottles with water and, by covering with cardboard, invert each in the trough of water. Arrange the test tube conveniently for heating, letting the end of the glass tube terminate under the mouth of one of the bottles (Fig. 58). Using an alcohol lamp or a Bunsen burner, heat over the greater portion of the tube at first, but gradually concentrate the flame upon the mixture. Do not heat too strongly, and when the gas is coming off rapidly, remove the flame entirely, putting it back as the action slows down. After all the bottles have been filled, remove the end of the glass tube from the water, but leave the bottles of oxygen inverted in the trough until they are to be used. On removing the bottles from the trough, keep the tops covered with wet cardboard.

1. Examine a bottle of oxygen, noting its lack of color. Insert a small burning splinter in the upper part of the bottle and observe the change in the rate of burning. The air contains free oxygen, but it is diluted with nitrogen. Compare this with the undiluted oxygen in the bottle as to effect in causing the splinter to burn.

2. In a second bottle of oxygen insert a splinter without the flame, but having a small spark on the end. As soon as the oxygen kindles the spark into a flame, withdraw from the bottle and blow out the flame, but again insert the spark. Repeat the experiment as long as the spark is kindled by the oxygen into a flame. This experiment is usually performed as a test for undiluted oxygen.

3. Make a hollow cavity in the end of a short piece of crayon. Fasten a wire to the crayon, and fill the cavity with powdered
[115] sulphur. Ignite the sulphur in the flame of an alcohol lamp or Bunsen burner, and lower it into a bottle of oxygen. Observe the change in the rate of burning, the color of the flame, and the material formed in the bottle by the burning. The gas remaining in the bottle is sulphur dioxide (SO_2), formed by the *uniting* of the sulphur and the oxygen.

4. Bend a small loop on the end of a piece of picture wire. Heat the loop in a flame and insert it in some powdered sulphur. Ignite the melted sulphur which adheres, and insert it quickly in a bottle of oxygen. Observe the dark, brittle material which is formed by the burning of the iron. It is a compound of the iron with oxygen, similar to iron rust, and formed by their uniting.

Preparation and Properties of Carbon Dioxide.—1. (*a*) Attach a piece of carbon (charcoal) no larger than the end of the thumb to a piece of wire. Ignite the charcoal in a hot flame and lower it into a vessel of oxygen. Observe its combustion, letting it remain in the bottle until it ceases to burn. Note that the burning has consumed a part of the carbon and has used up the free oxygen. Has anything been formed in their stead?

(*b*) Remove the charcoal and add a little limewater. Cover the bottle with a piece of cardboard, and bring the gas and the limewater in contact by shaking. Note any change in the color of the limewater. If it turns white, the presence of carbon dioxide is proved.

2. Burn a splinter in a large vessel of air, keeping the top covered. Add limewater and shake. Note and account for the result.

3. Place several pieces of marble (limestone) in a jar holding at least half a gallon. Barely cover the marble with water, and then add hydrochloric acid until a gas is rapidly evolved. This gas is carbon dioxide.

(*a*) Does it possess color?

(*b*) Insert a burning splinter to see if it supports combustion.

(*c*) Place a bottle of oxygen by the side of the vessel of carbon dioxide. Light a splinter and extinguish the flame by lowering it into the vessel of carbon dioxide. Withdraw immediately, and if a spark remains on the splinter, thrust it into the bottle of oxygen. Then insert the relighted splinter into the carbon dioxide. Repeat several times, kindling the flame in one gas and extinguishing it in the other. Finally show that the spark also may be extinguished by holding the splinter a little longer in the carbon dioxide.

(*d*) Tip the jar containing the carbon dioxide over the mouth of a tumbler, as in pouring water, though not far enough to spill the acid, and then insert a burning splinter in the tumbler. Account [116]
for the result. Inference as to the weight of carbon dioxide.

(*e*) Review experiments (page 101) showing the presence of carbon dioxide in the breath.

To illustrate the General Movement of Oxygen through the Body.—Into a glass tube, six inches in length and open at both ends, place several small lumps of charcoal (Fig. 59). Fit into one end of this tube, by means of a stopper, a smaller glass tube which is bent at right angles and which is made to pass

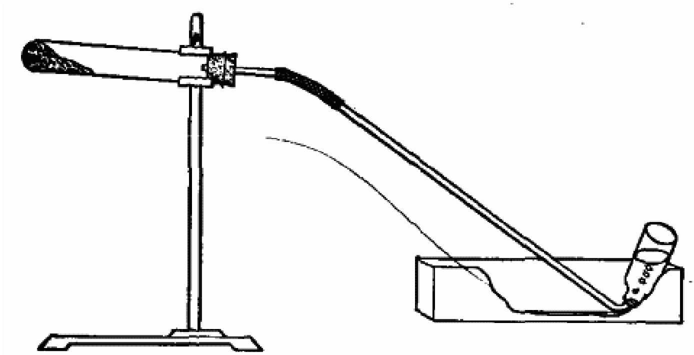

Fig. 58—**Apparatus** for generating oxygen.

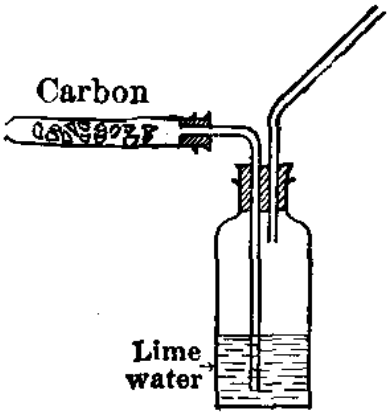

Fig. 59—**Simple apparatus** for illustrating passage of oxygen through the body.

through a close-fitting stopper to the bottom of a small bottle. Another small tube is fitted into a second hole in this stopper, but terminating near the top of the bottle, and to this is connected a rubber tube about eighteen inches in length. The arrangement is now such that by sucking air from the top of the bottle, it is made to enter at the distant end of the tube containing the charcoal. After filling the bottle one third full of limewater, heat the tube containing the charcoal until it begins to glow. Then suck the air through the apparatus (as in smoking, without drawing it into the lungs), observing what happens both in the tube and in the bottle. What are the proofs that the oxygen, in passing through the tube, unites with the carbon, forms carbon dioxide, and liberates energy? Compare the changes which the oxygen undergoes while passing through the tube with the changes which it undergoes in passing through the body.

[117]

CHAPTER IX - FOODS AND THE THEORY OF DIGESTION

The body is constantly in need of new material. Oxidation, as shown in the preceding chapter, rapidly destroys substances at the cells, and these have to be replaced. Upon this renewal depends the supply of energy. Moreover, there is found to be an actual breaking down of the living material, or protoplasm, in the body. While this does not destroy the cells, as is sometimes erroneously stated, it reduces the quantity of the protoplasm and makes necessary a process of repair, or rebuilding, of the tissues. This also requires new material. Finally, substances, such as water and common salt, are required for the aid which they render in the general work of the body. Since these are constantly being lost in one way or another, they also must be replaced. These different needs of the body for new materials are supplied through

The Foods.—Foods are substances that, on being taken into the healthy body, are of assistance in carrying on its work. This definition properly includes oxygen, but the term is usually limited to substances introduced through the digestive organs. As suggested above, foods serve at least three purposes:

1. They, with oxygen, supply the body with energy.
2. They provide materials for rebuilding the tissues.
3. They supply materials that aid directly or indirectly in the general work of the body.

[118] **The Simple Foods, or Nutrients.**—From the great variety of things that are eaten, it might appear that many different kinds of substances are suitable for food. When our various animal and vegetable foods are analyzed, however, they are found to be similar in composition and to contain only some five or six kinds

of materials that are essentially different. While certain foods may contain only a single one of these, most of the foods are mixtures of two or more. These few common materials which, in different proportions, form the different things that are eaten, are variously referred to as simple foods, food-stuffs, and *nutrients*, the last name being the one generally preferred. The different classes of nutrients are as follows:

Nutrients:
Proteids
(Albuminoids)
Carbohydrates
Fats
Mineral salts
Water

It is now necessary to become somewhat familiar with the different nutrients and the purposes which they serve in the body.

Proteids.—The proteids are obtained in part from the animal and in part from the plant kingdom, there being several varieties. A well-known variety, called *albumin*, is found in the white of eggs and in the plasma of the blood, while the muscles contain an abundance of another variety, known as *myosin*. Cheese consists largely of a kind of proteid, called *casein*, which is also present in milk, but in a more diluted form. If a mouthful of wheat is chewed for some time, most of it is dissolved and swallowed, but there remains in the mouth a sticky, gum-like substance. This is *gluten*, a form of proteid which occurs in different grains. Again, [119]
certain vegetables, as beans, peas, and peanuts, are rich in a kind of proteid which is called *legumen*.

Proteids are compounds of carbon, hydrogen, oxygen, nitrogen, and a small per cent of sulphur. Certain ones (the nucleo-proteids from grains) also contain phosphorus. All of the proteids are highly complex compounds and form a most important class of nutrients.

Purposes of Proteids.—The chief purpose of proteids in the body is to rebuild the tissues. Not only do they supply all of the main elements in the tissues, but they are of such a nature chemically that they are readily built into the protoplasm. They are absolutely essential to life, no other nutrients being able to take their place. An animal deprived of them exhausts the proteids in its body and then dies. In addition to rebuilding the tissues, proteids may also be oxidized to supply the body with energy.

Albuminoids form a small class of foods, of minor importance, which are similar to proteids in composition, but differ from them in being unable to rebuild the tissues. Gelatin, a constituent of soup and obtained from bones and connective tissue by boiling, is the best known of the albuminoid foods. On account of the nitrogen which they contain, proteids and albuminoids are often classed together as *nitrogenous foods*.

Carbohydrates.—While the carbohydrates are not so essential to life as are the proteids, they are of very great value in the body. They are composed of carbon, hydrogen, and oxygen, and are obtained mainly from plants. There are several varieties of carbohydrates, but they are similar in composition. All of those used as food to any great extent are starch and certain kinds of sugar.

[120] **Starch** is the carbohydrate of greatest importance as a food, and it is also the one found in the greatest abundance. All green plants form more or less starch, and many of them store it in their leaves, seeds, or roots (Fig. 60). From these sources it is obtained as food. *Glycogen*, a substance closely resembling starch, is found in the body of the oyster. It is also formed in the liver and muscles of the higher animals, being prepared from the sugar of the blood, and is stored by them as reserve food (Chapter XI). Glycogen is, on this account, called *animal starch*.

Starch on being eaten is first changed to sugar, after which it may be converted into glycogen in the liver and in the muscles.

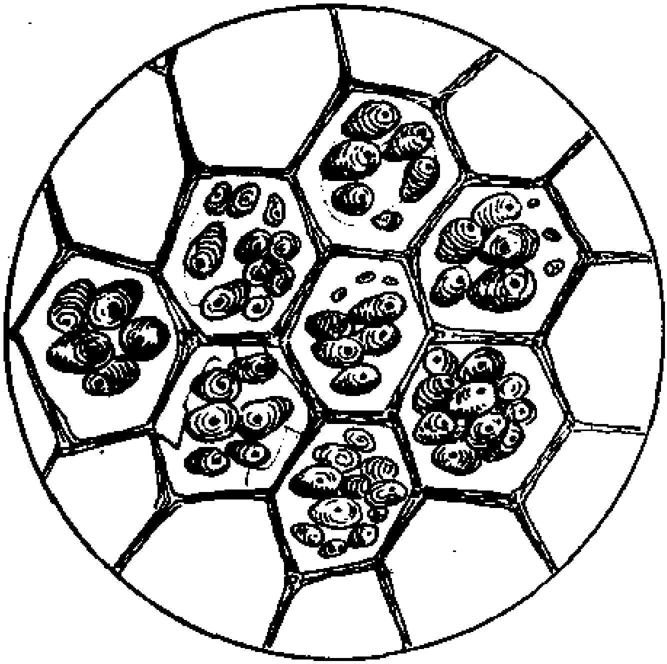

Fig. 60—**Starch grains** in cells of potato as they appear under the microscope. (See practical work.)

Sugars.—There are several varieties of sugar, but the important ones used as foods fall into one or the other of two classes, known as *double sugars* (disaccharides) and *single sugars* (monosaccharides). To the first class belong *cane sugar*, found in sugar cane and beets, *milk sugar*, found in sweet milk, and *maltose*, a kind of sugar which is made from starch by the action of malt. The important members of the second class are *grape sugar*, or dextrose, and *fruit sugar*, or levulose, both of which are found in fruits and in honey.

The most important of all sugars, so far as its use in the body is concerned, is *dextrose*. To this form all the other sugars, and starch also, are converted before they are finally used in the body. [121] The close chemical relation between the different carbohydrates makes such a conversion easily possible.

Fats.—The fats used as foods belong to one or the other of two classes, known as solid fats and oils. The solid fats are derived chiefly from animals, and the oils are obtained mostly from plants. Butter, the fat of meats, olive oil, and the oil of nuts are the fats of greatest importance as foods. Fats, like the carbohydrates, are composed of carbon, hydrogen, and oxygen. They are rather complex chemical compounds, though not so complex as proteids. Since neither fats nor carbohydrates contain nitrogen, they are frequently classed together as *non-nitrogenous* foods.

Purpose Served by Carbohydrates, Fats, and Albuminoids.—These classes of nutrients all serve the common purpose of supplying energy. By uniting with oxygen at the cells, they supply heat and the other forms of bodily force. This is perhaps their only purpose.[50] Proteids also serve this purpose, but they are not so well adapted to supplying energy as are the carbohydrates and the fats. In the first place they do not completely oxidize and therefore do not supply so much energy; and, in the second place, they form waste products that are removed with difficulty from the body.

Mineral Salts and their Uses.—Mineral salts are found in small quantities in all of the more common food materials, and,

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[50] While awaiting oxidation at the cells, the carbohydrates and fats are stored up by the body, the carbohydrates as glycogen and the fats as some form of fat. In this sense they are sometimes looked upon as serving to build up certain of the tissues.

as a rule, find their way into the body unnoticed. They supply the elements which are found in the body in small quantities and serve a variety of purposes.[51] Calcium phosphate and calcium [122] carbonate are important constituents of the bones and teeth; and the salts containing iron renew the hemoglobin of the blood. Others perform important functions in the vital processes. The mineral compound of greatest importance perhaps is sodium chloride, or common salt.[52] This is a natural constituent of most of our foods, and is also added to food in its preparation for the table. When it is withheld from animals for a considerable length of time, they suffer intensely and finally die. It is necessary in the blood and lymph to keep their constituents in solution, and is thought to play an important rôle in the chemical changes of the cells. It is constantly leaving the body as a waste product and must be constantly supplied in small quantities in the foods.

Importance of Water.—Water finds its way into the body as a pure liquid, as a part of such mixtures as coffee, chocolate, and milk, and as a constituent of all our solid foods. (See table of foods, page 126.) It is also formed in the body by the oxidation of hydrogen. It passes through the body unchanged, and is constantly being removed by all the organs of excretion. Though water does not liberate energy in the body nor build up

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[51] The following table shows the main elements in the body and their relation to the different nutrients:

[52] The recently advanced theory that the molecules of the mineral salts, by dissolving in water, separate into smaller divisions, part of which are charged with positive electricity and part with negative electricity, has suggested several possible uses for sodium chloride and other mineral salts in the body. The sodium chloride in the tissues is in such concentration as to be practically all separated into its sodium and chlorine particles, or ions. It has recently been shown that the sodium ions are necessary for the contraction of the muscles, including the muscles of the heart. There is also reason for believing that the different ions may enter into temporary combination with food particles, and in this way assist in the processes of nutrition.

the tissues in the sense that other foods do, it is as necessary to the maintenance of life as oxygen or proteids. It occurs in all the tissues, and forms about 70 per cent of the entire weight of the body. Its presence is necessary for the interchange of materials at the cells and for keeping the tissues soft and pliable. As it enters the body, it carries digested food substances with it, and as it leaves it is loaded with wastes. Its chief physiological work, which is that of a *transporter of material*, depends upon its ability to dissolve substances and to flow readily from place to place.

Relative Quantity of Nutrients Needed.—Proteids, carbohydrates, and fats are the nutrients that supply most of the body's nourishment. The most hygienic diet is the one which supplies the proteids in sufficient quantity to rebuild the tissues and the carbohydrates and fats in the right amounts to supply the body with energy. Much experimenting has been done with a view to determining these proportions, but the results so far are not entirely satisfactory. According to some of the older estimates, a person of average size requires for his daily use five ounces of proteid, two and one half ounces of fat, and fifteen ounces of carbohydrate. Recent investigations of this problem seem to show that the body is as well, if not better, nourished by a much smaller amount of proteid—not more than two and one half ounces (60 grams) daily.[53]

[123] While there is probably no necessity for the healthy individual's taking his proteid, fat, and carbohydrate in *exact* proportions (if the proportions best suited to his body were known), the fact needs to be emphasized that proteids, although absolutely necessary, should form but a small part (not over one fifth) of the daily bill of fare. In recognition of this fact is involved a principle of health and also one of economy. The proteids, especially those in meats, are the most expensive of the nutrients, whereas the carbohydrates, which should form the greater bulk of one's food,

[53] Chittenden, *The Nutrition of Man*.

are the least expensive.

Effects of a One-sided Diet.—The plan of the body is such as to require a *mixed diet*, and all of the great classes of nutrients are necessary. If one could subsist on any single class, it would be proteids, for proteids are able both to rebuild tissue and to supply energy. But if proteids are eaten much in excess of the body's need for rebuilding the tissues, and this excess is oxidized for supplying energy, a strain is thrown upon the organs of excretion, because of the increase in the wastes. Not only is there danger of overworking certain of these organs (the liver and kidneys), but the wastes may linger too long in the body, causing disorder and laying the foundation for disease. On the other hand, if an insufficient amount of proteid is taken, the tissues are improperly nourished, and one is unable to exert his usual strength. What is true of the proteids is true, though in a different way, of the other great classes of foods. A diet which is lacking in proteid, carbohydrate, or fat, or which has any one of them in excess, is not adapted to the requirements of the body.

Composition of the Food Materials.—One who intelligently provides the daily bill of fare must have some knowledge of the nature and quantity of the nutrients present in the different [124] materials used as food. This information is supplied by the chemist, who has made extensive analyses for this purpose. Results of such analyses are shown in Table 1 (page 126), which gives the percentage of proteids, fats, carbohydrates, water, and mineral salts in the edible portions of the more common of our foods.

[125]

Food Supply to the Table.—The main problem in supplying the daily bill of fare is that of securing through the different food materials the requisite amounts of proteids, carbohydrates, and fats. In this matter a table showing the composition of foods can be used to great advantage. Consulting the table on page 126, it is seen that large per cents of proteids are supplied by lean meat, eggs, cheese, beans, peas, peanuts, and oatmeal, while fat is in excess in fat meat, butter, and nuts (Fig. 61). Carbohydrates are supplied in abundance by potatoes, rice, corn, sugar, and molasses. The different cereals also contain a large percentage of carbohydrates in the form of starch.

TABLE I. THE COMPOSITION OF FOOD MATERIALS[54]

Food Materials	Water	Solids	Proteid	Fat	Carbohydrates	Mineral Matter	Heat Value of One Pound
Animal foods, edible portion	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Calories[55]
Beef: Shoulder	63.9	36.1	19.5	15.6	...	1	1020
Rib	48.1	51.9	15.4	35.6	...	.9	1790
Sirloin	60	40	18.5	20.5	...	1	1210
Round	68.2	31.8	20.5	10.1	...	1.2	805
Veal: Shoulder	68.8	31.2	20.2	9.8	...	...	790
Mutton: Leg	61.8	38.2	18.3	19	...	.9	1140
Loin	49.3	50.7	15	35	...	.7	1755
Pork: Shoulder	50.3	49.7	16	32.8	...	.9	1680
Ham, salted, smoked	41.5	58.5	16.7	39.1	...	2.7	1960

[0] The calorie is the adopted heat unit. As used in this table it may be defined as the quantity of heat required to raise 1 kilogram (2.2 pounds) of water, 1 degree centigrade. The calories also show the relative amount of energy supplied by the different foods.

Fat, salted	12.1	87.9	.9	82.8	...	4.2	3510
Sausage: Pork	41.5	58.8	13.8	42.8	...	2.2	2065
Bologna	62.4	37.6	18.8	42.8	...	3	1015
Chicken	72.2	27.8	24.4	1	...	1.4	540
Eggs	73.8	26.2	14.9	10.5	...	.8	721
Milk	87	13	3.6	4	4.7	.7	325
Butter	10.5	89	.6	85	.5	.3	3515
Cheese: Full cream	30.2	69.8	28.3	35.5	1.8	4.2	2070
Skim milk	41.3	58.7	38.4	6.8	6.9	4.6	1165
Fish: Codfish	82.6	17.4	15.8	.5	...	1.2	310
Salmon	63.6	36.4	21.6	13.4	...	1.4	965
Oysters	87.1	12.9	6	1.2	3.7	2	230
Vegetable foods							
Wheat flour	12.5	87.5	11	1.1	74.9	.5	1645
Graham flour (wheat)	13.1	86.9	11.7	1.7	71.7	1.8	1635
Rye flour	13.1	86.9	6.7	.8	78.7	.7	1625
Buckwheat flour	14.6	85.4	6.9	1.4	76.1	1	1605
Oatmeal	7.6	92.4	15.1	7.1	68.2	2	1850
Cornmeal	15	85	9.2	3.8	70.6	1.4	1645
Rice	12.4	87.6	7.4	.4	79.4	.4	1630
Peas	12.3	87.7	26.7	1.7	56.4	2.9	1565
Beans	12.6	87.4	23.1	2	59.2	3.1	1615

Potatoes	78.9	21.1	2.1	.1	17.9	1	375
Tomatoes	95.3	4.7	.8	.4	3.2	.3	80
Apples	83.2	16.8	.2	.4	15.9	.3	315
Sugar, granulated	2	98	...	...	97.8	.3	1820
White bread (wheat)	32.3	67.7	8.2	1.7	56.3	.0	1280
Peanuts	9.2	90.8	25.8	24.4	38.6	2	2560
Almonds	4.8	95.2	21	17.3	54.9	2	3030
Walnuts (English)	2.5	97.5	16.6	16.1	63.4	1.4	3285

[126] *Variety* in the selection of foods for the table is an essential feature, but this should not increase either the work or the expense of supplying the meals. Each single meal can, and should, be simple in itself and, at the same time, differ sufficiently from the meal preceding and the one following to give the necessary variety in the course of the day. The bill of fare should, of course, include fruits (for their tonic effects) and very small amounts perhaps of substances which stimulate the appetite, such as pepper, mustard, etc., known as condiments.

Purity of Food.—The fact that many of the food substances are perishable makes it possible for them to be eaten in a slightly decayed condition. Such substances are decidedly unwholesome (some containing poisons) and should be promptly rejected. Not only do fresh meats, fruits, and vegetables need careful inspection, but canned and preserved goods as well. If canned foods are imperfectly sealed or if not thoroughly cooked in the canning process, they decay and the acids which they generate act on the metals lining the cans, forming poisonous compounds. The contents of "tin" cans should for this reason be transferred to other vessels as soon as opened.

Elements found in the body	In abundance	Carbon Hydrogen Oxygen	Supplied by carbohydrates and fats
		Carbon Hydrogen Oxygen Nitrogen Sulphur Phosphorus	Supplied by proteids
	In small quantities	Sulphur Phosphorus Calcium Iron Magnesium Potassium Sodium Chlorine	Supplied by different kinds of mineral salts

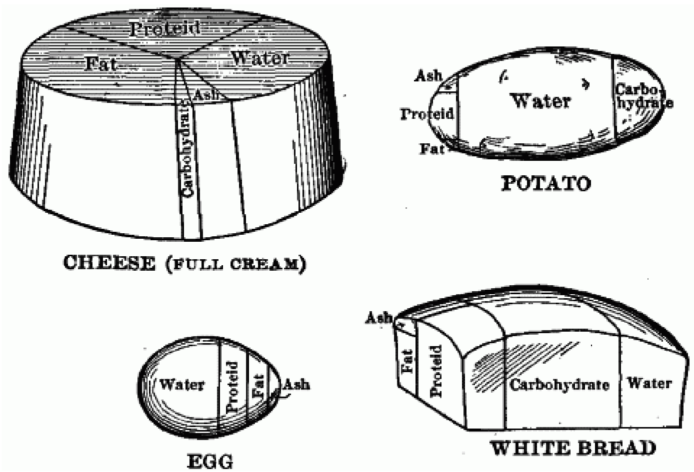

Fig. 61—Relative proportions of different nutrients in well-known foods.

Foods are also rendered impure or weakened through adulteration, the watering of milk being a familiar example. The manufacture of jellies, preserves, sirups, and various kinds of pickles and condiments has perhaps afforded the largest field for adulterations, although it is possible to adulterate nearly all of the leading articles of food. A long step in the prevention of food and drug adulteration was taken in this country by the passage of the *Pure Food Law*. By forcing manufacturers of foods and medicines to state on printed labels the composition of their products, this law has made it possible for the consumer to know what he is purchasing and putting into his body.

Alcohol not a Food.—Many people in this and other countries drink in different beverages, such as whisky, beer, wine, etc., a varying amount of alcohol. This substance has a temporary stimulating or exciting effect, and the claim has been made that
[128] it serves as a food. Recently it has been shown that alcohol when introduced into the body in small quantities and in a greatly diluted form, is nearly all oxidized, yielding energy as does fat or sugar. If no harmful effects attended the use of alcohol, it might on this account be classed as a food. But alcohol is known to be harmful to the body. When used in large quantities, it injures nearly all of the tissues, and when taken habitually, even in small doses, it leads to the formation of the alcohol habit which is now recognized and treated as a disease. This and other facts show that alcohol is not adapted to the body plan of taking on and using new material (Chapter XI), and no substance lacking in this respect can properly be classed as a food.[56] Instead of classing alcohol as a food, it should be placed in that long list

[56] While alcohol cannot be classed as a food, it is believed by some authorities to contain *food value* and, in the hands of the physician, to be a substance capable of rendering an actual service in the treatment of certain diseases. It might, for example, be used where one's power of digestion is greatly impaired, since alcohol requires no digestion. But upon this point there is a decided difference of opinion. Certain it is that no one should attempt to use alcohol as food or medicine except under the advice and direction of his physician.

of substances which are introduced into the body for special purposes and which are known by the general name of

Drugs.—Drugs act strongly upon the body and tend to bring about unusual and unnatural results. Their use should in no way be confused with that of foods. If taken in health, they tend to disturb the physiological balance of the body by unduly increasing or diminishing the action of the different organs. In disease where this balance is already disturbed, they may be administered for their counteractive effects, but always under the advice and direction of a physician. Knowing the nature of the disturbance which the drug produces, the physician can administer it to advantage, should the body be out of physiological [129]
balance, or diseased. Not only are drugs of no value in health, but their use is liable to do much harm.

NATURE OF DIGESTION

Before the nutrients can be oxidized at the cells, or built into the protoplasm, they undergo a number of changes. These are necessary for their entrance into the body, for their distribution by the blood and the lymph, and for the purposes which they finally serve. The first of these changes is preparatory to the entrance of the nutrients and is known as *digestion*. The organs which bring about this change, called digestive organs, have a special construction which adapts them to their work. It will assist materially in understanding these organs if we first learn something of the nature of the work which they have to perform.

How the Nutrients get into the Body.—The nature of digestion is determined by the conditions affecting the entrance of nutrients into the body. Food in the stomach and air in the lungs, although surrounded by the body, are still outside of what is called the *body proper*. To gain entrance into the body proper, a substance must pass through the body wall. This consists of the skin on the outside and of the mucous linings of the air passages and other tubes and cavities which are connected with the external surface.

To get from the digestive organs into the blood, the nutrients must pass through the mucous membrane lining these organs and also the walls of blood or lymph vessels. Only *liquid materials* can make this passage. It is necessary, therefore, to reduce to the liquid state all nutrients not already in that condition. *This reduction to the liquid state constitutes the digestive process*.

[130] **How Substances are Liquefied.**—While the reduction of solids to the liquid state is accomplished in some instances by heating them until they melt, they are more frequently reduced to this state by subjecting them to the action of certain liquids, called *solvents*. Through the action of the solvent the minute particles of the solid separate from each other and disappear from view. (Shown in dropping salt in water.) At the same time they mix with the solvent, forming a *solution*, from which they separate only with great difficulty. For this reason solids in solution can diffuse through porous partitions along with the solvents in which they are dissolved (page 73).

By digestion the nutrients are reduced to the form of a solution. *The process is*, simply speaking, *one of dissolving*. The liquid employed as *the digestive solvent is water*. The different nutrients dissolve in water, mixing with it to form a solution which is then passed into the body proper.

Digestion not a Simple Process.—Digestion is by no means a simple process, such, for instance, as the dissolving of salt or sugar in water. These, being soluble in water, dissolve at once on being mixed with a sufficient amount of this liquid. The majority of the nutrients, however, are insoluble in water and are unaffected by it when acting alone. Fats, starch, and most of the proteids do not dissolve in water. Before these can be dissolved they have to be changed chemically and converted into substances that are *soluble in water*. This complicates the process and *prevents the use of water alone* as the digestive solvent.

A Similar Case.—If a piece of limestone be placed in water, it does not dissolve, because it is insoluble in water. If hydrochloric acid is now added to the water, the limestone is soon dissolved [131] (Fig. 62). (See Practical Work.) It seems at first thought that the acid dissolves the limestone, but this is not the case. The acid produces a chemical change in the limestone (calcium carbonate) and converts it into a compound (calcium chloride) that is soluble in water. As fast as this is formed it is dissolved by the water, which is the real solvent in the case. The acid simply plays the part of a chemical converter.

[132]

The Digestive Fluids.—Several fluids—saliva, gastric juice, pancreatic juice, bile, and intestinal juice—are employed in the digestion of the food. The composition of these fluids is in keeping with the nature of the digestive process. While all of them have water for their most abundant constituent, there are dissolved in the water small amounts of active chemical agents. It is the work of these agents to convert the insoluble nutrients into substances that are soluble in water. The digestive fluids are thus able to act in a *double* manner on the nutrients—to change them chemically and to dissolve them. The chemical agents which bring about the changes in the nutrients are called *enzymes*, or digestive ferments.

Foods Classed with Reference to Digestive Changes.—With reference to the changes which they undergo during digestion, foods may be divided into three classes as follows:

1. Substances already in the liquid state and requiring no digestive action. Water and solutions of simple foods in water belong to this class. Milk and liquid fats, or oils, do not belong to this class.

2. Solid foods soluble in water. This class includes common salt and sugar. These require no digestive action other than dissolving in water.

3. Foods that are insoluble in water. These have first to be changed into soluble substances, after which they are dissolved.

Summary.—Materials called foods are introduced into the body for rebuilding the tissues, supplying energy, and aiding in its general work. Only a few classes of substances, viz., proteids, carbohydrates, fats, water, and some mineral compounds have all the qualities of foods and are suitable for introduction into the body. Substances known as drugs, which may be used as medicines in disease, should be avoided in health. Before foods can be passed into the body proper, they must be converted into the liquid form, or dissolved. In this process, known as digestion, water is the solvent; and certain chemical agents, called enzymes, convert the insoluble nutrients into substances that are soluble in water.

Exercises.—1. How does oxidation at the cells make necessary the introduction of new materials into the body?

2. What different purposes are served by the foods?

3. What is a nutrient? Name the important classes.

4. What are food materials? From what sources are they obtained?

5. Name the different kinds of proteids; the different kinds of carbohydrates. Why are proteids called nitrogenous foods and fats and carbohydrates non-nitrogenous foods?

6. Show why life cannot be carried on without proteids; without water.

7. What per cents of proteid, fat, and carbohydrate are found in wheat flour, oatmeal, rice, butter, potatoes, round beef, eggs, and peanuts?

8. State the objection to a meal consisting of beef, eggs, beans, bread, and butter; to one consisting of potatoes, rice, bread, and butter. Which is the more objectionable of these meals and why?

9. State the general plan of digestion.

[133] 10. Show that digestion is not a simple process like that of dissolving salt in water.

PRACTICAL WORK

Elements supplied by the Foods.—The following brief study will enable the pupil to identify most of the elements present in the body and which have, therefore, to be supplied by the foods.

Carbon.—Examine pieces of charred wood, coke, or coal, and also the "lead" in lead pencils. Show that the charred wood and the coal will burn. Recall experiment (page 114) showing that carbon in burning forms carbon dioxide.

Hydrogen.—Fill a test tube one third full of strong hydrochloric acid and drop into it several small scraps of zinc. The gas which is evolved is hydrogen. When the hydrogen is coming off rapidly, bring a lighted splinter to the mouth of the tube. The gas should burn. Hold a cold piece of glass over the flame and observe the deposit of moisture. Hydrogen in burning forms water. Extinguish the flame by covering the top of the tube with a piece of cardboard. Now let the escaping gas collect in a tumbler inverted over the tube. After holding the tumbler in this position for two or three minutes, remove and, keeping inverted, thrust a lighted splinter into it. (The gas should either burn or explode.) What does this experiment show relative to the weight of hydrogen as compared with that of air?

Nitrogen.—Nitrogen forms about four fifths of the atmosphere, where, like oxygen, it exists in a free state. It may be separated from the oxygen of an inclosed portion of air by causing that gas to unite with phosphorus. Place a piece of phosphorus the size of a pea in a depression in a flat piece of cork. (Handle phosphorus with wet fingers or with forceps.) Place the cork on water and have ready a glass fruit jar holding not more than a quart. Ignite the phosphorus with a hot wire and invert the jar over it, pushing the mouth below the surface of the water. The phosphorus uniting with the oxygen fills the jar with white fumes of phosphoric oxide. These soon dissolve in the water, leaving a clear gas above. This is nitrogen. Place a cardboard under the mouth of the jar and turn it right side up, leaving in the water and keeping the top covered. Light a splinter and, slipping the cover to one side, thrust the flame into the jar of nitrogen, noting the effect. (Flame is extinguished.) Compare nitrogen with oxygen in its relation to combustion. What purpose is served by each in the atmosphere?

[134] *Oxygen.*—Review experiments (page 114) showing the properties of oxygen.

Phosphorus.—Examine a small piece of phosphorus, noting that it has to be kept under water. Lay a small piece on the table and observe the tiny stream of white smoke rising from it, formed by slow oxidation. Dissolve a piece as large as a pea in a teaspoonful of carbon disulphide in a test tube, pour this on a piece of porous paper, and lay the paper on an iron support. When the carbon disulphide evaporates the phosphorus takes fire spontaneously. (The heat from the slow oxidation is sufficient to ignite the phosphorus in the finely divided condition.) What is the most striking property of phosphorus? What purpose does it serve in the match?

Sulphur.—Examine some sulphur, noting its color and the absence of odor or taste. (Impure sulphur may have an odor and a taste.) Burn a little sulphur in an iron spoon, noting that the compound which it forms with oxygen by burning has a decided odor.

Other Elements.—Magnesium. Examine and burn a piece of magnesium ribbon, noting the white compound of magnesium oxide which is formed. *Iron.* Examine pieces of the metal and also some of its compounds, as ferrous sulphate, ferric chloride, and ferric oxide or iron rust. *Sodium.* Drop a piece of the metal on water and observe results. Sodium decomposes water. It has to be kept under some liquid, such as kerosene, which contains no oxygen. (It should not be touched except with the fingers wet with kerosene.) *Chlorine.* Pour strong hydrochloric acid on a little manganese dioxide in a test tube, and warm gently over a low flame. The escaping gas is chlorine. Avoid breathing much of it.

Composition of the Nutrients.—The simplest way of determining what elements make up the different nutrients is by heating them and studying the products of decomposition, as follows:

To show that Carbohydrates contain Carbon, Hydrogen, and Oxygen.—Place one half teaspoonful of powdered starch in a test tube and heat strongly. Observe that *water* condenses on the sides of the tube and that a black, charred mass remains behind. The black mass consists mainly of *carbon*. The water is composed of hydrogen and oxygen. These three elements are thus shown to be present in the starch. The experiment may be repeated, using sugar instead of starch.

To show that Proteids contain Carbon, Hydrogen, Oxygen, Nitrogen, and Sulphur.—Place in a test tube some finely divided proteid which has been thoroughly dried (dried beef or the lean [135]
of hard cured bacon). Heat strongly in the hood of a chemical laboratory or some other place where the odors do not get into the room. First hold in the escaping gases a wet strip of red litmus paper. This will be turned blue, showing *ammonia* (NH_3) to be escaping. Next hold in the mouth of the tube a strip of a paper wet with a solution of lead nitrate. This is turned black or brown on account of *hydrogen sulphide*(H_2S) which is being driven off. Observe also that *water* condenses in the upper part of the tube and that a black, charred mass remains behind. Since the products of decomposition (H_2O, NH_3, H_2S, and the charred mass) contain hydrogen, oxygen, nitrogen, sulphur, and carbon, these elements are of course present in the proteid tested.

To show the Presence of Mineral Matter.—Burn a piece of dry bread by holding it in a clear, hot flame, and observe the ash that is left behind. This is the mineral matter present in the bread.

Tests for Nutrients. *Proteids.*—Cover the substance to be tested with strong nitric acid and heat gradually to boiling. If proteid is present it turns yellow and partly dissolves in the acid, forming a yellow solution. Let cool and then add ammonia. The yellow solid and the solution are turned a deep orange color. Apply this test to foods containing proteid such as white of egg, cheese, lean meat, etc.

Starch.—(a) Place a small lump of starch in one fourth of a pint of water and heat gradually to boiling, stirring well. Then add enough water to form a thin liquid and fill a test tube half full. Add to this a few drops of a solution of iodine. (Prepare by dissolving a crystal of iodine in 25 cubic centimeters (1/20 pint) of a solution of potassium iodide in water and add water to this until it is a light amber color.) The starch solution is turned blue, *(b)* Cut with a razor a thin slice from a potato. Place this in a weak solution of iodine for a few minutes and then examine with the microscope, using first a low and then a high power. Numerous starch grains inclosed in cellulose walls will be seen (Fig. 60).

Dextrose, or Grape Sugar.—Place a solution of the substance supposed to contain grape sugar in a test tube and add a few drops of a dilute solution of copper sulphate. Then add sodium hydroxide solution until the precipitate which first forms is redissolved and a clear blue liquid obtained. Heat the upper portion of the liquid slowly to near the boiling point. A little below the boiling point the blue color disappears and a yellow-
[136] red precipitate is formed. If the upper layer of the liquid is now boiled, the color deepens and this may be contrasted with the blue color below. Apply this test to the sugar in raisins and in honey.

Fat.—Fat is recognized by its effect on paper, making a greasy stain which does not disappear on heating and which renders the paper translucent. Try butter, lard, or olive oil. Also show the presence of fat in peanuts by crushing them in a mortar and rubbing the powder on thin paper. If the substance to be tested contains but little fat, this may be dissolved out with ether. If a drop of ether containing the fat is placed on paper, it evaporates, leaving the fat, which then forms the stain.

To show the Effect of Alcohol upon Proteid.—Place some of the white of a raw egg in a glass vessel and cover it with a small amount of alcohol. As the albumin (proteid) hardens, or coagulates, observe that the quantity of clear liquid increases. This is due to the *withdrawal* of water from the albumin by the alcohol. Since the tissues are made up chiefly of proteids, a piece of muscle or of liver may be used in the experiment, instead of the egg, with similar results.

To illustrate the Digestive Process.—To a tumbler two thirds full of water add a little salt. Stir and observe that the salt is dissolved. Taste the solution to see that the salt has not been changed chemically. Now add a little powdered limestone to the water and stir as before. Observe that the limestone does not dissolve. Then add some hydrochloric acid and observe the result. State the part played by the acid and by the water in dissolving the limestone. Apply to the digestion of the different classes of foods.

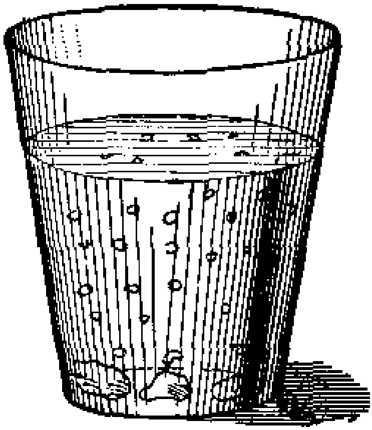

Fig. 62—The dissolving of limestone in water containing acid, suggesting the double action in the digestion of most foods.

CHAPTER X - ORGANS AND PROCESSES OF DIGESTION

The organs of digestion are adapted to the work of dissolving the foods by both their structure and arrangement. Most of them consist either of tubes or cavities and these are so connected, one with the other, as to form a continuous passageway entirely through the body. This passageway is known as

The Alimentary Canal. —The alimentary canal has a length of about thirty feet and, while it begins at the mouth, all but about eighteen inches of it is found in the abdominal cavity. On account of its length it lies for the most part in coils, the two largest ones being known as the small intestine and the large intestine. Connected with the alimentary canal are the glands that supply the liquids for acting on the food. The divisions of the canal and most of the glands that empty liquids into it are shown in Fig. 63 and named in the table below:

- Digestive Organs
  - Parts of Alimentary Canal
    - Mouth, containing teeth and tongue
    - Pharynx
    - Esophagus
    - Stomach
    - Intestines
      - Small
        - Duodenum
        - Jejunum
        - Ileum
      - Large
        - Cæcum and vermiform appendix
        - Colon
          - Ascending
          - Transverse
          - Descending
          - Sigmoid flexure
        - Rectum
  - Digestive Glands
    - Salivary
      - Parotid
      - Submaxillary
      - Sublingual
    - Gastric
    - Liver
    - Pancreas
    - Intestinal

[139] **Coats of the Alimentary Canal.**—The walls of the alimentary canal, except at the mouth, are distinct from the surrounding tissues and consist in most places of at least three layers, or coats, as follows:

1. An *inner coat*, or lining, known as the mucous membrane. This membrane is not confined to the alimentary canal, but lines, as we have seen, the different air passages. It covers, in fact, all those internal surfaces of the body that connect with the external surface. It derives its name from the substance which it secretes, called *mucus*. In structure it resembles the skin, being continuous with the skin where cavities open to the surface. It is made up of two layers—a thick underlayer which contains blood vessels, nerves, and glands, and a thin surface layer, called the *epithelium.* The epithelium, like the cuticle, is without blood vessels, nerves, or glands.

2. A *middle coat*, which is muscular and which forms a continuous layer throughout the canal, except at the mouth. (Here its place is taken by the strong muscles of mastication
[140] which are separate and distinct from each other.) As a rule the muscles of this coat are involuntary. They surround the canal as thin sheets and at most places form two distinct layers. In the inner layer the fibers encircle the canal, but in the outer layer they run longitudinally, or lengthwise, along the canal.[57]

3. An *outer* or *serous coat*, which is limited to those portions of the canal that occupy the abdominal cavity. This coat is not found above the diaphragm. It is a part of the lining membrane of the cavity of the abdomen, called

[57] A layer of connective tissue between the mucous membrane and the muscular coat is usually referred to as the *submucous* coat. This contains numerous blood vessels and nerves and binds the muscular coat to the mucous membrane.

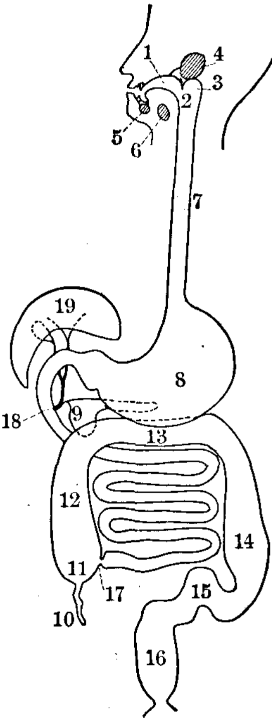

Fig. 63—**Diagram of the digestive system.** 1. Mouth. 2. Soft palate. 3. Pharynx. 4. Parotid gland. 5. Sublingual gland. 6. Submaxillary gland. 7. Esophagus. 8. Stomach. 9. Pancreas. 10. Vermiform appendix. 11. Cæcum. 12. Ascending colon. 13. Transverse colon. 14. Descending colon. 15. Sigmoid flexure. 16. Rectum. 17. Ileo-cæcal valve. 18. Duct from liver and pancreas. 19. Liver.

Diagram does not show comparative length of the small intestine.

The Peritoneum.—The peritoneum is to the abdominal cavity what the pleura is to the thoracic cavity. It forms the outer covering for the alimentary canal and other abdominal organs and supplies the inner lining of the cavity itself. It is also the means of holding these organs in place, some of them being suspended by it from the abdominal walls (Fig. 64). By the secretion of a small amount of liquid, it prevents friction of the parts upon one another.

Digestive Glands.—The glands which provide the different fluids for acting on the foods derive their constituents from the blood. They are situated either in the mucous membrane or at
[141] convenient places outside of the canal and pass their liquids into it by means of small tubes, called ducts. In the canal the food and the digestive fluids come in direct contact—a condition which the dissolving processes require. Each kind of fluid is secreted by a special kind of gland and is emptied into the canal at the place where it is needed.

The Digestive Processes.—Digestion is accomplished by acting upon the food in different ways, as it is passed along the canal, with the final result of reducing it to the form of a solution. Several distinct processes are necessary and they occur in such an order that those preceding are preparatory to those that follow. These processes are known as *mastication, insalivation, deglutition*, *stomach digestion*, and *intestinal* digestion. As the different materials become liquefied they are transferred to the blood, and substances not reduced to the liquid state are passed on through the canal as waste. The first two of the digestive processes occur in

The Mouth.—This is an oval-shaped cavity situated at the very beginning of the canal. It is surrounded by the lips in front, by the cheeks on the sides, by the hard palate above and the soft palate behind, and by the tissues of the lower jaw below. The

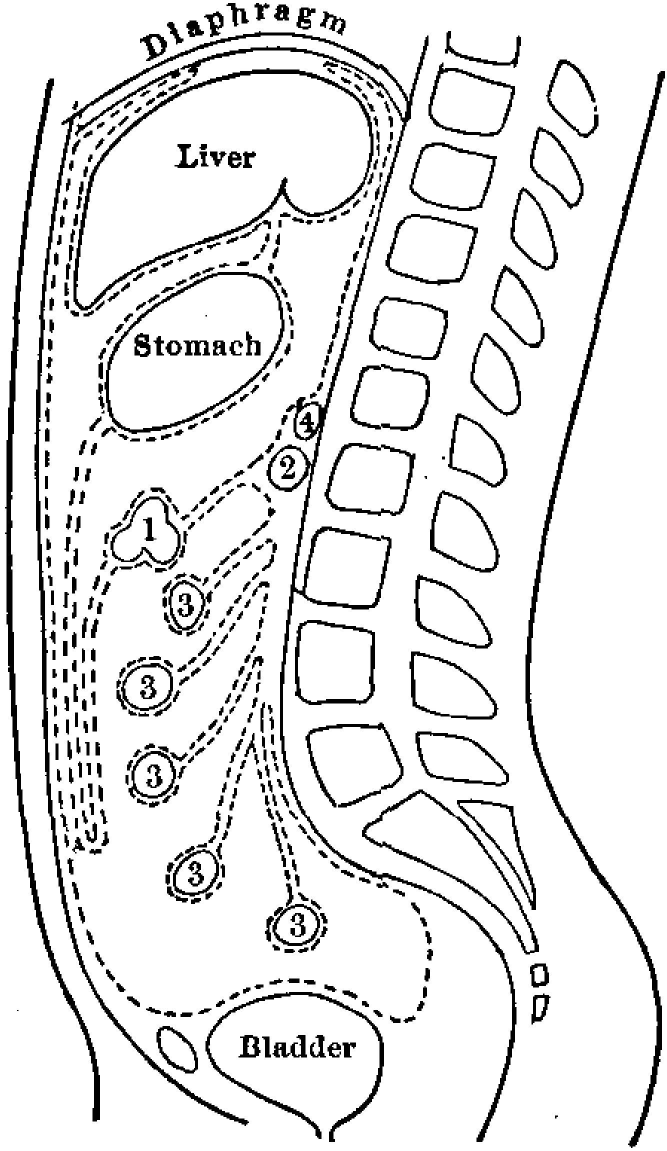

Fig. 64—**Diagram of the peritoneum.** 1. Transverse colon. 2. Duodenum. 3. Small intestine. 4. Pancreas.

mucous membrane lining the mouth is, soft and smooth, being covered with flat epithelial cells. The external opening of the mouth is guarded by the lips, and the soft palate forms a *movable* partition between the mouth and the pharynx. In a condition of repose the mouth space is practically filled by the teeth and the tongue, but the cavity may be enlarged and room provided for food by depressing the lower jaw.

The mouth by its construction is well adapted to carrying on the processes of mastication and insalivation. By the first process
[142] the solid food is reduced, by the cutting and grinding action of the teeth, to a finely divided condition. By the second, the saliva becomes mixed with the food and is made to act upon it.

Accessory Organs of the Mouth.—The work of mastication and insalivation is accomplished through organs situated in and around the mouth cavity. These comprise:

1. *The Teeth.*—The teeth are set in the upper and lower jaws, one row directly over the other, with their hardened surfaces facing. In reducing the food, the teeth of the lower jaw move against those of the upper, while the food is held by the tongue and cheeks between the grinding surfaces. The front teeth are thin and chisel-shaped. They do not meet so squarely as do the back ones, but their edges glide over each other, like the blades of scissors—a condition that adapts them to cutting off and separating the food (*D*, Fig. 65). The back teeth are broad and irregular, having surfaces that are adapted to crushing and grinding.

Each tooth is composed mainly of a bone-like substance, called *dentine,* which surrounds a central space, containing
[143] blood vessels and nerves, known as the *pulp cavity*. It is set in a depression in the jaw where it is held firmly in place by a bony substance, known as *cement*. The part of the tooth exposed above the gum is the *crown*, the part surrounded by the gum is

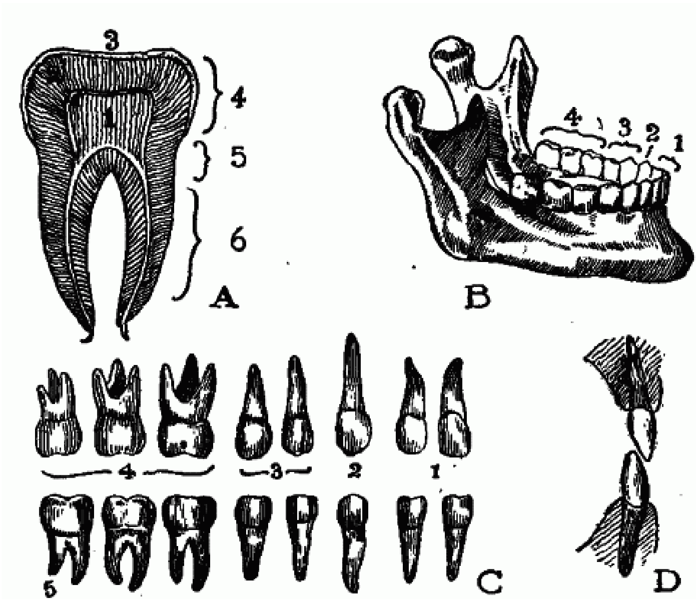

Fig. 65—**The teeth.** *A.* Section of a single molar. 1. Pulp. 2. Dentine. 3. Enamel. 4. Crown. 5. Neck. 6. Root. *B.* Teeth in position in lower jaw. 1. Incisors. 2. Canine. 3. Biscuspids. 4. Molars. *C.* Upper and lower teeth on one side. 1. Incisors. 2. Canines. 3. Biscuspids. 4. Molars. 5. Wisdom. *D.* Upper and lower incisor, to show gliding contact.

the *neck*, and the part which penetrates into the jaw is the *root* (*A*, Fig. 65). A hard, protective material, called *enamel*, covers the exposed surface of the tooth.

The teeth which first appear are known as the *temporary*, or milk, teeth and are twenty in number, ten in each jaw. They usually begin to appear about the sixth month, and they disappear from the mouth at intervals from the sixth to the thirteenth year. As they leave, teeth of the second, or *permanent*, set take their place. This set has thirty-two teeth of four different kinds arranged in the two jaws as follows:

In front, above and below, are four chisel-shaped teeth, known as the *incisors*. Next to these on either side is a tooth longer and thicker than the incisors, called the *canine*. Back of these are two short, rounded and double pointed teeth, the *bicuspids*, and back of the bicuspids are three heavy teeth with irregular grinding surfaces, called the *molars* (*B* and *C*, Fig. 65). Since the molar farthest back in each jaw is usually not cut until maturity, it is called a *wisdom* tooth. The molars are known as the superadded permanent teeth because they do not take the place of milk teeth, but form farther back as the jaw grows in length.

2. *The Tongue.*—The tongue is a muscular organ whose fibers extend through it in several directions (Fig. 66). Its structure adapts it to a variety of movements. During mastication the tongue transfers the food from one part of the mouth to another, and, with the aid of the cheeks, holds the food between the rows of teeth. (By an outward pressure from the tongue and an inward pressure from the cheek the food is kept between the grinding surfaces.) The tongue has functions in addition to these and is a most useful organ.

[144] 3. *The Muscles of Mastication.*—These are attached to the lower jaw and bring about its different movements. The *masseter* muscles, which are the heavy muscles in the cheeks, and the

temporal muscles, located in the region of the temples, raise the lower jaw and supply the force for grinding the food. Small muscles situated below the chin depress the jaw and open the mouth.

4. *The Salivary Glands.*—These glands are situated in the tissues surrounding the mouth, and communicate with it by means of ducts (Fig. 67). They secrete the saliva. The salivary glands are six in number and are arranged in three pairs. The largest, called the *parotid* glands, lie, one on either side, in front of and below the ears. A duct from each gland passes forward along the cheek until it opens in the interior of the mouth, opposite the second molar tooth in the upper jaw. Next in size to the parotids are the *submaxillary* glands. These are located, one on either side, just below and in front of the triangular bend in the lower jaw. The smallest of the salivary glands are the *sublingual*. They are situated in the floor of the mouth, on either side, at the front and base of the tongue. Ducts from the submaxillary and sublingual glands open into the mouth below the tip of the tongue.

The Saliva and its Uses.—The saliva is a transparent and somewhat slimy liquid which is slightly alkaline. It consists [145] chiefly of water (about 99 per cent), but in this are dissolved certain salts and an active chemical agent, or enzyme, called *ptyalin*, which acts on the starch. The ptyalin changes starch into a form of sugar (maltose), while the water in the saliva dissolves the soluble portions of the food. In addition to this the saliva moistens and lubricates the food which it does not dissolve, and prepares it in this way for its passage to the stomach. The last is considered the most important use of the saliva, and dry substances, such as crackers, which require a considerable amount of this liquid, cannot be eaten rapidly without choking. Slow mastication favors the secretion and action of the saliva.

Deglutition.—Deglutition, or swallowing, is the process by which food is transferred from the mouth to the stomach. Though this is not, strictly speaking, a digestive process, it is, nevertheless, necessary for the further digestion of the food. Mastication and insalivation, which are largely mechanical, prepare the food for certain chemical processes by which it is dissolved. The first of these occurs in the stomach and to this organ the food is transferred from the mouth. The chief organs concerned in deglutition are the tongue, the pharynx, and the esophagus.

The Pharynx is a round and somewhat cone-shaped cavity, about four and one half inches in length, which lies just back of the nostrils, mouth, and larynx. It is remarkable for its openings, seven in number, by means of which it communicates with other cavities and tubes of the body. One of these openings is into the mouth, one into the esophagus, one into the larynx, and one into each of the nostrils, while two small tubes (the eustachian) pass from the upper part of the pharynx to the middle ears.

[146] The pharynx is the part of the food canal that is crossed by the passageway for the air. To keep the food from passing out of its natural channel, the openings into the air passages have to be carefully guarded. This is accomplished through the soft palate and epiglottis, which are operated somewhat as valves. The muscular coat of the pharynx is made up of a series of overlapping muscles which, by their contractions, draw the sides together and diminish the cavity. The mucous membrane lining the pharynx is smooth, like that of the mouth, being covered with a layer of flat epithelial cells.

The Esophagus, or gullet, is a tube eight or nine inches long, connecting the pharynx with the stomach. It lies for the most part in the thoracic cavity and consists chiefly of a thick mucous lining surrounded by a heavy coat of muscle. The muscular coat is composed of two layers—an inner layer whose fibers encircle the tube and an outer layer whose fibers run lengthwise.

Steps in Deglutition.—The process of deglutition varies with the kind of food. With bulky food it consists of three steps, or stages, as follows: 1. By the contraction of the muscles of the cheeks, the food ball, or bolus, is pressed into the center of the mouth and upon the upper surface of the tongue. Then the tongue, by an upward and backward movement, pushes the food under the soft palate and into the pharynx.

2. As the food passes from the mouth, the pharynx is drawn up to receive it. At the same time the soft palate is pushed upward and backward, closing the opening into the upper pharynx, while the epiglottis is made to close the opening into the larynx. By this means all communication between the food canal and the air passages is temporarily closed. The upper muscles of the pharynx now contract upon the food, forcing it downward and into the esophagus.

3. In the esophagus the food is forced along by the successive contractions of muscles, starting at the upper end of the tube, until the stomach is reached.

Swallowing is doubtless aided to some extent by the force of gravity. That it is independent of this force, however, is shown by [147] the fact that one may swallow with the esophagus in a horizontal position, as in lying down.

The Stomach.—The stomach is the largest dilatation of the alimentary canal. It is situated in the abdominal cavity, immediately below the diaphragm, with the larger portion toward the left side. Its connection with the esophagus is known as the *cardiac orifice* and its opening into the small intestine is called the *pyloric orifice*. It varies greatly in size in different individuals, being on the average from ten to twelve inches at its greatest length, from four to five inches at its greatest width, and holding from three to five pints. It has the coats common to the canal, but these are modified somewhat to adapt them to its work.

The mucous membrane of the stomach is thick and highly developed. It contains great numbers of minute tube-shaped bodies, known as the *gastric glands* (Fig. 68). These are of two general kinds and secrete large quantities of a liquid called the gastric juice. When the stomach is empty, the mucous membrane is thrown into folds which run lengthwise over the inner surface. These disappear, however, when the walls of the stomach are distended with food.

[148] *The muscular coat* consists of *three* separate layers which are named, from the direction of the fibers, the circular layer, the longitudinal layer, and the oblique layer (Fig. 69). The circular layer becomes quite thick at the pyloric orifice, forming a distinct band which serves as a valve.

The outer coat of the stomach, called the *serous coat*, is a continuation of the peritoneum, the membrane lining the abdominal cavity.

Stomach Digestion.—In the stomach begins the definite work of dissolving those foods which are insoluble in water. This, as already stated, is a double process. There is first a chemical action in which the insoluble are changed into soluble substances, and this is followed immediately by the dissolving action of water. The chief substances digested in the stomach are the proteids. These, in dissolving, are changed into two soluble substances,
[149] known as *peptones* and *proteoses*. The digestion of the proteids is, of course, due to the

Gastric Juice.—The gastric juice is a thin, colorless liquid composed of about 99 per cent of water and about 1 per cent of other substances. The latter are dissolved in the water and include, besides several salts, three active chemical agents—hydrochloric acid, pepsin, and rennin. *Pepsin* is the enzyme which acts upon proteids, but it is able to act only in an acid medium—a condition which is supplied by the *hydrochloric acid*. Mixed with the hydrochloric acid it converts the proteids into peptones and proteoses.

Other Effects of the Gastric Juice.—In addition to digesting proteids, the gastric juice brings about several minor effects, as follows:

1. It checks, after a time, the digestion of the starch which was begun in the mouth by the saliva.[58] This is due to the presence of the hydrochloric acid, the ptyalin being unable to act in an acid medium.

2. While there is no appreciable action on the fat itself, the proteid layers that inclose the fat particles are dissolved away (Fig. 79), and the fat is set free. By this means the fat is broken up and prepared for a special digestive action in the small intestine.

3. Dissolved albumin, like that in milk, is curded, or coagulated, in the stomach. This action is due to the *rennin*. The curded mass is then acted upon by the pepsin and hydrochloric acid in the same manner as the other proteids.

4. The hydrochloric acid acts on certain of the insoluble mineral salts found in the foods and reduces them to a soluble condition. [150]

5. It is also the opinion of certain physiologists that cane sugar and maltose (double sugars) are converted by the hydrochloric acid into dextrose and levulose (single sugars).

After a variable length of time, the contents of the stomach is reduced to a rather uniform and pulpy mass which is called *chyme*. Portions of this are now passed at intervals into the small intestine.

Muscular Action of the Stomach.—The muscles in the walls of the stomach have for one of their functions the mixing of the food with the gastric juice. By *alternately* contracting

[58] The saliva may continue to act for a considerable time after the food enters the stomach. "Careful examination of the contents of the fundus (large end of the stomach) by Cannon and Day has shown that no inconsiderable amount of salivary digestion occurs in the stomach."—FISCHER, *The Physiology of Alimentation*.

and relaxing, the different layers of muscle keep the form of the stomach changing—a result which agitates and mixes its contents. This action varies in different parts of the organ, being slight or entirely absent at the cardiac end, but quite marked at the pyloric end.

Another purpose of the muscular coat is to empty the stomach into the small intestine. During the greater part of the digestive period the muscular band at the pyloric orifice is contracted. At intervals, however, this band relaxes, permitting a part of the contents of the stomach to be forced into the small intestine. After the discharge the pyloric muscle again contracts, and so remains until the time arrives for another discharge.

In addition to emptying the stomach into the small intestine, these muscles also aid in emptying the organ upward and through the esophagus and mouth, should occasion require. Vomiting in case of poisoning, or if the food for some reason fails to digest, is a necessary though unpleasant operation. It is accomplished
[151] by the contraction of all the muscles of the stomach, together with the contraction of the walls of the abdomen. During these contractions the pyloric valve is closed, and the muscles of the esophagus and pharynx are in a relaxed condition.[59]

The Small Intestine.—This division of the alimentary canal consists of a coiled tube, about twenty-two feet in length, which occupies the central, lower portion of the abdominal cavity (Fig. 71). At its upper extremity it connects with the pyloric end of the stomach (Fig. 70), and at its lower end it joins the

[59] Perhaps the simplest method of inducing vomiting is that of thrusting a finger down the throat. To make this method effective the finger should be held in the throat until the vomiting begins. An emetic, such as a glass of lukewarm salt water containing a teaspoonful of mustard, should also be taken, and, in the case of having swallowed poison, the vomiting should be repeated several times. It may even be advantageous to drink water and then vomit it up in order to wash out the stomach.

large intestine. It averages a little over an inch in diameter, and gradually diminishes in size from the stomach to the large intestine. The first eight or ten inches form a short curve, known as the *duodenum*. The upper two fifths of the remainder is called the *jejunum*, and the lower three fifths is known as the *ileum*. The ileum joins that part of the large intestine known as the cæcum, and at their place of union is a marked constriction which prevents material from passing from the large into the small intestine (Fig. 73). This is known as the *ileo-cæcal valve*.

The mucous membrane of the small intestine is richly supplied with blood vessels and contains glands that secrete a digestive [152] fluid known as the *intestinal juice*. The membrane is thrown into many transverse, or circular, folds which increase its surface and also prevent materials from passing too rapidly through the intestine. One important respect in which the small intestine differs from all other portions of the food canal is that its surface is covered with great numbers of minute elevations known as the villi. The purpose of these is to aid in the absorption of the nutrients as they become dissolved (Chapter XI).

The muscular coat of the small intestine is made up of two distinct layers—the inner layer consisting of circular fibers and the outer of longitudinal fibers. These muscles keep the food materials mixed with the juices of the small intestine, but their main purpose is to force the materials undergoing digestion through this long and much-coiled tube.

The outer, or *serous*, coat of the small intestine, like that of the stomach, is an extension from the general lining of the abdominal cavity, or peritoneum. In fact, the intestine lies in a fold of the peritoneum, somewhat as an arm in a sling, while the peritoneum, by connecting with the back wall of the abdominal cavity, holds this great coil of digestive tubing in place (Fig. 64). The portion of the peritoneum which attaches the intestine to the wall of the abdomen is called the *mesentery*.

Most of the liquid acting on the food in the small intestine is supplied by two large glands, the liver and the pancreas, that connect with it by ducts.

The Liver is situated immediately below the diaphragm, on the right side (Figs. 71 and 72), and is the largest gland in the body. It weighs about four pounds and is separated into two main divisions, or lobes. It is complex in structure and differs from the other glands in several particulars. It receives blood from
[154] two distinct sources—the portal vein and the hepatic artery. *The portal vein* collects the blood from the stomach, intestines, and spleen, and passes it to the liver. This blood is loaded with food materials, but contains little or no oxygen. The *hepatic artery*, which branches from the aorta, carries to the liver blood rich in oxygen. In the liver the portal vein and the hepatic artery divide and subdivide, and finally empty their blood into a single system of capillaries surrounding the liver cells. These capillaries in turn empty into a single system of veins which, uniting to form the *hepatic veins* (two or three in number), pass the blood into the inferior vena cava (Fig. 72).

The liver secretes daily from one to two pounds of a liquid called *bile*. A reservoir for the bile is provided by a small, membranous sack, called the *gall bladder*, located on the underside of the liver. The bile passes from the gall bladder, and from the right and left lobes of the liver, by three separate ducts. These unite to form a common tube which, uniting with the duct from the pancreas, empties into the duodenum. Though usually described as a digestive gland, the liver has other functions of equal or greater importance (Chapter XIII).

[155] **The Bile** is a golden yellow liquid, having a slightly alkaline reaction and a very bitter taste. It consists, on the average, of

about 97 per cent of water and 3 per cent of solids.[60] The solids include bile pigments, bile salts, a substance called cholesterine, and mineral salts. The pigments (coloring matter) of the bile are derived from the hemoglobin of broken-down red corpuscles (page 27).

Much about the composition of the bile is not understood. It is known, however, to be necessary to digestion, its chief use being to aid in the digestion and absorption of fats. It is claimed also that the bile aids the digestive processes in some general ways—counteracting the acid of the gastric juice, preventing the decomposition of food in the intestines, and stimulating muscular action in the intestinal walls. No enzymes have been discovered in the bile.

The Pancreas is a tapering and somewhat wedge-shaped gland, and is so situated that its larger extremity, or head, is encircled by the duodenum. From here the more slender portion extends across the abdominal cavity nearly parallel to and behind the lower part of the stomach. It has a length of six or eight inches and weighs from two to three and one half ounces. Its secretion, the pancreatic juice, is emptied into the duodenum by a duct which, as a rule, unites with the duct from the liver.

The Pancreatic Juice is a colorless and rather viscid liquid, having an alkaline reaction. It consists of about 97.6 per cent of water and 2.4 per cent of solids. The solids include mineral salts (the chief of which is sodium carbonate) and four different chemical agents, or enzymes,—trypsin, amylopsin, steapsin, and a milk-curding enzyme. These active constituents make of the pancreatic juice the most important of the digestive fluids. It acts [156]
with vigor on all of the nutrients insoluble in water, producing the following changes:

1. It converts the starch into maltose, completing the work

[60] Hammerstein, *Text-book of Physiological Chemistry.*

begun by the saliva. This action is due to the *amylopsin*,[61] which is similar to ptyalin but is more vigorous.

2. It changes proteids into peptones and proteoses, completing the work begun by the gastric juice. This is accomplished by the *trypsin*, which is similar to, but more active than, the pepsin.

3. It digests fat. In this work the active agent is the *steapsin*.

The necessity of a milk-curding enzyme, somewhat similar to the rennin of the gastric juice, is not understood.

Digestion of Fat.—Several theories have been proposed at different times regarding the digestion and absorption of fat. Among these, what is known as the "solution theory" seems to have the greatest amount of evidence in its favor. According to this theory, the fat, under the influence of the steapsin, absorbs water and splits into two substances, recognized as glycerine and fatty acid. This finishes the process so far as the glycerine is concerned, as this is soluble in water; but the fatty acid, which (from certain fats) is insoluble in water,[62] requires further treatment. The fatty acid is now supposed to be acted on in one, or both, of the following ways: 1. To be dissolved as fatty acid by
[157] the action of the bile (since bile is capable of dissolving it under certain conditions). 2. To be converted by the sodium carbonate into a form of soap which is soluble in water.

The emulsification of fat is known to occur in the small intestine. By this process the fat is separated into minute particles which are suspended in water, but not changed chemically, the mixture being known as an *emulsion*. While this is believed by some to be an actual process of digestion, the advocates of the solution theory claim that it is a process accompanying and

[61] Amylopsin is absent from the pancreatic juice of infants, a condition which shows that milk and not starch is their natural food.

[62] The fact that butter is more easily digested than other fatty substances is probably due to its consisting largely of a kind of fat which, on splitting, forms a fatty acid (butyric) which is soluble in water.

aiding the conversion of fat into fatty acid and glycerine.[63]

The Intestinal Juice is a clear liquid with an alkaline reaction, containing water, mineral salts, and certain proteid substances that may act as enzymes. It assists in bringing about an alkaline condition in the small intestine and aids in the reduction of cane sugar and maltose to the simple sugars, dextrose and levulose. Since it is difficult to obtain this liquid in sufficient quantities for experimenting, its uses have not been fully determined. Recent investigators, however, assign to it an important place in the work of digestion.

Work of the Small Intestine.—The small intestine is the most important division of the alimentary canal. It serves as a receptacle for holding the food while it is being acted upon; it secretes the intestinal juice and mixes the food with the digestive fluids; it propels the food toward the large intestine; and, in addition to all this, serves as an organ of absorption.

Digestion is practically finished in the small intestine, and a large portion of the reduced food is here absorbed. There is always present, however, a variable amount of material that is not digested. This, together with a considerable volume of liquid, is passed into

The Large Intestine.—The large intestine is a tube from five [158]
to six feet in length and averaging about one and one half inches in diameter. It begins at the lower right side of the abdominal cavity, forms a coil which almost completely surrounds the coil of small intestine, and finally terminates at the surface of the body (Figs. 2, 71 and 73). It has three divisions, known as the cæcum, the colon, and the rectum.

The cæcum is the pouch-like dilatation of the large intestine which receives the lower end of the small intestine. It measures

[63] Fischer, *Physiology of Alimentation.*

about two and one half inches in diameter and has extending from one side a short, slender, and blind tube, called the *vermiform appendix*. This structure serves no purpose in digestion, but appears to be the rudiment of an organ which may have served a purpose at some remote period in the history of the human race. The cæcum gradually blends into the second division of the large intestine, called the colon.

The colon consists of four parts, described as the ascending colon, the transverse colon, the descending colon, and the sigmoid flexure, or sigmoid colon. The first three divisions are named from the direction of the movement of materials through them and the last from its shape, which is similar to that of the Greek letter sigma (Σ).

[159] *The rectum* is the last division of the large intestine It is a nearly straight tube, from six to eight inches in length, and connects with the external surface of the body.

The general structure of the large intestine is similar to that of the small intestine, and, like the small intestine, it is held in place by the peritoneum. It differs from the small intestine, however, in its lining of mucous membrane and in the arrangement of the muscular coat. The mucous membrane presents a smooth appearance and has no villi, while the longitudinal layer of the muscular coat is limited to three narrow bands that extend along the greater length of the tube (Fig. 74). These bands are shorter than the coats, and draw the large intestine into a number of shallow pouches, by which it is readily distinguished from the small intestine (Fig. 71).

Work of the Large Intestine.—The large intestine serves as a receptacle for the materials from the small intestine. The digestive fluids from the small intestine continue their action here, and the dissolved materials also continue to be absorbed. In these respects the work of the large intestine is similar to that of the small intestine. It does, however, a work peculiar to itself in that it collects and retains undigested food particles, together with other wastes, and ejects them periodically from the canal.

Work of the Alimentary Muscles.—The mechanical part of digestion is performed by the muscles that encircle the food canal. Their uses, which have already been mentioned in connection with the different organs of digestion, may be here summarized: [160]
They supply the necessary force for masticating the food. They propel the food through the canal. They mix the food with the different juices. At certain places they partly or completely close the passage until a digestive process is completed. They may even cause a reverse movement of the food, as in vomiting. All of the alimentary muscles, except those around the mouth, are involuntary. Their work is of the greatest importance.

Other Purposes of the Digestive Organs.—The digestive organs serve other important purposes besides that of dissolving the foods. They provide favorable conditions for passing the dissolved material into the blood. They dispose of such portions of the foods as fail, in the digestive processes, to be reduced to a liquid state. A considerable amount of waste material is also separated from the blood by the glands of digestion (especially the liver), and this is passed from the body with the undigested portions of food. Then the food canal (stomach in particular) is a means of holding, or storing, food which is awaiting the processes of digestion. Considering the number of these purposes, the digestive organs are remarkably simple, both in structure and in method of operation.

HYGIENE OF DIGESTION

Many of the ills to which flesh is heir are due to improper methods of taking food and are cured by observing the simple rules of eating. Habit plays a large part in the process and children should, for this reason, be taught early to eat properly.

Since the majority of the digestive processes are involuntary and the food, after being swallowed, is practically beyond control, careful attention must be given to the proper mastication of the food and to such other phases of digestion as are under control.

Necessity for Thorough Mastication.—Mastication prepares the food for the digestive processes which follow. Unless the
[161] food has been properly masticated, the digestive fluids in the stomach and intestines cannot act upon it to the best advantage. When the food is carefully chewed, a larger per cent of it is actually digested—a point of importance where economy in the use of food needs to be practiced.

A fact not to be overlooked is that one cannot eat hurriedly and practice thorough mastication. The food must not be swallowed in lumps, but reduced to a finely divided and pulpy mass. This requires time. The one who hurries through the meal is necessarily compelled to bolt his food. Thirty minutes is not too long to give to a meal, and a longer period is even better.

Perhaps the most important result of giving plenty of time to the taking of food is that of *stimulating the digestive glands to a proper degree of activity*. That both the salivary and gastric glands are excited by the sight, smell, and thought of food and, through taste, by the presence of food in the mouth, has been fully demonstrated. Food that is thoroughly masticated and relished will receive more saliva and gastric juice, and probably more of other juices, than if hastily chewed and swallowed. This has a most important bearing upon the efficiency of the digestive processes.

Order of Taking Food.—There has been evolved through experience a rather definite order of taking food, which our knowledge of the process of digestion seems to justify. The heavy foods (proteids for the most part) are eaten first; after which are taken starchy foods and fats; and the meal is finished off with sweetmeats and pastry.[64] The scientific arguments for

[64] Beginning the meal with a little soup, as is frequently done, may be of slight

this order are the following:

1. By receiving the first of the gastric flow the proteids can begin digesting without delay. Since these are the main substances acted on in the stomach, the time required for their digestion is shortened by eating them first. [162]

2. Sugar, being of the nature of predigested starch, quickly gets into the blood and *satisfies the relish* for food. The result of taking sugar first may be to cause one to eat less than he needs and to diminish the activity of the glands.

3. Fat or grease, if taken first, tends to form a coating over the walls of the stomach and around the material to be digested. This prevents the juices from getting to and mixing with the foods upon which they are to act.

4. Starch following the proteids, for the most part, does not so quickly come in contact with the gastric juice. This enables the ptyalin of the saliva to continue its action for a longer time than if the starch were eaten first.

Liquids during the Meal.—Liquids as ordinarily taken during the meal are objectionable. They tend to diminish the secretion of the saliva and to cause rapid eating. Instead of eating slowly and swallowing the food only so fast as the glands can supply the necessary saliva, the liquid is used to wash the food down. Water or other drinks should be taken after the completion of the meal or when the mouth is completely free from food. Even then it should be taken in small sips. While the taking of a small amount of water in this way does no harm, a large volume has the effect of weakening the gastric juice. Most of the water needed by the body should be taken between meals.

The State of Mind has much to do with the proper digestion of the food. Worry, anger, fear, and other disturbed mental states are known to check the secretion of fluids and to interfere with

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advantage in stimulating the digestive glands. To serve this purpose, however, and not interfere with the meal proper, it should contain little greasy or starchy material and should be taken in small amount.

the digestive processes. While the cultivation of cheerfulness is important for its general hygienic effects, it is of especial value in relation to digestion. Intense emotions, either during or
[163] following the meal, should if possible be avoided. The table is no place for settling difficulties or administering rebuke. The conversation, on the other hand, should be elevating and joy giving, thereby inducing a desirable reactionary influence upon the digestive processes.

Care of the Teeth.—The natural teeth are indispensable for the proper mastication of the food. Of especial value are the molars—the teeth that grind the food. The development of the profession of dentistry has made possible the preservation of the teeth, even when naturally poor, as long as one has need of them. To preserve the teeth they must be kept clean. They should be washed at least once a day with a soft-bristled brush, and small particles of food, lodged between them, should be removed with a wooden pick. The biting of hard substances, such as nuts, should be avoided, on account of the danger of breaking the enamel, although the chewing of tough substances is considered beneficial.

Decayed places in the teeth should be promptly filled by the dentist. It is well, even when decayed places are not known to exist, to have the teeth examined occasionally in order to detect such places before they become large. On account of the expense, pain, and inconvenience there is a tendency to put off dental work which one knows ought to be done. Perhaps in no other instance is procrastination so surely punished. The decayed places become larger and new points of decay are started; and the pain, inconvenience, and expense are increased proportionately.

The Natural Appetite should be followed with reference to both the kind and the amount of food eaten. No system of knowledge will ever be devised which can replace the appetite as
[164] an aid in the taking of food. *It is nature's means of indicating the needs of the body*. The natural appetite may be spoiled, however,

by overeating and by the use of highly seasoned foods, or by indulging in stimulants during the meal. It is spoiled in children by too free indulgence in sweetmeats. By cultivating the natural appetite and heeding its suggestions, one has at his command an almost infallible guide in the taking of food.

Preparation of Meals.—The cooking of food serves three important purposes. It renders the food more digestible, relieving the organs of unnecessary work; it destroys bacteria that may be present in the food, diminishing the likelihood of introducing disease germs into the body; and it makes the food more palatable, thereby supplying a necessary stimulus to the digestive glands. While the methods employed in the preparation of the different foods have much to do with the ease with which they are digested and with their nourishing qualities, the scope of our subject does not permit of a consideration of these methods.

Quantity of Food.—Overeating and undereating are both objectionable from a hygienic standpoint. Overeating, by introducing an unnecessary amount of food into the body, overworks the organs of digestion and also the organs of excretion. It may also lead to the accumulation of burdensome fat and of harmful wastes. On the other hand, the taking of too little food impoverishes the blood and weakens the entire body. As a rule, however, more people eat too much than too little, and to quit eating before the appetite is fully satisfied is with many persons a necessary precaution. The power of self-control, valuable in all phases of life, is indispensable in the avoidance of overeating. [165]

Frequency of Taking Food.—Eating between meals is manifestly an unhealthful practice. The question has also been raised as to whether the common habit of eating three times a day is best suited to all classes of people. Many people of weak digestive organs have been benefited by the plan of two meals a day, while others adopt the plan of eating one heavy meal and two light ones. Either plan gives the organs of digestion more time to rest and diminishes the liability of overeating. On the other hand, those doing heavy muscular work can hardly derive the energy which they need from less than three good meals a day. Though no definite rule can be laid down, there is involved a hygienic principle which all should follow: *Meals should not overlap*. The stomach should be free from food taken at a previous meal before more is introduced into it. When this principle is not observed, material ferments in the stomach, causing indigestion and other disorders. It should be noted, however, that the overlapping may be due to overeating as well as to eating too frequently.

Dangers from Impure Food.—Food is frequently the carrier of disease germs and for this reason requires close inspection (page 128). Typhoid fever, a most dangerous disease, is usually contracted through either impure food or impure water (Chapter XXIII). One safeguard against disease germs, as stated above, is thorough cooking. Too much care cannot be exercised with reference to the water for drinking purposes. Water which is not perfectly clear, which smells of decaying material, or which forms a sediment on standing is usually not fit to drink. It can, however, be rendered comparatively harmless by boiling. The objections which many people have to drinking boiled water are
[166] removed when it is boiled the day before it is used, so as to give it time to cool, settle, and replace the air driven off by the boiling.

Care of the Bowels.—In considering the hygiene of the alimentary canal, the fact that it is used as a means of separating the impurities from the body must not be overlooked. Frequently, through lack of exercise, negligence in evacuating the bowels, or other causes, a weakened condition of the canal is induced which results in the retention of impurities beyond the time when they should be discharged. This is a great annoyance and at the same time a menace to the health.

In most cases this condition can be relieved, and prevented from recurring, by observing the following habits: 1. Have a regular time each day for evacuating the bowels. This is a most important factor in securing the necessary movements. 2. Drink a cup of cold water on rising in the morning and on retiring at night. 3. Eat generously of fruits and other coarse foods, such as corn bread, oatmeal, hominy, cabbage, etc. 4. Practice persistently such exercises as bring the abdominal muscles into play. These exercises strengthen indirectly the muscles of the canal. 5. Avoid overwork, especially of the nervous system.

Alcohol and Digestion.—Though exciting temporarily a greater flow of the digestive fluids, alcoholic drinks taken in any but very small quantities are considered detrimental to the work of digestion. Large doses retard the action of enzymes, inflame the mucous lining of the stomach,[65] and bring about a [167] diseased condition of the liver. It may be noted, however, that the bad effects of alcoholic beverages upon the stomach, the liver, and the body in general are less pronounced when these are taken as a part of the regular meals.

Effects of Tea and Coffee.—In addition to the stimulating agent caffeine, tea and coffee contain a bitter, astringent substance, known as tannin. On account of the tannin these beverages tend to retard digestion and to irritate the lining of the stomach—effects that may be largely obviated by methods of preparing tea and coffee which dissolve little of the tannin. (They should be made without continued boiling or steeping.) The caffeine may do harm through its stimulating effect upon the nervous system (page 56) and through the introduction of a special waste into the body. In chemical composition caffeine closely resembles a waste, called uric acid, and in the body is converted into this substance. If one is in a weakened condition,

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[65] Dr. William Beaumont, an American surgeon of the last century, made a series of observations upon a human stomach (that of Alexis St. Martin) having an artificial opening, the result of a gunshot wound. Much of our knowledge of the digestion of different foods was obtained through these observations. In spite of the protests of his physician, St. Martin would occasionally indulge in strong drink and always with the same result—the lining of the stomach became much inflamed and very sensitive, and the natural processes of digestion were temporarily suspended.

the uric acid may fail to be oxidized to urea, as occurs normally, or to be thrown off as uric acid. In this case it accumulates in the body, causing rheumatism and related diseases. It thus happens that while some people may use tea and coffee without detriment, others are injured by them.

Summary.—The main structure in the digestive system is the alimentary canal. This provides cavities where important dissolving processes take place, and tubes for joining these cavities, while glands connecting with the canal supply the necessary liquids for changing and dissolving the foods. The general plan of digestion is that of passing the food through the canal, beginning with the mouth, and of acting on it at various places, with the final result of reducing most of it to the
[168] liquid state. The digestive fluids supply water which acts as a solvent and carries the active chemical agents, or enzymes, that convert the insoluble foods into substances that are soluble. The muscles in the walls of the canal perform the mechanical work of digestion, while the nervous system controls and regulates the activity of the various organs concerned in this work.

Exercises.—1. State the general purpose of digestion. How does digested food differ from that not digested?

2. Name all the divisions of the alimentary canal in the order in which the food passes through them.

3. What other work besides digestion is carried on by the alimentary canal?

4. What is gained by the mastication of the food? Why should mastication precede the other processes of digestion?

5. What is the work of the tongue in digestion?

6. State the purposes served by the gastric juice.

7. Give reasons for regarding the small intestine as the most important division of the food canal.

8. At what places, and by the action of what liquids, are fats, proteids, and starch digested?

9. What enzymes are found in the pancreatic juice? What is the digestive action of each?

10. Describe the work performed by the muscles of the stomach, the mouth, the esophagus, and the small intestine.

11. What advantages are derived from the use of cooked food?

12. State the advantages of drinking pure water.

13. If all the food that one needs to take at a single meal can be thoroughly masticated in fifteen minutes, why is it better to spend a longer time at the table?

14. What is meant by the overlapping of meals? What bad results follow? How avoided?

PRACTICAL WORK

Examine a dissectible model of the human abdomen (Fig. 75), noting the form, location, and connection of the different organs. Find the connection of the esophagus with the stomach, of the stomach with the small intestine, and of the small intestine with the large intestine. Sketch a general outline of the cavity, and [169] locate in this outline its chief organs.

Where it is desirable to learn something of the actual structure of the digestive organs, the dissection of the abdomen of some small animal is necessary. On account of unpleasant features likely to be associated with such a dissection, however, this work is not recommended for immature pupils.

Dissection of the Abdomen. (Optional)—For individual study, or for a small class, a half-grown cat is perhaps the best available material. It should be killed with chloroform, and then stretched, back downward, on a board, the feet being secured to hold it in place.

The teacher should make a preliminary examination of the abdomen to see that it is in a fit condition for class study. If the bladder is unnaturally distended, its contents may be forced out by slight pressure. The following materials will be needed during the dissection, and should be kept near at hand: a sharp knife with a good point, a pair of heavy scissors, a vessel of water, some cotton or a damp sponge, and some fine cord. During the dissection the specimen should be kept as clean as possible, and any escaping blood should be mopped up with the cotton or the sponge. The dissection is best carried out by observing the following order:

1. Cut through the abdominal wall in the center of the triangular space where the ribs converge. From here cut a slit downward to the lower portion of the abdomen, and sideward as far as convenient. Tack the loosened abdominal walls to the board, and proceed to study the exposed parts. Observe the muscles in the abdominal walls, and the fold of the *peritoneum* which forms an apron-like covering over the intestines.

2. Observe the position of the stomach, liver, spleen, and intestines, and then, by pushing the intestines to one side, find the kidneys and the bladder.

3. Study the liver with reference to its location, size, shape, and color. On the under side, find the gall bladder, from which a small tube leads to the small intestine. Observe the portal vein as
[170] it passes into the liver. As the liver is filled with blood, neither it nor its connecting blood vessels should be cut at this time.

4. Trace out the continuity of the canal. Find the esophagus where it penetrates the diaphragm and joins the stomach. Find next the union of the stomach with the small intestine. Then, by carefully following the coils of the small intestine, discover its union with the large intestine.

5. Within the first coil of the small intestine, as it leaves the stomach, find the *pancreas*. Note its color, size, and branches. Find its connection with the small intestine.

6. Beginning at the cut portion of the abdominal wall, lift the thin lining of the peritoneum and carefully follow it toward

the back and central portion of the abdomen. Observe whether it extends back of or in front of the kidneys, the aorta, and the inferior vena cava. Find where it leaves the wall as a *double* membrane, the *mesentery*, which surrounds and holds in place the large and small intestines. Sketch a coil of the intestine, showing the mesentery.

7. Find in the center of the coils of small intestine a long, slender body having the appearance of a gland. This is the beginning of the *thoracic duct* and is called the *receptacle of the chyle*. From this the thoracic duct rapidly narrows until it forms a tiny tube difficult to trace in a small animal.

8. Cut away about two inches of the small intestine from the remainder, having first tied the tube on the two sides of the section removed. Split it open for a part of its length, and wash out its contents. Observe its coats. Place it in a shallow vessel containing water, and examine the mucous membrane with a lens to find the *villi*. Make a drawing of this section, showing the coats.

9. Study the connection of the small intestine with the large. Split them open at the place of union, wash out the contents, and examine the ileo-cæcal valve.

10. Observe the size, shape, and position of the kidneys. Do they lie in front of or back of the peritoneum? Do they lie exactly opposite each other? Note the connection of each kidney with the aorta and the inferior vena cava by the renal artery and the renal vein. Find a slender tube, the *ureter*, running from each kidney to the bladder. Do the ureters connect with the top or with the base of the bladder? Show by a sketch the connection of the kidneys with the large blood vessels and the bladder.

To demonstrate the Teeth.—Procure from the dentist a [171]
collection of different kinds of teeth, both sound and decayed.

(*a*) Examine external surfaces of different kinds of teeth, noting general shape, cutting or grinding surfaces, etc. Make a drawing of an incisor and also of a molar.

(*b*) After soaking some of the teeth for a couple of days in warm water saw one of them in two lengthwise, and another in two crosswise, and smooth the cut surfaces with fine emery or sand paper. Examine both kinds of sections, noting arrangement and extent of dentine, enamel, and pulp. Make drawings.

(*c*) Examine a decayed tooth. Which substance of the tooth appears to decay most readily? Why is it necessary to cut away a part of the tooth before filling?

(*d*) Test the effect of acids upon the teeth by leaving a tooth over night in a mixture of one part hydrochloric acid to four parts water, and by leaving a second tooth for a couple of days in strong vinegar. Examine the teeth exposed to the action of acids, noting results.

To show the Importance of Mastication.—Fill two tumblers each half full of water. Into one put a lump of rock salt. Into the other place an equal amount of salt that has been finely pulverized. Which dissolves first and why?

To illustrate Acid and Alkaline Reactions.—To a tumbler half full of water add a teaspoonful of hydrochloric or other acid, as vinegar. To a second tumbler half full of water add an equal amount of cooking soda. Taste each liquid, noting the sour taste of the acid, and the alkaline taste of the soda. Hold a piece of red litmus paper in the soda solution, noting that it is turned blue. Then hold a piece of blue litmus paper in the acid solution, noting that it is turned red. Add acid to the soda solution, and soda to the acid solution, until the conditions are reversed, testing with the red and blue litmus papers.

Hold, for a minute or longer, a narrow strip of red litmus paper in the mouth, noting any change in the color of the paper. Repeat, using blue litmus paper. What effect, if any, has the saliva upon the color of the papers? Has the mouth an acid or an alkaline reaction?

To show the Action of Saliva on Starch.—1 (Optional). Prepare starch paste by mixing half a teaspoonful of starch in half a pint of water and heating the mixture to boiling. Place some of this in a test tube and thin it by adding more water. Then add a small drop of iodine solution (page 136) to the solution of [172] starch. It should turn a deep blue color. This is the test for starch.

Now collect from the mouth, in a clean test tube, two or three teaspoonfuls of saliva. Add portions of this to small amounts of fresh starch solution in two test tubes. Let the tubes stand for five or ten minutes surrounded by water having about the temperature of the body. Test for changes that have occurred as follows:

(*a*) To one tube add a little of the iodine solution. If it does not turn blue, it shows that the starch has been converted into some other substance by the saliva, (*b*) To the other tube add a few drops of a very dilute solution of copper sulphate. Then add sodium (or potassium) hydroxide, a few drops at a time, until the precipitate which first forms dissolves and turns a deep blue. Then gradually heat the upper portion of the liquid to boiling. If it turns an orange or yellowish red color, the presence of a form of sugar (maltose or dextrose) is proved. See page 136.

2. Hold some powdered starch in the mouth until it completely dissolves and observe that it gradually acquires a sweetish taste. This shows the change of starch into sugar.

To illustrate the Action of the Gastric Juice.—Add to a tumbler two thirds full of water as much scale pepsin (obtained from a drug store) as will stay on the end of the large blade of a penknife. Then add enough hydrochloric acid to give a slightly sour taste. Place in the artificial gastric juice thus prepared some boiled white of egg which has been finely divided by pressing it through a piece of wire gauze. Also drop in a single large lump. Keep in a warm place (about the temperature of the body) for several hours or a day, examining from time to time. What is the general effect of the artificial gastric juice upon the egg?

To illustrate Effect of Alcohol upon Gastric Digestion.—Prepare a tumbler half full of artificial gastric juice as in the above experiment, and add 10 cubic centimeters of this to each of six clean test tubes bearing labels. To five of the tubes add alcohol from a burette as follows: (1) .5 c.c., (2) 1 c.c., (3) 1.5 c.c., (4) 2 c.c., and (5) 3 c.c., leaving one tube without alcohol. Now add to each tube about 1/4 gram of finely divided white of egg from the experiment above, and place all of the tubes in a beaker half full of water. Keep the water a little above the temperature of the body for several hours, examining the tubes at intervals to note the progress of digestion. Inferences.

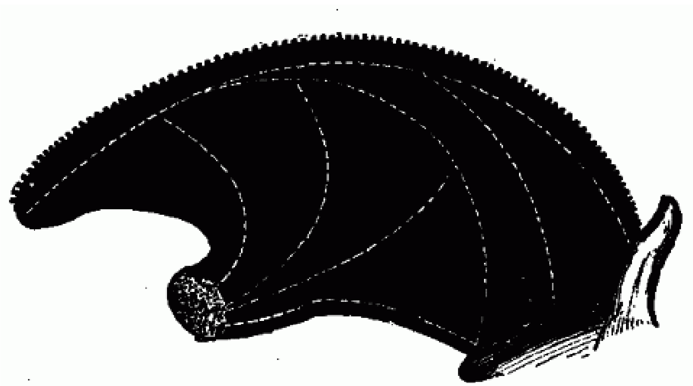

Fig. 66—**Diagram** showing directions of muscular fibers in tongue.

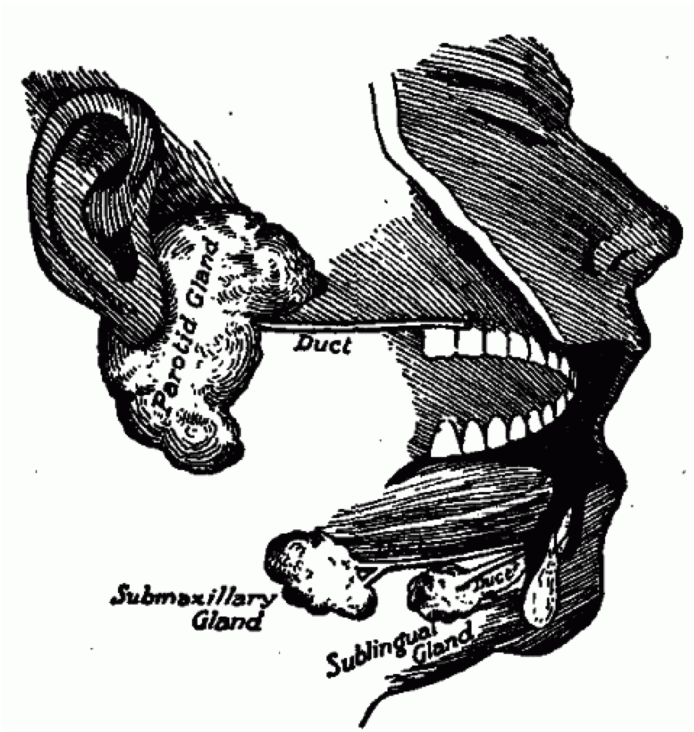

Fig. 67—**Salivary glands** and the ducts connecting them with the mouth.

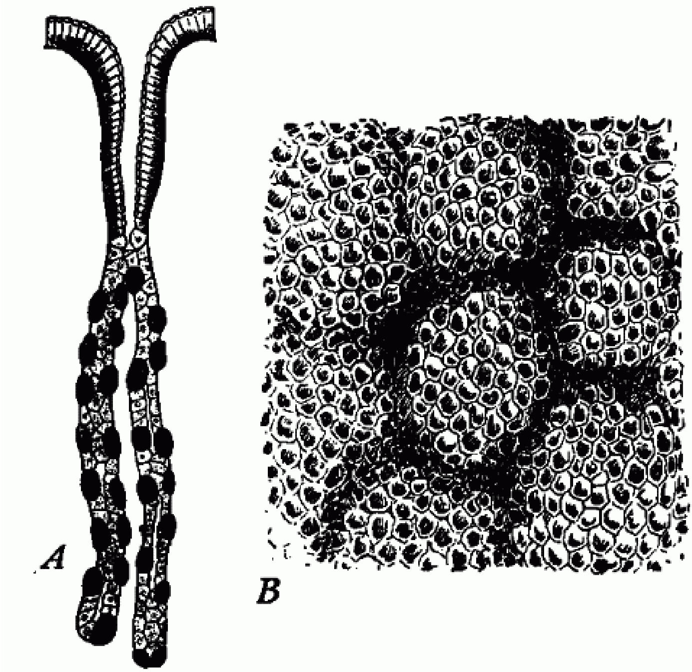

Fig. 68—**Gastric Glands.** *A.* Single gland showing the two kinds of secreting cells and the duct where the gland opens on to the surface. *B.* Inner surface of stomach magnified. The small pits are the openings from the glands.

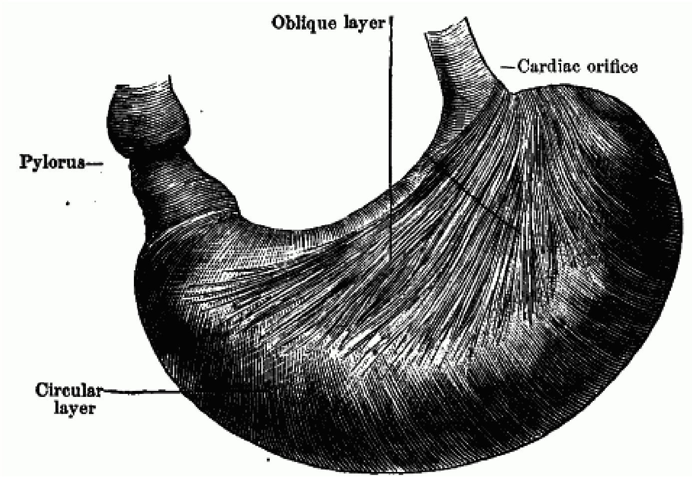

Fig. 69—**Muscles of the stomach** (from Morris' *Human Anatomy*). The layer of Longitudinal fibers removed.

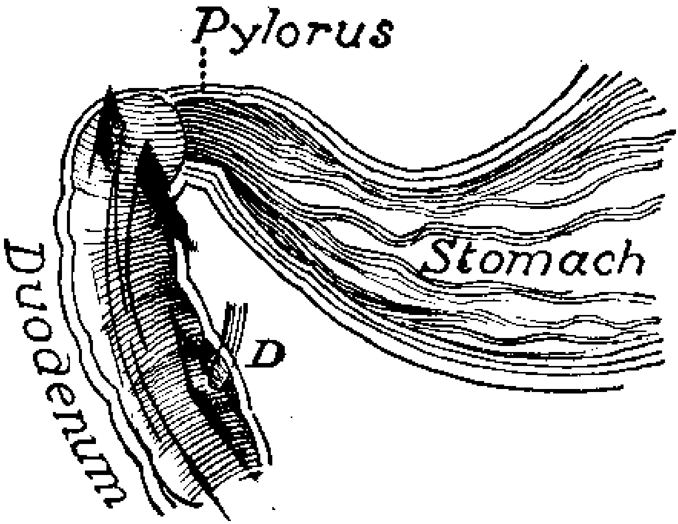

Fig. 70—**Passage from stomach** into small intestine. Illustration also shows arrangement of mucous membrane in the two organs. *D.* Bile duct.

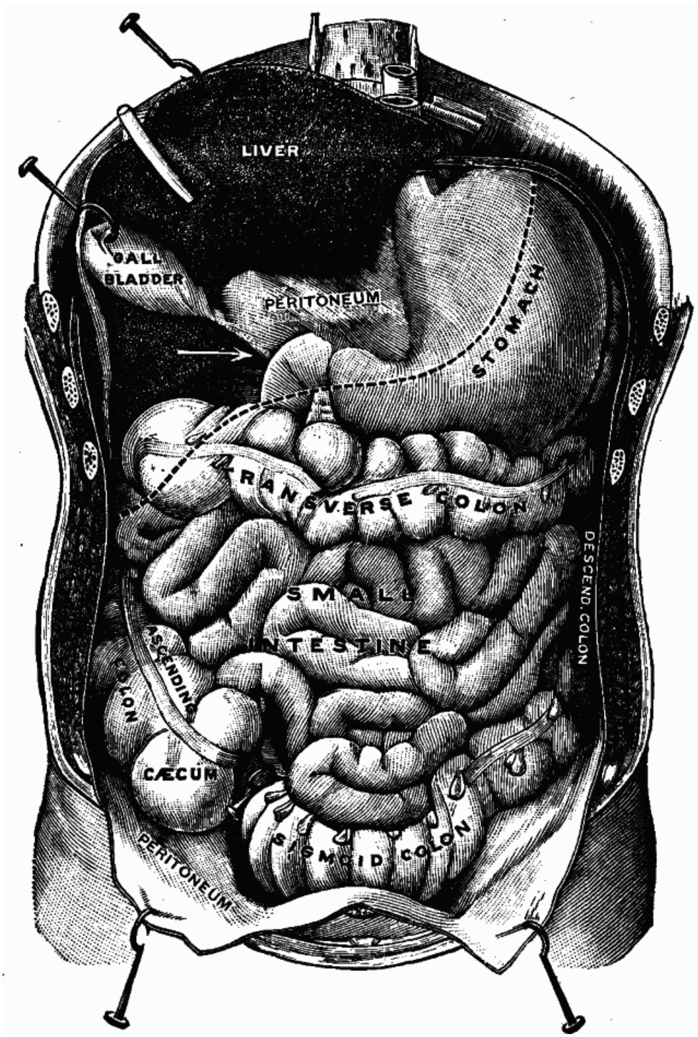

Fig. 71—**Abdominal cavity** with organs of digestion in position.

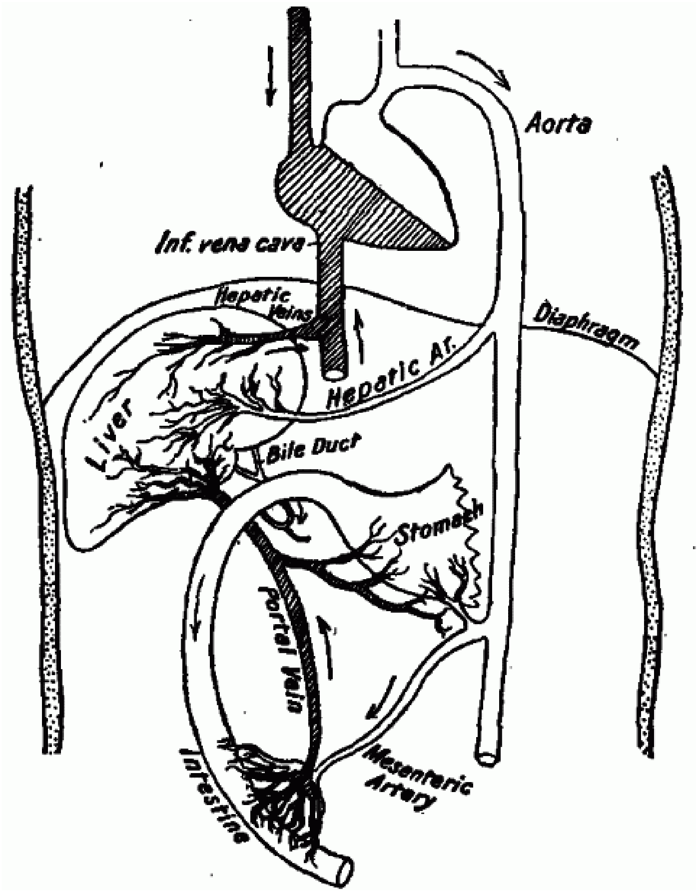

Fig. 72—**Relations of the liver.** Diagram showing the connection of the liver with the large blood vessels and the food canal.

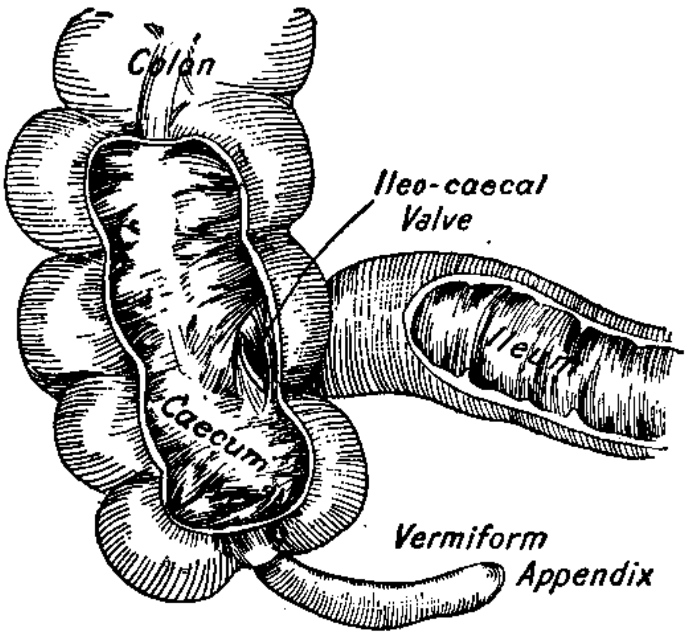

Fig. 73—**Passage from small into large intestine.** At the ileo-cæcal valve is the narrowest constriction of the food canal.

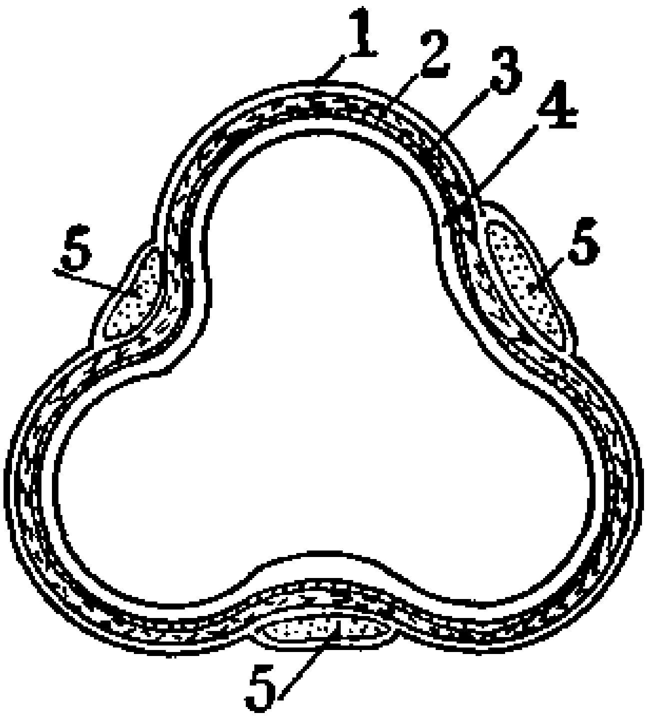

Fig. 74—**Section of large intestine**, showing the coats. 1. Serous coat. 2. Circular layer of muscle. 3. Submucous coat. 4. Mucous membrane. 5. Muscular bands extending lengthwise over the intestine.

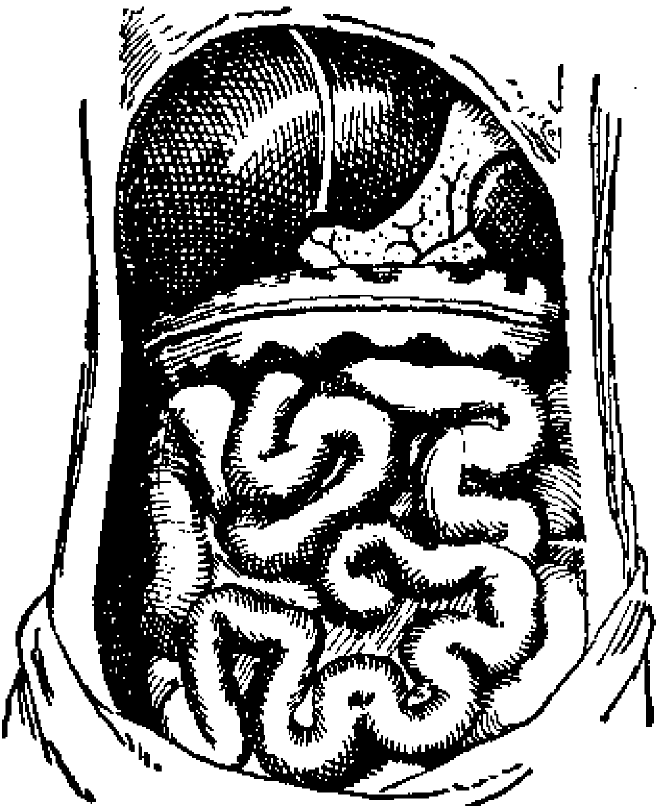

Fig. 75—Model for demonstrating the abdomen and its contents.

CHAPTER XI - ABSORPTION, STORAGE, AND ASSIMILATION

The dissolved nutrients, to reach the cells, must be transferred from the alimentary canal to the blood stream. This process is known as *absorption*. In general, absorption means the penetration of a liquid into the pores of a solid, and takes place according to the simple laws of molecular movements. The absorption of food is, however, not a simple process, and the passage takes place through an *active* (living) membrane. Another difference is that certain foods undergo chemical change while being absorbed.

Small Intestine as an Organ of Absorption.—While absorption may occur to a greater or less extent along the entire length of the alimentary canal, most of it takes place at the small intestine. Its great length, its small diameter, and its numerous blood vessels all adapt the small intestine to the work of absorption. The transverse folds in the mucous membrane, by retarding the food in its passage and by increasing the absorbing surface, also aid in the process. But of greatest importance are the minute elevations that cover the surface of the mucous membrane, known as

The Villi.—Each single elevation, or villus, has a length of about one fiftieth of an inch and a diameter about half as great (*A*, Fig. 76), and contains the following essential parts:

1. An outer layer of epithelial cells, resting upon a connective tissue support.

2. A small lymph tube, called a *lacteal*, which occupies the center of the villus and connects at the base with other lymph tubes, also called lacteals (*B*, Fig. *76*). [174]

3. A network of capillaries.

The villi are structures especially adapted to the work of absorption, and they are found only in the small intestine. The mucous membrane in all parts of the canal, however, is capable of taking up some of the digested materials.

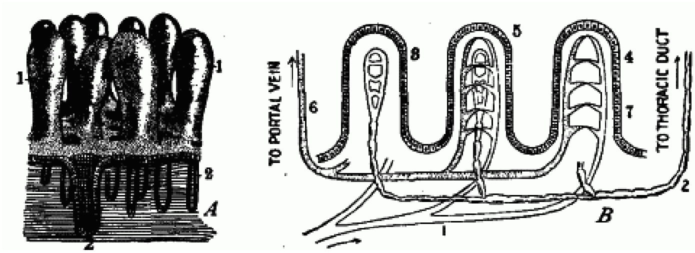

Fig. 76—**The villi.** *A.* Diagram of a small section of mucous membrane of small intestine. 1. Villi. 2. Small glands, called *crypts*.

B. Diagram showing structure of villi. 1. Small artery. 2. Lacteal. 3. Villus showing termination of the lacteal. 4. Villus showing capillaries. 5. Villus showing both the lacteal and the capillaries. 6. Small vein. 7. Layer of epithelial cells.

Work of Capillaries and Lacteals.—The capillaries and lacteals act as receivers of material as it passes through the layer of epithelial cells covering the mucous membrane. The lacteals take up the digested fats,[66] and the capillaries receive all the other kinds of nutrients. These vessels do not, of course, retain the absorbed materials, but pass them on. Their final destination is the general circulation, which they reach by two well-defined channels, or routes.

Routes to the Circulation.—The two routes from the place of absorption to the general circulation are as follows:

1. *Route taken by the Fat.*—The fat is conveyed by the lacteals from the villi to the receptacle of the chyle. At this place it mingles with the lymph from the lower parts of the body, and with it passes through the thoracic duct to the left subclavian vein. Here it enters the general circulation. Thus, to reach the general circulation, the fat has to pass through the villi, the lacteals, the receptacle of the chyle, and the thoracic duct (Fig. 77). Its passage through these places, like the movements in all lymph vessels, is slow, and it is only gradually admitted to the blood stream.

2. *Route of All the Nutrients except Fat.*—Water and salts and the digested proteids and carbohydrates, in passing into the capillaries, mix there with the blood. But this blood, instead of flowing directly to the heart, is passed through the portal vein to the liver, where it enters a *second set of capillaries* and is brought very near the liver cells. From the liver it is passed through the hepatic veins into the inferior vena cava, and by [176]
these it is emptied into the right auricle. This route then includes the capillaries in the mucous membrane of the stomach and intestines, the branches of the portal vein, the portal vein proper, the liver, and the hepatic veins (Fig. 77). In passing through the liver, a large portion of the food material is temporarily retained for a purpose and in a manner to be described later (page 177).

Absorption Changes.—During digestion the insoluble foods are converted into certain soluble materials, such as peptones, maltose, and glycerine,—the conversion being necessary to their solution. A natural supposition is that these materials enter and become a part of the blood, but examination shows them to be

[66] The lacteals (from the Latin *lacteus*, milky) are so called on account of their appearance, which is white, or milk-like, due to the fat droplets.

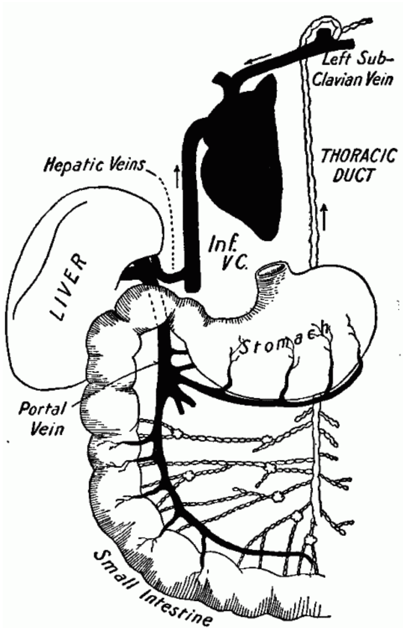

Fig. 77—**Diagram of routes** from food canal to general circulation. See text.

absent from this liquid. (See Composition of the Blood, page 30.) There are present in the blood, however, substances closely related to the peptones, maltose, glycerine, etc.; substances which have in fact been formed from them. During their transfer from the food canal, the dissolved nutrients undergo changes, giving rise to the materials in the blood. Thus are the serum albumin and serum globulin of the blood derived from the peptones and proteoses; the dextrose, from the maltose and other forms of sugar; and the fat droplets, from the glycerine, fatty acid, and soluble soap.

While considerable doubt exists as to the cause of these changes and as to the places also where some of them occur, their purpose is quite apparent. The materials forming the dissolved foods, although adapted to absorption, are not suited to the needs of the body, and if introduced in this form are likely to interfere with its work.[67] They are changed, therefore, into the forms which the body can use.

A Second Purpose of Digestion.—Comparing the digestive changes with those of absorption, it is found that they are of a directly opposite nature; that while digestion is a process of tearing down, or separating,—one which reduces the food to a more finely divided condition—there is in absorption a process of building up. From the comparatively simple compounds formed by digestion, there are formed during absorption the more complex compounds of the blood. The one exception is dextrose, which is a simple sugar; but even this is combined in the liver and the muscles to form the more complex compound known as glycogen. (See Methods of Storage, below.) These facts have suggested a second purpose of digestion—that of reducing foods to forms sufficiently simple to enable the body to construct out of them the more complex materials that it needs. Evidence that digestion serves such a purpose is found in the fact [177]

[67] Peptones and proteoses, when injected directly into the blood, are found to act as poisons.

that both proteids and carbohydrates are reduced to a simpler form than is necessary for dissolving them.[68]

The Storage of Nutriment.—For some time after the taking of a meal, food materials are being absorbed more rapidly than they can be used by the cells. Following this is an interval when the body is taking no food, but during which the cells must be supplied with nourishment. It also happens that the total amount of food absorbed during a long interval may be in excess of the needs of the cells during that time; and it is always possible, as in disease, that the quantity absorbed is not equal to that consumed. To provide against emergencies, and to keep up a uniform supply of food to the cells, it is necessary that the body store up nutrients in excess of its needs.

Methods of Storage.—The general plan of storage varies with the different nutrients as follows:

1. *The carbohydrates* are stored in the form of *glycogen*. This, as already stated (page 120), is a substance closely resembling
[178] starch. It is stored in the cells of both the liver and the muscles, but mainly in the liver (Fig. 78). It is a chief function of the liver to collect the excess of dextrose from the blood passing through it, and to convert it into glycogen, which it then stores within its cells. It does not, however, separate all of the dextrose from the blood, a small amount being left for supplying the immediate needs of the tissues. As this is used, the glycogen in the liver is changed back to dextrose and, dissolving, again finds its way into the blood. In this way, the amount of dextrose in the blood is kept practically constant. The carbohydrates are stored also by converting them into fat.

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[68] The soluble double sugars (maltose, milk sugar, and cane sugar) are reduced to the simple sugars (dextrose and levulose). Furthermore the action on the proteids does not stop with the production of peptones and proteoses, but these in turn are still further reduced.

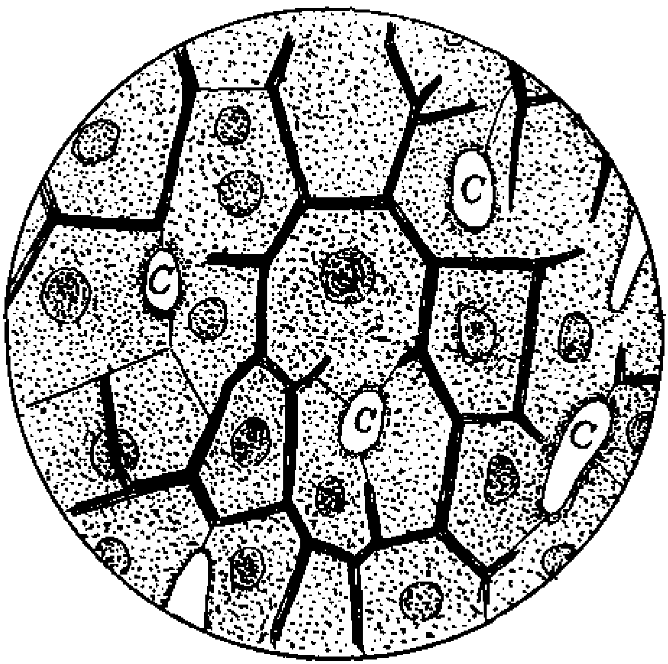

Fig. 78—**Liver cells** where is stored the glycogen. *C.* Capillaries.

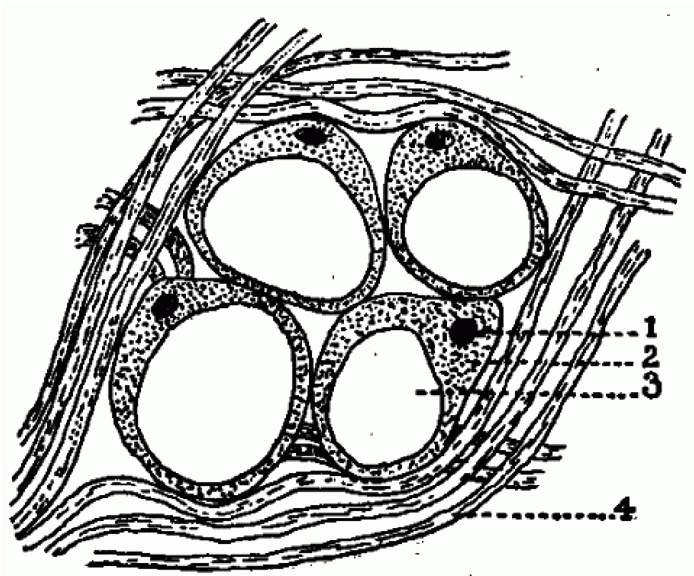

Fig. 79—**Stored-up fat.** The figure shows four connective tissue cells containing small particles of fat. 1. Nucleus. 2. Protoplasm. 3. Fat. 4. Connective tissue fibers.

2. *The fat* is stored for the most part in the connective tissue. Certain of the connective tissue cells have the property of taking fat from the blood and of depositing it within their inclosing membranes (Fig. 79). When this is done to excess, and the cells become filled with fat, they form the so-called *adipose tissue*. Most of this tissue is found under the skin, between the muscles, and among the organs occupying the abdominal cavity. If one
[179] readily takes on fat, it may also collect in the connective tissue around the heart. The stored-up fat is redissolved as needed, and

enters the blood, where it again becomes available to the active cells.

3. *The proteids* form a part of all the tissues, and for this reason are stored in larger quantities than any of the other food substances. The large amount of proteid found in the blood may also be looked upon as storage material. The proteids in the various tissues are spoken of as *tissue proteids*, and those in the blood as *circulating proteids*. The proteids of the tissues serve the double purpose of forming a working part of the cell protoplasm, and of supplying reserve food material. That they are available for supplying energy, and are properly regarded as *storage material*, is shown by the rapid loss of proteid in starving animals. When the proteids are eaten in excess of the body's need for rebuilding the tissues, they are supposed to be broken up in such a manner as to form glycogen and fat, which may then be stored in ways already described.

General Facts Relating to Storage.—The form into which the food is converted for storage in the body is that of *solids*—the form that takes up the least amount of space. These solids are of such a nature that they can be changed back into their former condition and, by dissolving, reënter the blood.

Only energy-yielding foods are stored. Water and salts, though they may be absorbed in excess of the needs of the body, are not converted into other substances and stored away. Oxygen, as already stated (page 108), is not stored. The interval of storage may be long or short, depending upon the needs of the body. In the consumption of stored material the glycogen is used first, then as a rule the fat, and last of all the proteids.

Storage in the Food Canal.—Not until three or four hours have elapsed are all the nutrients, eaten at a single meal, digested and passed into the body proper. The undigested food is held in reserve, awaiting digestion, and is only gradually absorbed as [180]
this process takes place. It may properly, on this account, be regarded as *stored material*. That such storage is of advantage is

shown by the observed fact that substances which digest quickly (sugar, dextrin, "predigested foods," etc.) do not supply the needs of the body so well as do substances which, like starch and proteids, digest slowly. Even substances digesting quite slowly (greasy foods and pastry), since they can be stored longer in the food canal, may be of real advantage where, from hard work or exposure, the body requires a large supply of energy for some time. These "stay by" the laborer, giving him strength after the more easily digested foods have been used up. Storage by the food canal is limited chiefly to the stomach.

Regulation of the Food Supply to the Cells.—The storage of food materials is made to serve a second purpose in the plan of the body which is even more important than that of supplying nourishment to the cells during the intervals when no food is being taken. It is largely the means whereby the rate of supply of materials to the cells is regulated. The cells obtain their materials from the lymph, and the lymph is supplied from the blood. Should food substances, such as sugar, increase in the blood beyond a low per cent, they are converted into a form, like glycogen, in which they are held in reserve, or, for the time being, placed beyond the reach of the cells. When, however, the supply is reduced, the stored-up materials reënter the blood and again become available to the cells. By this means their rate of supply to the cells is practically constant.

We are now in a position to understand why carbohydrates, fats, and proteids are so well adapted to the needs of the body,
[181] while other substances, like alcohol, which may also liberate energy, prove injurious. It is because foods are of such a chemical nature that they are adapted in all respects to the body plan of taking up and using materials, while the other substances are lacking in some particular.

Why Alcohol is not a Food.—If the passage of alcohol

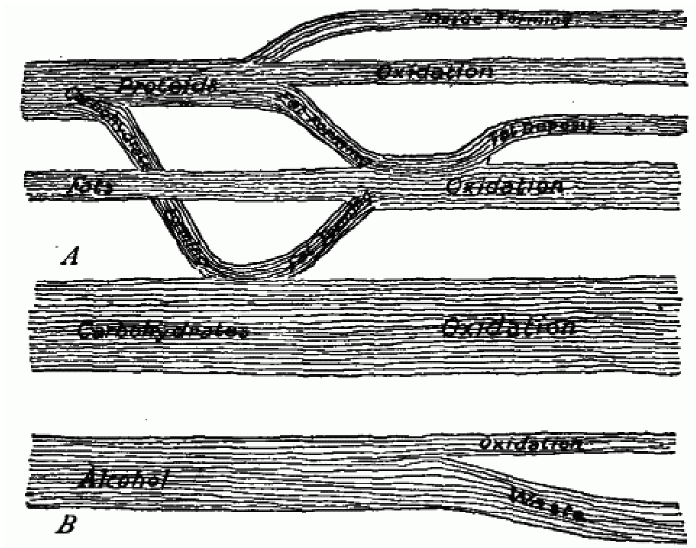

Fig. 80—**Diagrams illustrating the relation of nutrients** and the non-relation of these to alcohol. *A.* Inter-relation and convertibility of proteids, fats, and carbohydrates (after Hall).

B. Diagram showing disposition of alcohol if this substance is taken in quantity corresponding to that of the nutrients (F.M.W.). The alcohol thrown off as waste is unoxidized and yields no energy.

through the body is followed, it is seen, in the first place, that it is a simple liquid and undergoes no digestive change; and in the second place, that it is rapidly absorbed from the stomach in both weak and concentrated solutions. This introduces it quickly into the blood, and once there, it diffuses rapidly into the lymph and then into the cells. Since the body cannot store alcohol or convert it into some nutrient that can be stored (Fig. 80), *there*
[182] *is no way of regulating the amount that shall be present in the blood, or of supplying it to the cells as their needs require*. They must take it in excess of their needs, regardless of the effect, at least until the organs of excretion can throw off the surplus as waste. Compared with proteid, carbohydrates, or fats, alcohol is an *unmanageable* substance in the body. Attempting to use it as a food is as foolish as trying to burn gasolene or kerosene in an ordinary wood stove. It may be done to a limited extent, but is an exceedingly hazardous experiment. Not being adapted to the body method of using materials, alcohol cannot be classed as a food.

Assimilation.—Digestion, absorption, circulation, and storage of foods are the processes that finally make them available to the cells in the different parts of the body. There still remains another process for these materials to undergo before they serve their final purposes. This last process, known as *assimilation*, is the appropriation of the food material by the cell protoplasm. In a sense the storage of fat by connective tissue cells and of glycogen by the liver cells is assimilation. The term is limited, however, to the disposition of material with reference to its final use. Whether all the materials used by the cells actually become a part of the protoplasm is not known. It is known, however, that the cells are the places where most of the oxidations of the body occur and that materials taking part in these oxidations must, at least, come in close contact with the protoplasm. Assimilation, then, is the last event in a series of processes by which oxygen, food materials, and cell protoplasm are brought into close and *active* relations. The steps leading up to assimilation are shown in Table II. [183]

TABLE II. THE PASSAGE OF MATERIALS TO THE CELLS

MATERIALS	DIGESTION	ABSORPTION	ROUTE TO THE GENERAL CIRCULATION	STORAGE	CONDITION IN THE BLOOD
Proteids	Changed into proteoses and peptones by the action of the gastric and pancreatic juices.	In passing into the capillaries, the proteoses and peptones change into the proteids of the blood.	Through the portal vein to the liver and from there through the hepatic veins into the inferior vena cava.	Become a part of the protoplasm of all the cells.	As proteids in colloidal solution.
Fat	Changed into fatty acid, glycerine, and soluable soap by the bile and pancreatic juice.	In passing into the lacteals, the glycerine unites with the soluable soap and fatty acid to form the oil droplets of the blood.	Through the lacteals to the thoracic duct, by which it is emptied into the left subclavian vein.	As fat in the cells of collective tissue.	Chiefly as minute oil droplets.
Starch	Reduced to some of the different forms of sugar, as maltose, dextrose, etc.	Enters the capillaries as dextrose.	Through the portal vein, liver, hepatic veins, into inferior vena cava.	As glycogen chiefly by the liver, but to some extent by muscle cells.	As dextrose in solution.

Water	Undergoes no change.	Taken up by both the lacteals and capillaries, but to the greater extent by the capilaries.	Both routes, but mostly by way of the liver.	Is not stored in the sense that energy foods are.	As the water which serves as a carrier of all the other constituents of the blood.
Common salt	Undergoes no change.	Taken up by the capillaries without undergoing apparent change.	By way of portal vein, liver, and hepatic veins into inferior vena cava.	Not stored.	In solution.
Oxygen		Taken up by the capillaries at the lungs.	Already in the general circulation.	Is not stored.	United with the hemoglobin and to a small extent in solution in the plasma.

[184] **Tissue Enzymes.**—The important part played by enzymes in the digestion of the food has suggested other uses for them in the body. It has been recently shown that many of the chemical changes in the tissues are in all probability due to the presence of enzymes. An illustration of what a tissue enzyme may do is seen in the changes which fat undergoes. In order for the body to use up its reserve fat, it must be transferred from the connective tissue cells, where it is stored, to the cells of the active tissues where it is to be used. This requires that it be reduced to the form of a solution and that it reënter the blood. In other words, it must be *redigested*. For bringing about these changes a substance identical in function with the steapsin of the pancreatic juice has been shown to exist in several of the tissues.

Although this subject is still under investigation, it may be stated with certainty that there are present in the tissues, enzymes that change dextrose to glycogen and *vice versa*, that break down and build up the proteids, and that aid in the oxidations at the cells. The necessity for such enzymes is quite apparent.

Summary.—The digested nutrients are taken up by the capillaries and the lymph vessels and transferred by two routes to the circulation. In passing from the alimentary canal into the circulation the more important of the foods undergo changes which adapt them to the needs of the body. Since materials are absorbed more rapidly than they are used, means are provided for storing them and for supplying them to the cells as their needs require. *Capability of storage is an essential quality of energy-yielding foods*; and substances, such as alcohol, which lack this quality are not adapted to the needs of the body. For causing the chemical changes that occur in the storage of foods, as well as the oxidations at the cells, the presence of active agents, or enzymes, is necessary.

Exercises.—1. In what respects does the absorption of food materials from the alimentary canal differ from the absorption of a simple liquid by a solid?

2. In what different ways is the small intestine especially [185]
adapted to the work of absorption?

3. What are the parts of a villus? What are the lacteals? Account for the name.

4. What part is played by the capillaries and the lacteals in the work of absorption? How does their work differ?

5. What changes, if any, take place in water, common salt, fat, proteids, and carbohydrates during absorption?

6. What double purpose is served by the processes of digestion?

7. Trace the passage of proteids, fats, and carbohydrates from the small intestine into the general circulation.

8. What is the necessity for storing nutrients in the body? Why is it not also necessary to store up oxygen?

9. In what form and at what places is each of the principal nutrients stored?

10. How is the rate of supply of food to the cells regulated? Why is the body unable to regulate the supply of alcohol to the cells when this substance is taken?

11. Explain Fig. 80, page 181. What becomes of the alcohol if this is taken in any but very small quantities?

12. State the general purpose of enzymes in the body. Name the enzymes found in each of the digestive fluids. What ones are found in the tissues?

PRACTICAL WORK

Illustrate the ordinary meaning of the term "absorption" by bringing the end of a piece of crayon in contact with water, or a piece of blotting paper in contact with ink, noting the passage of the liquid into the crayon or the paper. Show how absorption from the food canal differs from this kind of absorption.

Show by a diagram similar to Fig. 77 the two routes by which the foods pass from the alimentary canal into the blood stream.

CHAPTER XII - ENERGY SUPPLY OF THE BODY

If one stops taking food, it becomes difficult after a time for him to move about and to keep warm. These results show that food has some relation to the energy of the body, for motion and heat are forms of energy. The relation of oxygen to the supply of energy has already been discussed (Chapter VIII). We are now to inquire more fully into the energy supply of the body, and to consider those conditions which make necessary the introduction of both food and oxygen for this purpose.

Kinds of Bodily Energy.—The healthy body has at any time a considerable amount of *potential*, or reserve, energy,—energy which it is not using at the time, but which it is able to use as its needs require. When put to use, this energy is converted into such forms of *kinetic* energy[69] as are indicated by the different kinds of bodily power. These are as follows:

1. *Power of Motion.*—The body can move itself from place to place and it can give motion to things about it.

2. *Heat Power.*—The body keeps itself warm and is able to communicate warmth to its surroundings. [187]

[69] Energy, which is defined as *the ability to do work*, or *to cause motion*, exists in two general types, or forms, known as kinetic energy and as potential energy. *Kinetic* energy is energy at work, or energy in the act of producing motion; while *potential* energy is reserve, or stored, energy. All moving bodies have kinetic energy, and all stationary bodies which have within them the *capability* of causing motion possess potential energy. A bent bow, a piece of stretched rubber, a suspended weight, the water above a mill dam, all have the capability of causing motion and all have potential energy. Examples of kinetic energy are found in the movements of machinery, in steam and electricity, in winds, and in currents of water. Kinetic is the active, and potential the inactive, form of energy.

3. *Nervous Power.*—Through the nervous system the body exercises the power of control over its different parts.

As motion, heat, and nervous power the body uses most of its energy.

The Source of Bodily Energy.—As already indicated, the energy of the body is supplied through the food and the oxygen. These contain energy in the potential form, which becomes kinetic (active) through their uniting with each other in the body. Somewhat as the power of the steam engine is derived from the combustion of fuel in the furnaces, the energy of the body is supplied through the oxidations at the cells. How the food and oxygen come to possess energy is seen by a study of the general methods by which energy is stored up and used.

Simple Methods of Storing Energy.—Energy is stored by converting the kinetic into the potential form. Two of the simplest ways of doing this are the following:

1. *Storing of Energy through Gravity.*—On account of the attraction between the earth and all bodies upon the earth, the mere lifting of a weight puts it in a position where gravity can cause it to move (Fig. 81). As a consequence *the raising of bodies above the earth's surface is a means of storing energy*—the
[188] energy remaining stored until the bodies fall. As they fall, the stored-up (potential) energy becomes kinetic and can be made to do work.

2. *Storing of Energy through Elasticity.*—Energy is stored also by doing work in opposition to elasticity, as in bending a bow or in winding a clock spring. The bending, twisting, stretching, or compressing of elastic substances puts them in a condition of *strain* which causes them to exert a pressure (called elastic force) that tends to restore them to their former condition. Energy stored by this means becomes active as the distorted or compressed substance returns to its former shape or volume.

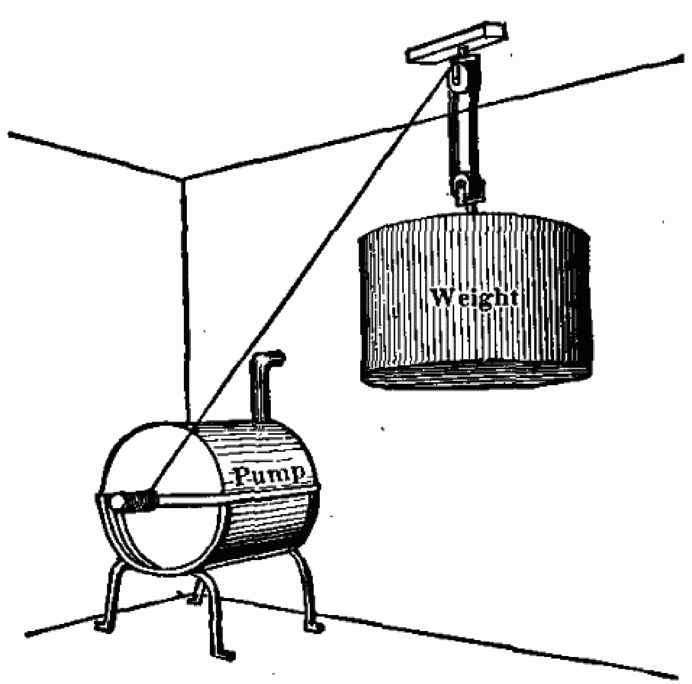

Fig. 81—**Simple device** for storing energy through gravity.

These simple methods of storing energy will serve to illustrate the general principles upon which such storage depends:

1. To store energy, energy must be expended, or work done.

2. The work must be against some force, such as gravity or elasticity, which can undo the work, i.e., bring about an effect opposite to that of the work.

3. The stored energy becomes active (kinetic) as the force through which the energy was stored undoes the work, or puts the substance upon which the work was done into its former condition (gravity causing bodies to fall, etc.).

These principles are further illustrated by the

Storing of Energy through Chemical Means.—A good example of storing energy by chemical means is that of decomposing water with electricity. If a current of electricity is passed through acidulated water in a suitable apparatus (Fig. 82), the water separates into its component gases, oxygen and hydrogen. These gases now have power (energy) which they did not possess before they were separated. The hydrogen will burn
[189] in the oxygen, giving heat; and if the two gases are mixed in the right proportions and then ignited, they explode with violence. This energy was derived from the electricity. It was stored by *decomposing* the water.

Energy is stored by chemical means by causing it to do work in opposition to the force of chemism, or chemical affinity. Instead of changing the form of bodies or moving them against gravity, it overcomes the force that causes atoms to unite and to hold together after they have united. Since in most cases the atoms on separating from any given combination unite at once to form other combinations, we may say that *energy is stored when strong chemical combinations are broken up and weak ones formed*. Energy stored by this means becomes active when

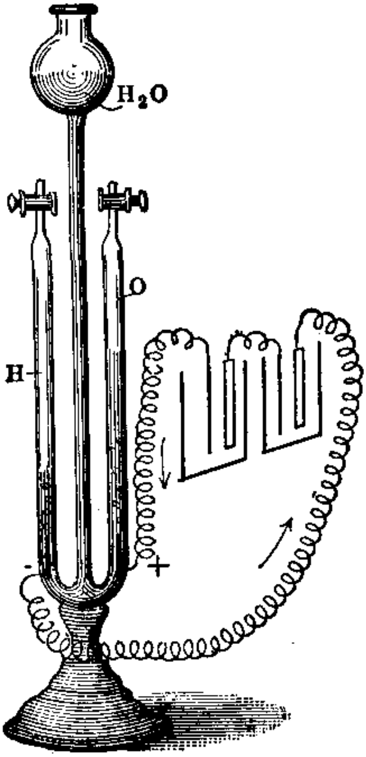

Fig. 82—**Storing energy by chemical means.** Apparatus for decomposing water with electricity.

the atoms of weak combinations unite to form combinations that are strong.[70]

How Plants store the Sun's Energy.—The earth's supply of energy comes from the sun. While much of this, after warming and lighting the earth's surface, is lost by radiation, a portion of it is stored up and retained. The sun's energy is stored both
[190] through the force of gravity[71] and by chemical means, the latter being the more important of the two methods. Plants supply the means for storing it chemically (Fig. 83). Attention has already been called to the fact (page 112) that growing plants are continually taking carbon dioxide into their leaves from the air. This they decompose, adding the carbon to compounds in their tissues and returning the oxygen to the air. It is found, however, that this process does not occur unless the plants are exposed to sunlight. The sunlight supplies the energy for overcoming the attraction between the atoms of oxygen and the atoms of carbon, while the plant itself serves as the instrument through which the sunlight acts. The energy for decomposing the carbon dioxide then comes from the sun, and through the decomposition of the carbon dioxide the sun's energy is stored—becomes potential. It remains stored until the carbon of the plant again unites with the oxygen of the air, as in combustion.

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[70] As the atoms of hydrogen and oxygen that make up the molecules of water separate, they unite with atoms of their own kind—the hydrogen with hydrogen and the oxygen with oxygen atoms. Since these combinations are weaker than those of the water molecules, energy is required to bring about the change. But when hydrogen burns in the oxygen, the change is from a weaker to a stronger combination. The stored-up energy is then given up or becomes active.

[71] In the evaporation of water, the energy of the sun is stored with reference to the force of gravity. In evaporating, water rises as a gas, or vapor, above the earth's surface, but on condensing into a liquid, it falls as rain. It then finds its way through streams back to the ocean. All water above the sea level is in such a position that gravity can act on it to cause motion, and it possesses, on this account, potential or stored-up energy. It is because of this energy that rapids and waterfalls are such important sources of power.

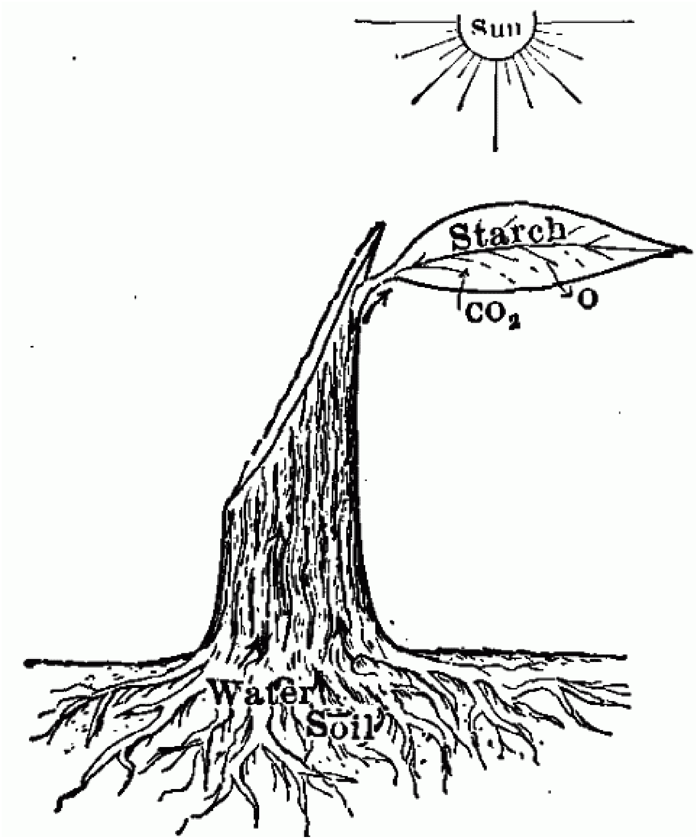

Fig. 83—**Nature's device** for storing energy from the sun. See text.

The Sun's Energy in Food and Oxygen.—Food is derived directly or indirectly from plants and sustains the same relation to the oxygen of the air as do the plants themselves. (The elements [191] in the food have an attraction for the oxygen, but are separated chemically from it.) On account of this relation they have potential energy—the energy derived through the plant from the sun. When a person eats the food and breathes the oxygen, this energy becomes the possession of the body. It is then converted into kinetic energy as the needs of the body require.

From the Sun to the Cells.—It thus appears that the body comes into possession of energy, and is able to use it, through a series of transferences and transformations that can be traced back to the sun.[72] Coming to the earth as kinetic energy, it is transformed into potential energy and stored in the compounds of plants and in the oxygen of the air. Through the food and the oxygen the potential energy is transferred to the cells of the body. Then by the uniting of the food and the oxygen at the cells

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[72] Energy, like matter, can neither be created nor destroyed. It can, however, be transferred from one body to another and transformed from one form to another form. Whenever work is done, energy is transferred from the body doing the work, to the body upon which the work is done. During this process there may, or may not, be a transformation of energy. In turning a grindstone, kinetic energy is passed to the stone and used without transformation, but in winding a clock, the kinetic energy from the hand is transformed into potential energy in the clock spring. Then as the clock runs down this is retransformed into kinetic energy, causing the movements of the wheels.

Not only is kinetic transformed into potential energy and *vice versa*, but the different forms of kinetic energy (heat, light, electricity, sound, and mechanical motion) are readily transformed the one into the other. With suitable devices, mechanical motion can be changed into heat, sound, or electricity; heat into motion and light; and electricity into all the other forms of energy. These transformations are readily explained by the fact that the different varieties of kinetic energy are but different forms of motion (Fig. 84).

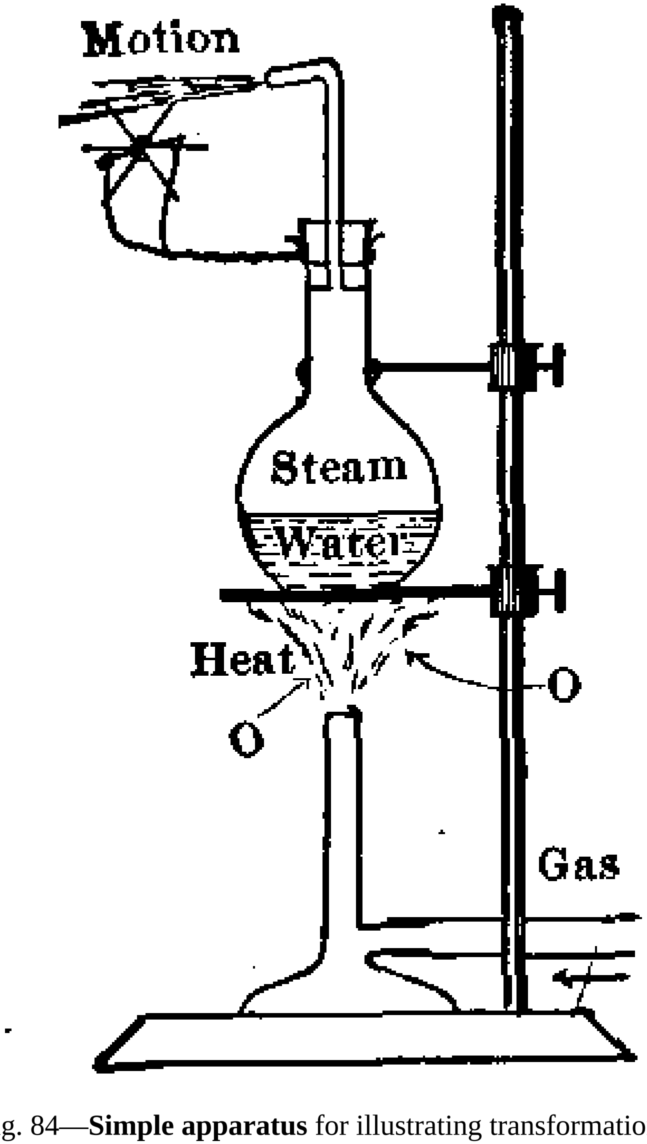

Fig. 84—**Simple apparatus** for illustrating transformation of energy. Potential energy is converted into heat and heat into motion.

[192] (oxidation), the potential becomes kinetic energy and is used by the body in doing its work. The phrase "Child of the Sun" has sometimes been applied to man to express his dependence upon the sun for his supply of energy.

Why Oxygen and Food are Both Necessary.—The necessity for introducing both oxygen and food into the body for the purpose of supplying energy is now apparent. The energy which is used in the body is not the energy of food alone. Nor is it the energy of oxygen alone. It belongs to both. It is due to their attraction for each other and their condition of separation. It cannot, therefore, become kinetic except through their union. To introduce one of these substances into the body without the other, would neither introduce the energy nor set it free. They must both be introduced into the body and there caused to unite.

Bodily Control of Energy.—A fact of importance in the supply of energy to the body is that the rate of transformation (changing of potential to kinetic) is just sufficient for its needs. It is easily seen that too rapid or too slow a rate would prove injurious. The oxidations at the cells are, therefore, under such control that the quantity of kinetic energy supplied to the body as a whole, and to the different organs, is proportional to the work that is done. This is attained, in part at least, through the ability of the body to store up the food materials and hold them in reserve until they are to be oxidized (page 180).

Animal Heat and Motion.—Most of the body's energy is expended as heat in keeping warm. It is estimated that as much as five sixths of the whole amount is used in this way. The proportion, however, varies with different persons and is not constant in the same individual during different seasons of the year. This heat is used in keeping the body at that temperature
[193] which is best suited to carrying on the vital processes. All parts of the body, through oxidation, furnish heat. Active organs, however, such as the muscles, the brain, and the glands (especially the liver), furnish the larger share. The blood in its

circulation serves as a *heat distributer* for the body and keeps the temperature about the same in all its parts (page 33).

Next to the production of heat, in the consumption of the body's energy, is the production of motion. This topic will be considered in the study of the muscular system (Chapter XV).

Some Questions of Hygiene.—The heat-producing capacity of the body sustains a very important relation to the general health. A sudden chill may result in a number of derangements and is supposed to be a predisposing cause of *colds*. One's capacity for producing heat may be so low that he is unable to respond to a sudden demand for heat, as in going from a warm room into a cold one. As a consequence, the body is unable to protect itself against unavoidable exposures.

Impairment of the heat-producing capacity is brought about in many ways. Several diseases do this directly, or indirectly, to quite an extent. In health too great care in protecting the body from cold is the most potent cause of its impairment. Staying in rooms heated above a temperature of 70° F., wearing clothing unnecessarily heavy, and sleeping under an excess of bed clothes, all diminish the power of the body to produce heat. They accustom it to producing only a small amount, so that it does not receive sufficient of what might be called *heat-producing exercise*. Lack of physical exercise in the open air, as well as too much time spent in poorly lighted and ventilated rooms, tends also to reduce one's ability to produce heat. Moreover, since most of the heat of the body comes from the union of oxygen and [194]
food materials at the cells, a lack of either of these will interfere with the production of heat.

Results of Exhaustion.—Through overwork, or excesses in pleasurable pursuits, one may make greater demands upon the energy of his body than it can properly supply. The resulting condition, known as *exhaustion*, is not only a matter of temporary inconvenience, but may through repetition lead to a serious impairment of the health. It should be noted, in this connection, that the energy of the body is spent in two general ways: first, in carrying on the vital processes; and second, in the performance of voluntary activities. Since, in all cases, there is a limit to one's energy, it is easily possible to expend so much in the voluntary activities that the amount left is not sufficient for the vital processes. This leads to various disturbances and, among other things, renders the body less able to supply itself with energy.

The Problem of Increasing One's Energy.—Since the energy supply is kept up through the food and the oxygen, it might be inferred that the introduction of these substances into the body in larger amounts would increase the energy at one's disposal. This does not necessarily follow. Oxidation at the cells is preceded by digestion, absorption, circulation, and assimilation. It is followed and influenced by the removal of wastes from the body. A careful study of the problem leads to the conclusion that while the energy supply to the body does depend upon the introduction of the proper amounts of food and oxygen, it also depends upon the efficiency of the vital processes. The maximum amount of energy may, therefore, be expected when the body is in a condition of perfect health. Hence, one desiring to increase the
[195] amount of his energy must give attention to all those conditions that improve the health.

Effect of Stimulants on the Energy Supply.—In the effort to get out of the body as much as possible of work or of pleasure, various stimulants, such as alcohol, tobacco, and strong tea and coffee, have been used. Though these have the effect of giving a temporary feeling of strength and of enabling the individual in some instances to accomplish results which he could not otherwise have brought about, the general effect of their use is to lessen, rather than to increase, the sum total of bodily power. The student, for example, who drinks strong coffee in order to study late at night is able to command less energy on the day following. While enabling him to draw upon his reserve of nervous power for the time being, the coffee deprives him of sleep and needed rest.

The danger of stimulants, so far as energy is concerned, is this: they tend to exhaust the bodily reserve so that there is not sufficient left for properly running the vital processes. Evidences of their weakening effect are found in the feeling of discomfort and lassitude which result when stimulants to which the body has become accustomed are withdrawn. Not until one gets back his bodily reserve is he able to work normally and effectively. Increase in bodily energy comes through health and not through the use of stimulants.

Summary.—The body requires a continuous supply of energy. To obtain this supply, materials possessing potential, or stored-up, energy are introduced into it. The free oxygen of the air and the substances known as foods, on account of the chemical relations which they sustain to each other, contain potential energy and are utilized for supplying the body. So long as the foods are not oxidized, the energy remains in the potential form, but in the process of oxidation the potential energy is changed to kinetic energy and made to do the work of the body.

Exercises.—1. In what different ways does the body use energy?

2. Show that a stone lying against the earth has no energy, while the same stone above the earth has energy.

3. How does potential energy differ from kinetic energy? [196]

4. What kind of energy is possessed by a bent bow? By a revolving wheel? By a coiled spring? By the wind? By gunpowder?

5. How does decomposing water with electricity store energy?

6. Account for the energy possessed by the oxygen of the air and food substances.

7. Trace the energy supply of the body back to the sun.

8. Why must both oxygen and food be introduced into the body in order to supply it with energy?

9. How may overwork and overexercise diminish the energy supply of the body?

10. How may one increase the amount of his energy?

PRACTICAL WORK

Suggested Experiments.—1. The change of kinetic into potential energy may be shown by stretching a piece of rubber, by lifting a weight, and by separating the armature from a magnet.

2. The change of potential into kinetic energy may be shown by letting weights fall to the ground, by releasing the end of a piece of stretched rubber, and by burning substances.

3. The change of one form of kinetic energy to another may be illustrated by rubbing together two pieces of wood until they are heated, by ringing a bell, and by causing motion in air or in water by heating them. If suitable apparatus is at hand, the transformation of electrical energy into heat, light, sound, and mechanical motion can easily be shown.

4. A weight connected by a cord with some small machine and made to run it, will help the pupil to grasp the general principles in the storage of energy through gravity. A vessel of water on a high support from which the water is siphoned on to a small water wheel will serve the same purpose.

5. The storing of energy by chemical means may be illustrated by decomposing potassium chlorate with heat or by decomposing water by means of a current of electricity.

6. Study the transfer of energy from the body to surrounding objects, as in moving substances and lifting weights.

Fill a half gallon jar two thirds full of water and carefully take the temperature with a chemical thermometer. Hold the hand in the water for four or five minutes and take the temperature again. Inference.

[197]

CHAPTER XIII - GLANDS AND THE WORK OF EXCRETION

In our study so far we have been concerned mainly with the introduction of materials into the body. We are now to consider the removal of materials from the body. The structures most directly concerned in this work are known as

Glands.—As generally understood, glands are organs that prepare special liquids in the body and pour them out upon free surfaces. These liquids, known as *secretions*, are used for protecting exposed parts, lubricating surfaces that rub against each other, digesting food, and for other purposes. They differ widely in properties as well as in function, but are all alike in being composed chiefly of water. The water, in addition to being necessary to the work of particular fluids, serves in all cases as a carrier of solid substances which are dissolved in it.

General Structure of Glands.—While the various glands differ greatly in size, form, and purpose, they present striking similarities in structure. All glands contain the following parts:

1. Gland, or secreting, cells. These are *specialized* cells for the work of secretion and are the active agents in the work of the gland. They are usually cubical in shape.

2. A basement membrane. This is a thin, connective tissue support upon which the secreting cells rest.

3. A network of capillary and lymph vessels. These penetrate [198] the tissues immediately beneath the secreting cells.

4. A system of nerve fibers which terminate in the secreting cells and in the walls of the blood vessels passing to the glands.

These structures—secreting cells, basement membrane, capillary and lymph vessels, and nerve fibers—form the essential parts of all glands. The capillaries and the lymph vessels supply the secreting cells with fluid, and the nerves control their activities.

Kinds of Glands.—Glands differ from one another chiefly in the arrangement of their essential parts.[73] The most common plan is that of arranging the parts around a central cavity formed by the folding or pitting of an exposed surface. Many such glands are found in the mucous membrane, especially that lining the alimentary canal, and are most numerous in the stomach, where they supply the gastric juice. If these glands have the general form of tubes, they are called *tubular* glands; if sac-like in shape, they are called *saccular* glands. Both the tubular and the saccular glands may, by branching, form a great number of similar divisions which are connected with one another, and which communicate by a common opening with the place where the secretion is used. This forms a *compound* gland which, depending on the structure of the minute parts, may be either a *compound tubular* or a *compound saccular* gland. The larger of the compound saccular glands are also called *racemose* glands, on account of their having the general form of a cluster, or raceme,
[199] similar to that of a bunch of grapes. The general structure of the different kinds of glands is shown in Fig. 85.

Nature of the Secretory Process.—At one time the gland was regarded merely as a kind of filter which separated from the blood the ingredients found in its secretions. Recent study, however, of several facts relating to secretion has led to important modifications of this view. The secretions of many glands are known to contain substances that are not found in the blood, or, if present, are there in exceedingly small amounts. Then again

[73] The simplest arrangement of the parts of a gland is that where they are spread over a plain surface. This arrangement is found in serous membranes, such as the pleura and peritoneum. These membranes, however, are not called glands, but secreting surfaces.

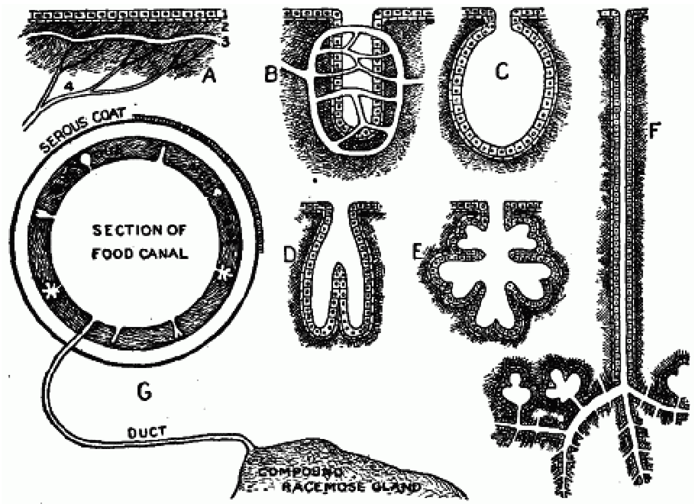

Fig. 85—**Diagram illustrating evolution of glands.** *A.* Simple secreting surface. 1. Gland cells. 2. Basement membrane. 3. Blood vessel. 4. Nerve. *B.* Simple tubular gland. *C.* Simple saccular gland. *D.* Compound tubular gland. *E.* Compound saccular gland. *F.* A compound racemose gland with duct passing to a free surface. *G.* Relation of food canal to different forms of glands. The serous coat has a secreting surface.

the cells of certain glands have been found to undergo marked
[200] changes during the process of secretion. If, for example, the cells of the pancreas be examined after a period of rest, they are found to contain small granular bodies. On the other hand, if they are examined after a period of activity, the granules have disappeared and the cells themselves have become smaller (Fig. 86). The granules have no doubt been used up in forming the secretion. These and other facts have led to the conclusion that secretion is, in part, the separation of materials without change from the blood, and, in part, a process by which special substances are prepared and added to the secretion. According to this view the gland plays the double rôle of a *filtering apparatus* and of a *manufacturing organ*.

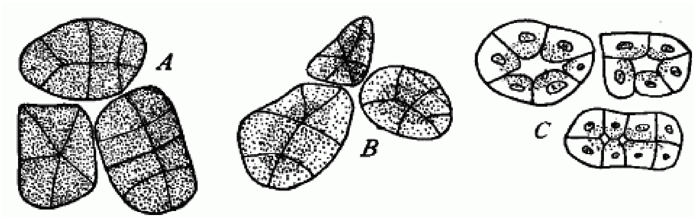

Fig. 86—**Secreting cells from the pancreas** (after Langley). *A.* After a period of rest. *B.* After a short period of activity. C. After a period of prolonged activity. In *A* and *B* the nuclei are concealed by the granules that accumulate during the resting period.

Kinds of Secretion.—In a general way all the liquids produced by glands may be considered as belonging to one or the other of two classes, known as the *useful* and the *useless* secretions. To the first class belong all the secretions that serve some purpose in the body, while the second includes all those liquids that are separated as waste from the blood. The first are usually called *true secretions*, or secretions proper, while the second are called *excretions*. The most important glands producing liquids of the first class are those of digestion (Chapter X).

Excretory Work of Glands.—The process of removing wastes from the body is called *excretion*. While in theory excretion may be regarded as a distinct physiological act, it is, in fact, leaving out the work of the lungs, but a phase of the work of glands. From the cells where they are formed, the waste materials pass into the lymph and from the lymph they find their way into the blood. They are removed from the blood by glands and then passed to the exterior of the body. [201]

The Necessity for Excretion is found in the results attending oxidation and other chemical changes at the cells (page 107). Through these changes large quantities of materials are produced that can no longer take any part in the vital processes. They correspond to the ashes and gases of ordinary combustion and form wastes that must be removed. The most important of these substances, as already noted (page 110), are carbon dioxide, water, and urea.[74] A number of mineral salts are also to be included with the waste materials. Some of these are formed in the body, while others, like common salt, enter as a part of the food. They are solids, but, like the urea, leave the body dissolved in water.

Waste products, if left in the body, interfere with its work (some of, them being poisons), and if allowed to accumulate, cause death. Their removal, therefore, is as important as the introduction of food and oxygen into the body. The most important of the excretory glands are

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[74] In the oxidations that occur in the body it is not supposed that the nutrients are immediately converted to carbon dioxide, water, and urea. On the other hand, it is held that their reduction takes place gradually, as the reduction of sugar by fermentation, and that the wastes leaving the body are but the "end products" and show only the final results.

The Kidneys.—The kidneys are two bean-shaped glands,
[202] situated in the back and upper portion of the abdominal cavity, one on each side of the spinal column. They weigh from four to six ounces each, and lie between the abdominal wall and the peritoneum. Two large arteries from the aorta, called the *renal arteries*, supply them with blood, and they are connected with the inferior vena cava by the *renal veins*. They remove from the blood an exceedingly complex liquid, called the *urine*, the principal constituents of which are water, salts of different kinds, coloring matter, and urea. The kidneys pass their secretion by two slender tubes, the *ureters*, to a reservoir called the *bladder* (Fig. 87).

Structure of the Kidneys.—Each kidney is a compound tubular gland and is composed chiefly of the parts concerned in secretion. The ureter serves as a duct for removing the secretion, while the blood supplies the materials from which the secretion is formed. On making a longitudinal section of the kidney, the upper end of the ureter is found to expand into a basin-like enlargement which is embedded in the concave side of the kidney. The cavity within this enlargement is called the *pelvis of the kidney*, and into it project a number of cone-shaped elevations from the kidney substance, called the *pyramids* (Fig. 88).

From the summits of the pyramids extend great numbers of
[203] very small tubes which, by branching, penetrate to all parts of the kidneys. These are the *uriniferous tubules*, and they have their beginnings at the outer margin of the kidney in many small, rounded bodies called the *Malpighian capsules* (*A*, Fig. 88). Each capsule incloses a cluster of looped capillaries and connects with a single tubule (Fig. 89). From the capsule the tubule extends toward the concave side of the kidney and, after uniting with similar tubules from other parts, finally terminates

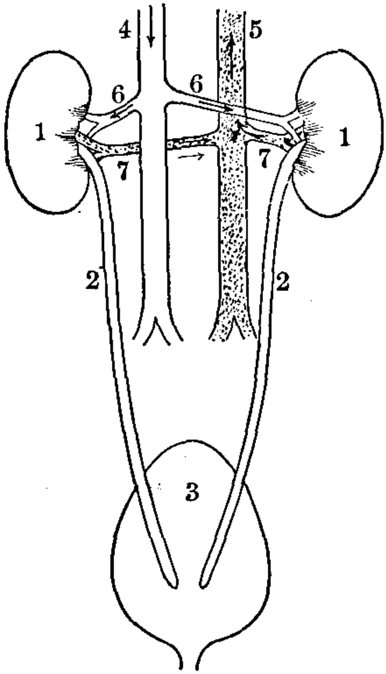

Fig. 87—**Relations of the kidneys.** (Back view.) 1. The kidneys. 2. Ureters. 3. Bladder. 4. Aorta. 5. Inferior vena cava. 6. Renal arteries. 7. Renal veins.

at the pyramid. Between its origin and termination, however, are several convolutions and one or more loops or turns. After passing a distance many times greater than from the surface to the center of the kidney, the tubule empties its contents into the expanded portion of the ureter.

[204] The uriniferous tubules are lined with secreting cells. These differ greatly at different places, but they all rest upon a basement membrane and are well supplied with capillaries. These cells provide one means of separating wastes from the blood (Fig. 90).

Blood Supply to the Kidneys.—The method by which the kidneys do their work is suggested by the way in which the blood circulates through them. The renal artery entering each kidney divides into four branches and these send smaller divisions to all parts of the kidney. At the outer margin of the kidney, called the *cortex*, the blood is passed through *two sets of capillaries*. The first forms the clusters in the Malpighian capsules and receives the blood directly from the smallest arteries. The second forms a network around the uriniferous tubules and receives the blood which has passed from the capillary clusters into a system of small veins (Fig. 90). From the last set of capillaries the blood is passed into veins which leave the kidneys where the artery branches enter, uniting there to form the main renal veins.

[205] **Work of the Kidneys.**—Why should the blood pass through two systems of capillaries in the kidneys? This is because the separation of waste is done in part by the Malpighian capsules and in part by the uriniferous tubules. Water and salts are removed chiefly at the capsules, while the remaining solid constituents of the urine pass through the secreting cells that line the tubules. It

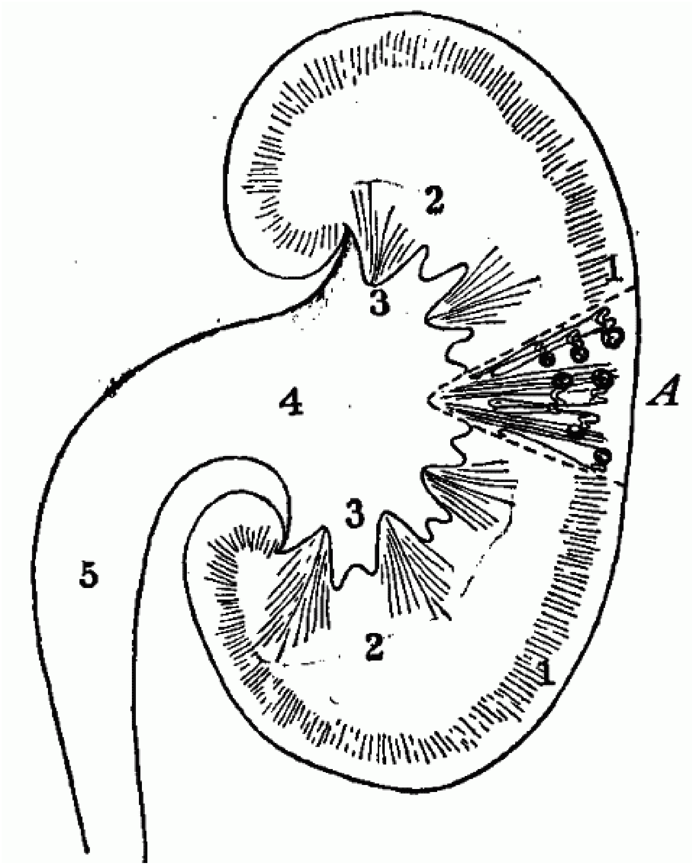

Fig. 88—**Sectional view of kidney.** 1. Outer portion or cortex. 2. Medullary portion. 3. Pyramids. 4. Pelvis. 5. Ureter. *A.* Small section enlarged to show the tubules and their connection with the capsules.

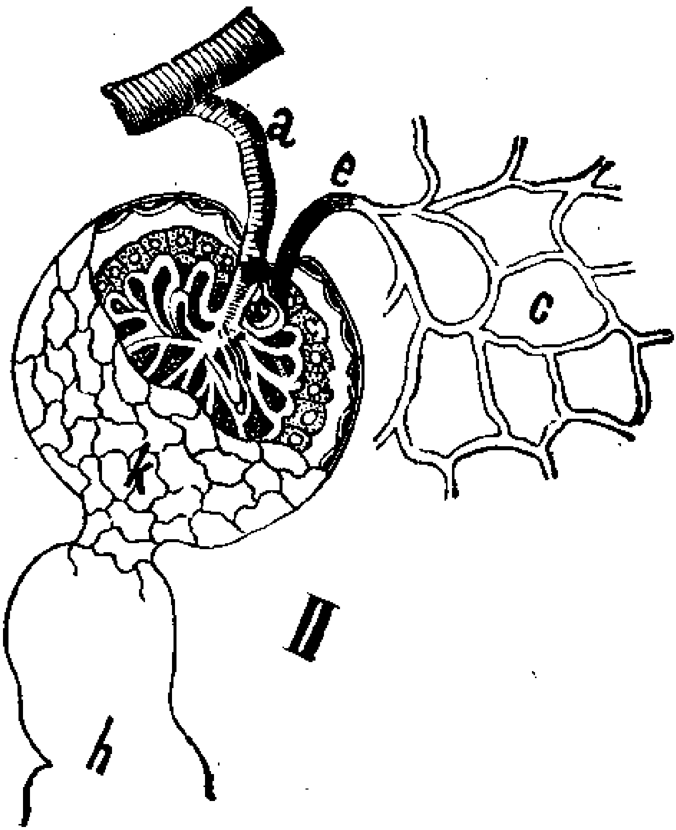

Fig. 89—**Malpighian capsule** highly magnified (Landois). *a.* Small artery entering capsule and forming cluster of capillaries within. *e.* Small vein leaving capsule and branching into *c*, a second set of capillaries, *h.* Beginning of uriniferous tubule.

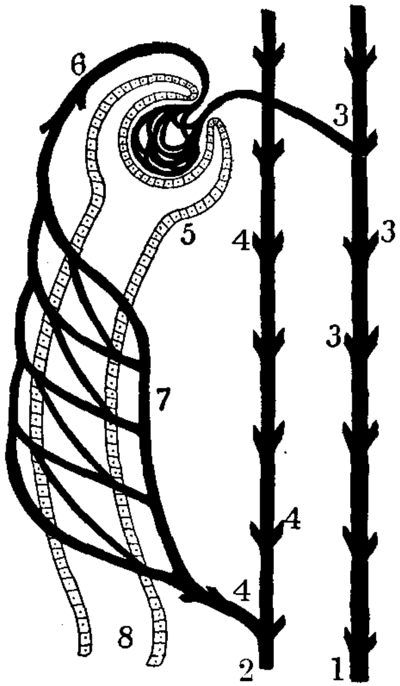

Fig. 90—**Diagram illustrating renal circulation.** 1. Branch from renal artery. 2. Branch from renal vein. 3. Small artery branches, one of which enters a Malpighian capsule (5). 6. Small vein leaving the capsule and branching into the capillaries (7) which surround the uriniferous tubules. 4. Small veins which receive blood from the second set of capillaries. 8. Tubule showing lining of secreting cells.

was formerly believed that the kidneys obtained their secretion by a process of filtration from the blood, but this belief has been gradually modified. The prevailing view now is that the processes of filtration and secretion are both carried on by the kidneys,—that the capillary clusters in the Malpighian bodies serve as delicate filters for the separation of water and salts, while the secreting cells of the tubules separate substances by the process of secretion.

On account of the large volume of blood passing through the kidneys this liquid is still a bright red color as it flows into the renal veins (Fig. 90). The kidney cells require oxygen, but the amount which they remove from the blood is not sufficient to affect its color noticeably. The blood in the renal veins, having given up most of its impurities and still retaining its oxygen, is considered the purest blood in the body.

Urea is the most abundant solid constituent of the urine and is the chief waste product arising from the oxidation of nitrogenous substances in the body. Although secreted by the cells lining the uriniferous tubules, it is not formed in the kidneys. The secreting cells simply separate it from the blood where it already exists. The muscles also have been suggested as a likely source of urea, for here the proteids are broken down in largest quantities; but the muscles produce little if any urea. Its production has been found to be the *work of the liver*. In the muscular tissue, and in the other tissues as well, the proteids are reduced to a lower order
[206] of compounds, such as the compounds of ammonia, which pass into the blood and are then taken up by the liver. By the action of the liver cells these are converted into urea and this is turned back into the blood. From the blood the urea is separated by the secreting cells of the kidneys.

Work of the Liver.—The liver, already described as an organ of digestion (page 152), assists in the work of excretion both by changing waste nitrogenous compounds into urea and by removing from the blood the wastes found in the bile. While the chief work of the liver is perhaps not that of excretion, its functions may here be summarized. The liver is, first of all, a *manufacturing organ*, producing, as we have seen, three distinct products—bile, glycogen, and urea. On account of the nature of the urea and the bile, the liver is properly classed as an *excretory organ*; but in the formation of the glycogen it plays the part of a *storage organ*. Then, on account of the use made of the bile after it is passed into the food canal, the liver is also classed as a *digestive organ*. These different functions make of the liver an organ of the first importance.

Excretory Work of the Food Canal.—The glands connected with the food canal, other than the liver, while secreting liquids that aid in digestion, also separate waste materials from the blood. These are passed into the canal, whence they leave the body with the undigested portions of the food and the waste from the liver. Though the nature and quantity of the materials removed by these glands have not been fully determined, recent investigations have tended to enhance the importance attached to this mode of excretion.

The Perspiratory Glands.—The perspiratory, or sweat, glands are located in the skin. They belong to the type of simple tubular glands and are very numerous over the entire [207] surface of the body. A typical sweat gland consists of a tube which, starting at the surface of the cuticle, penetrates to the under portion of the true skin and there forms a ball-shaped coil. The coiled extremity, which forms the secreting portion, is lined with secreting cells and surrounded by a network of capillaries. The portion of the tube passing from the coil to the surface serves as a duct (Figs. 91 and 121).

The sweat glands secrete a thin, colorless fluid, called *perspiration*, or sweat. This consists chiefly of water, but contains a small per cent of salts and of urea. The excretory work of these

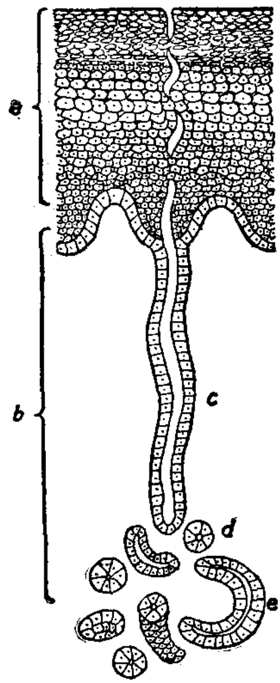

Fig. 91—**Diagram of section through a sweat gland.** *a.* Outer layer of skin or cuticle. *b.* Dermis or true skin. *d, e.* Sections of the tube forming the coiled portion of the gland. *c.* Duct passing to the surface. The other structures of the skin not shown.

glands seems not to be so great as was formerly supposed, but they supplement in a practical way the work of the kidneys and, during diseases of these organs, show an increase in excretory function to a marked degree. The perspiration also aids in the regulation of the temperature of the body (Chapter XVI).

Excretory Work of the Lungs.—While the lungs cannot be regarded as glands, they do a work in the removal of waste from the body which must be considered in the general process of excretion. They are especially adapted to the removal of gaseous substances from the blood, and it is through them that most of the carbon dioxide leaves the body. The lungs remove also a [208] considerable quantity of water. This is of course in the gaseous form, being known as water vapor.

Ductless Glands and Internal Secretion.—Midway in function between the glands that secrete useful liquids and those that remove waste materials from the blood is a class of bodies, found at various places, known as the *ductless glands.* They are so named from their having the general form of glands and from the fact that they have no external openings or ducts. They prepare special materials which are passed into the blood and which are supposed to exert some beneficial effect either upon the blood or upon the tissues through which the blood circulates. The most important of the ductless glands are the thyroid gland, located in the neck; the suprarenal bodies, situated one just over each kidney; and the thymus gland, a temporary gland in the upper part of the chest. The spleen and the lymphatic glands (page 68) are also classed with the ductless glands. The liver, the pancreas, and (according to some authorities) the kidneys, in addition to their external secretions, produce materials that pass into the blood. They perform in this way a function like that of the ductless glands. The work of glands in preparing substances that enter the blood is known as *internal secretion.*

Quantity of Excretory Products.—If the weight of the normal body be taken at intervals, after growth has been attained, there will be found to be practically no gain or loss from time to time. This shows that materials are leaving the body as fast as they enter and that the tissues are being torn down as fast as they are built up. It also shows that substances do not remain in the body *permanently*, but only so long perhaps as is necessary for them to give up their energy, or serve some additional purpose in the ever changing protoplasm. The excretory organs then remove from the body a quantity of material that is equal in weight to the materials absorbed by the organs of digestion and respiration. This is estimated for the average individual to be about five pounds daily. The passage of waste from the body is summarized in Table III.

TABLE III. THE PASSAGE OF WASTE MATERIALS FROM THE BO

Materials	State	How Formed in the Body	Condition in the Blood	How Removed from the Blood
Carbon dioxide	Gas	By the oxidation of the carbon of proteids, carbohydrates, and fats.	Dissolved in the plasma and in loose combination with salts in the blood.	Separated from the blood at the alveoli of the lungs and then forced through the air passages into the atmosphere.
Urea	Solid	By the oxidation in the liver of nitrogenous compounds.	Dissolved in the plasma.	Removed by the uriniferous tubules of the kidneys and to a small extent by the perspiratory glands.
Water	Liquid	By the oxidation of the hydrogen of proteids, carbohydrates, and fats. Amount formed in the body is small.	As water.	Removed by all the organs of excretion, but in the largest quantities by the kidneys and the skin.

Salts	Solid		Dissolved in the plasma.	By the kidneys, liver, and skin.

[210]

HYGIENE

The separation of wastes from the body has such a close relation to the health that all conditions affecting it should receive the most careful attention. Their retention beyond the time when they should be discharged undoubtedly does harm and is the cause of many bodily disorders.

Value of Water.—As a rule the work of excretion is aided by drinking *freely* of pure water. As water is the natural dissolver and transporter of materials in the body, it is generally conceded by hygienists and physicians that the taking of plenty of water is a healthful practice. People do not as a rule drink a sufficient amount of water, about three pints per day being required by the average adult, in addition to that contained in the food. Most of the water should, of course, be taken between meals, although the sipping of a small amount during meals does not interfere with digestion. As stated elsewhere, the taking of a cup of water on retiring at night and again on rising in the morning is very generally recommended.

Protection of Kidneys and Liver.—The kidneys and liver are closely related in their work and in many instances are injured or benefited by the same causes. Both, as already stated (page 124), are liable to injury from an *excess of proteid food*, especially meats, and also by a condition of inactivity of the bowels (page 166). The free use of alcohol also has an injurious effect on both of these organs.[75] On the other hand, increasing the activity of

[75] Alcohol, if used in considerable quantity, leads to cirrhosis of the liver and Bright's disease of the kidneys, both very dangerous diseases. Dr. William Osler in his treatise, *The Practice of Medicine*, states that alcohol is the chief

[211] the skin has a beneficial effect upon them, especially the kidneys. Exercise and bathing, which tend to make the skin more active, are valuable aids both in ridding the body of impurities and in lessening the work of the other excretory organs. One having a disease of the kidneys, however, needs to exercise great care in bathing on account of the bad results which follow getting chilled.

Special Care after Certain Diseases.—Certain diseases, as measles, diphtheria, scarlet fever, and typhoid fever, sometimes have the effect of weakening the kidneys (and other vital organs) and of starting disease in them. When this occurs it is usually the result of exposure or of over-exertion while the body is in a weakened condition. Severe chilling at such a time, by driving blood from the surface to the parts within, often causes inflammation of the kidneys. On recovering from any wasting disease one should exercise great caution both in resuming his regular work and in exposing his body to wet or cold.

Misunderstood Symptoms.—Pains in the small of the back, an increase in the secretions of the kidneys, and a sediment in the urine very naturally suggest some disorder of the kidneys. It is a fact, however, that these symptoms have little or no relation to the state of the kidneys and may occur when the kidneys are in a perfectly healthy condition. The kidneys are not located in the small of the back, but above this place, so that pains in this region are evidently not from the kidneys, while the increase in the flow of the urine may arise from a number of causes, one of which is an increase of certain waste products passed into the blood. The symptoms referred to are frequently the results of nervous exhaustion, resulting from overstudy, worry, eye strain, or some other condition that overtaxes the nervous system. When this is the case, relief is obtained through resting

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cause of cirrhosis of the liver. Dr. T.N. Bogart, specialist in kidney diseases, asserts that one third of all the cases of Bright's disease coming under his observation are caused by alcohol.

the nerves. Actual disease of the kidneys can only be determined through a chemical and microscopic examination of the urine. To resort to some patent medicine for kidney trouble without knowing that such trouble exists, as is sometimes done, is both foolish and unhygienic. [212]

Alcoholic Beverages and the Elimination of Waste.—Causing as it does such serious diseases as cirrhosis of the liver and Bright's disease of the kidneys (footnote, page 210), alcohol will greatly interfere in this way with the elimination of waste. There is also evidence to the effect that it interferes with waste elimination before the stage is reached of causing disease of these organs. Researches have shown that alcohol increases the amount of uric acid in the body and decreases the amount of urea found in the urine. The conclusion to be drawn is that alcohol interferes in some way with the change of the harmful uric acid into the comparatively harmless urea—an interference which in some instances results in great harm. It has also been shown that malted liquors, such as beer and ale, contain substances which, like the caffein of tea and coffee (page 167), are readily converted into uric acid.[76] Wines contain acids which may also act injuriously. The harm which such substances do is, of course, additional to that caused by the alcohol.

Summary.—As a result of the oxidations and other changes at the cells, substances are produced that can no longer serve a purpose in the body. They are of the nature of waste, and their continuous removal from the body is as necessary to the maintenance of life as the introduction of food and oxygen. The organs whose work it is to remove the waste, excepting the lungs, are glands; and the material which they remove are of the nature of secretions. From the cells, the waste passes through the lymph in the blood. From the blood it is separated by the excretory organs and passed to the exterior of the body.

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[76] Hall, *The Purin Bodies*.

Exercises.—1. What general purposes are served by the glands in the body?

[213] 2. What are the parts common to all glands? What purpose is served by each of these parts?

3. How do tubular glands differ in structure from saccular glands? What is a racemose gland? Why so called?

4. Describe the nature of the secretory process.

5. What conditions render necessary the formation of waste materials in the body? Why must these be removed?

6. How do the waste materials get from the cells to the organs of excretion?

7. Show by a drawing the connections of the kidneys with the large blood vessels and the bladder. Name parts of drawing.

8. In what do the uriniferous tubes have their beginning? In what do they terminate? With what are they lined?

9. Why should the blood pass through two sets of capillaries in the kidneys?

10. Bright's disease of the kidneys affects the uriniferous tubes and interferes with their work. What impurity is then left in the blood?

11. Trace water and salts from the Malpighian capsules to the bladder, naming parts through which they pass.

12. Trace carbon dioxide from the cells to the outside atmosphere.

13. How does the quantity of material introduced into the body compare with that which is removed by the organs of excretion?

14. Name two ways of lessening the work of the kidneys.

15. Why is the drinking of plenty of pure water a healthful practice?

PRACTICAL WORK

To suggest the Double Work of Glands.—Prepare a simple filter by fitting a piece of porous paper into a glass funnel.

Through this pass pure water and also water having salt dissolved in it and containing some sediment, as sand. The water and the dissolved salt pass through, while the sediment remains on the filter. Now substitute a fresh piece of paper in the funnel and drop on its surface a little solid coloring matter, such as cochineal. Again pass the liquid through the funnel. This time it comes through colored, the color being added by the filter. Compare the filter and materials filtered to the gland and the materials concerned in secretion (blood, the liquid secreted, substances added by the gland, etc.).

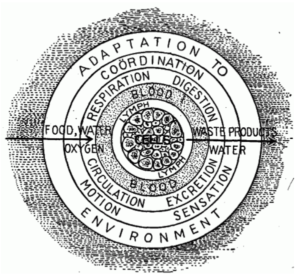

Fig. 92—**The physiological scheme.** Diagram suggesting the essential relation of the bodily activities. See Summary of Part I, page 215, and Summary of Part II, page 413.

[215]

SUMMARY OF PART I

The body is an organization of different kinds of cells; it grows through the growth and reproduction of these cells; and its life as a whole is maintained by providing such conditions as will enable the cells to keep alive. Of chief importance in the work of the body is a nutrient fluid which supplies the cells with food and oxygen and relieves them of waste. A moving portion of this fluid, called the blood, serves as a transporting agent, while another portion, called the lymph, passes the materials between the blood and the cells. Through their effects upon the blood and the lymph, the organs of circulation, respiration, digestion, and excretion minister in different ways to the cells, and aid in the maintenance of life. By their combined action two distinct movements are kept up in the body, as follows:

1. An *inward* movement which carries materials from the outside of the body toward the cells.

2. An *outward* movement which carries materials from the cells to the outside of the body.

Passing *inward* are the oxygen and food materials *in a condition to unite with each other* and thereby change their potential into kinetic energy. Passing *outward* are the oxygen and the elements that formed the food materials *after having united* at the cells and liberated their energy.

As a final and all-important result, there is kept up a *continuous series of chemical changes* in the cells. These liberate the energy, provide special substances needed by the cells, and preserve the life of the body (Fig. 92).

In the chapters which follow, we are to consider the problem of adjusting the body to and of bringing it into proper relations with its surroundings.

PART II: MOTION, COORDINATION, AND SENSATION

CHAPTER XIV - THE SKELETON

One necessary means of establishing proper relations between the body and its surroundings is *motion*.[77] Not only can the body move itself from place to place, but it is able to move surrounding objects as well. In the production of motion three important systems are employed—the muscular system, the nervous system, and a system of mechanical devices which are found mainly in the skeleton. The muscular system supplies the energy for operating the mechanical devices, while the nervous system controls the movements.[78] Although the skeleton serves other purposes, such as giving shape to the body and protecting

[77] Review "Main Physiological Problems," page 21.

[78] In the production of motion in the body, as well as in the production of any kind of *purposeful* motion outside of the body, three conditions must be fulfilled. There is required, in the first place, a mechanical device or machine which is so constructed as to produce a certain kind of motion. In the second place, energy is needed to operate this device. And, finally, there must be some controlling force, by means of which the motion is made to accomplish definite results. The driving of a horse hitched to a wagon will illustrate these conditions. The wagon is the mechanical device, the horse furnishes the

certain organs, its main use is that of an aid in the production of motion.

[217] **Skeleton Tissues.**—The tissues employed in the construction of the skeleton are the osseous, the cartilaginous, and the connective tissues. These are known as the supporting tissues of the body. They form the bones, supply the elastic pads at the ends of the bones, and furnish strong bands, called ligaments, for fastening the bones together. The skeleton forms about 16 per cent of the weight of the body. Its tissues, being of a more durable nature than the rest of the body, do not so readily decay. Especially is this true of the osseous tissue, which may be preserved indefinitely, after removal from the body, by simply keeping it dry.

The Bones.—The separate units, or parts, of which the skeleton is constructed are called bones. They are the hard structures that can be felt in all parts of the body, and they comprise nearly the entire amount of material found in the prepared skeleton. As usually estimated, the bones are 208 in number. They vary greatly in size and shape in different parts of the body.

Composition and Properties of Bones.—The most noticeable and important properties of the bones are those of hardness, stiffness, and toughness. Upon these properties the uses of the bones depend. These properties may, in turn, be shown to depend upon the presence in osseous tissue of two essentially different kinds of substance, known as the *animal matter* and the *mineral matter*. If a bone is soaked in an acid, the mineral matter is dissolved out, and as a result it loses its properties of hardness and stiffness. (See Practical Work.) This is because the mineral matter supplies these properties, being composed of substances which are hard and closely resemble certain kinds of rock. The

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energy, and the driver supplies the controlling force. In this, as in most cases, the machinery, the source of energy, and the controlling force are disconnected except when at work; but in the body all three occur together in the same structure.

chief materials forming the mineral matter are calcium phosphate and calcium carbonate.

On the other hand, burning a bone destroys the animal matter. [218] When this is done the bone loses its toughness, and becomes quite brittle. The property of toughness is, therefore, supplied by the animal matter. This consists mainly of a substance called *ossein*, which may be dissolved out of the bones by boiling them. Separated from the bones it is known as *gelatine*. The blood vessels and nerves in the bones, and the protoplasm of the bone cells, are also counted in with the animal matter.

If a dry bone from a full-grown, but not old, animal be weighed before and after being burned, it is found to lose about one third of its weight. From this we may conclude that about one third of the bone by weight is animal matter and two thirds is mineral matter. This proportion, however, varies with age, the mineral matter increasing with advance of years.

Gross Structure of Bones.—The gross structure of the bones is best learned by studying both dry and fresh specimens. (See Practical Work.) The ends of the bones are capped by a layer of smooth, elastic cartilage, while all the remaining surface is covered by a rather dense sheath of connective tissue, called the *periosteum*. Usually the central part of the long bones is hollow, [219] being filled with a fatty substance known as the *yellow marrow*. Around the marrow cavity the bone is very dense and compact, but most of the material forming the ends is porous and spongy. These materials are usually referred to as the *compact substance* and the *cancellous*, or *spongy, substance* of the bones (Fig. 93).

The arrangement of the compact and spongy substance varies with the different bones. In the short bones (wrist and ankle bones, vertebræ, etc.) and also in the flat bones (skull bones, ribs, shoulder blades, etc.) there is no cavity for the yellow marrow, all of the interior space being filled with the spongy substance.

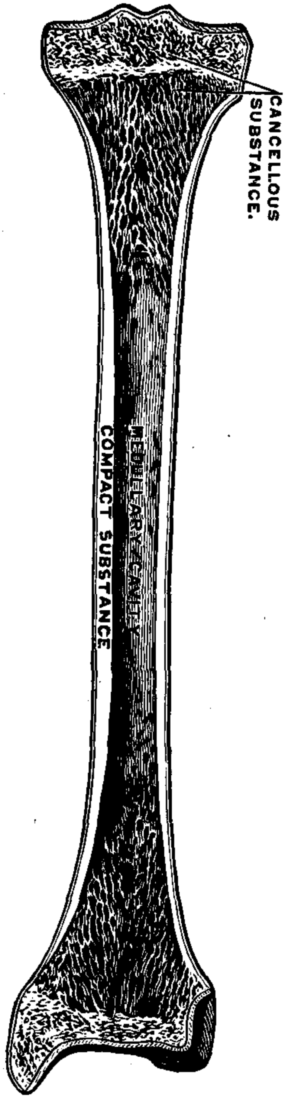

Fig. 93—**Section of a long bone** (*tibia*), showing the gross structure.

The *red marrow*, relations of which to the red corpuscles of the blood have already been noted (page 27), occupies the minute spaces in the spongy substance.

Minute Structure of Bone.—A microscopic examination of a thin slice of bone taken from the compact substance shows this to be porous as well as the spongy substance. Two kinds of small channels are found running through it in different directions, known as the Haversian canals and the canaliculi (Fig. 94). These serve the general purpose of distributing nourishment through the bone. The *Haversian canals* are larger than the [220] canaliculi and contain small nerves and blood vessels, chiefly capillaries (Fig. 95). They extend lengthwise through the bone. The *canaliculi* are channels for conveying lymph. They pass out from the Haversian canals at right angles, going to all portions of the compact substance except a thin layer at the surface. In the surface layer of the bone the canaliculi are in communication with the periosteum.

The Bone Cells.—Surrounding the Haversian canals are thin layers of bone substance called the *laminæ*, and within these are great numbers of irregular bodies, known as the *lacunæ*. The walls of the lacunæ are hard and dense, but within each is an open space. In this lies a flattened body, having a nucleus, which is recognized as the *bone cell*, or the bone corpuscle (Fig. 96). It appears to be the work of the bone cells to deposit mineral matter in the walls surrounding them and in this way to supply the properties of hardness and stiffness to the bones. The canaliculi connect with the lacunæ in all parts of the bone, causing them to appear under the microscope like so many burs fastened together by their projecting spines (Fig. 94).

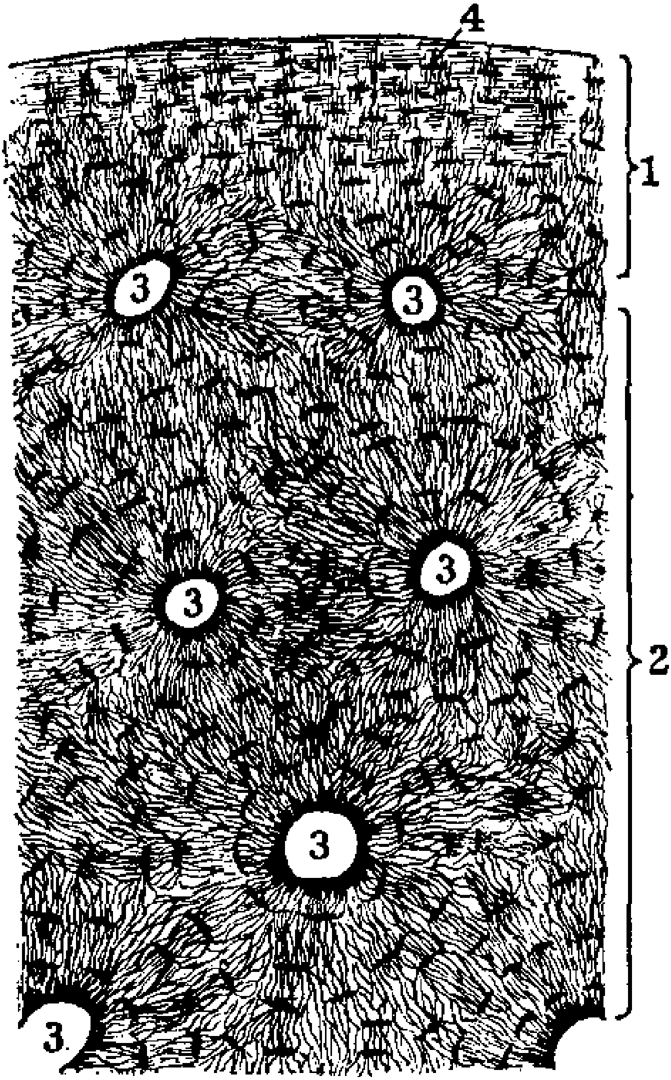

Fig. 94—**Cross section of bone showing minute structure.** Magnified. 1. Surface layer of bone. 2. Deeper portion. 3. Haversian canals from which pass the canaliculi. 4. A lacuna. Observe arrangement of lacunæ at surface and in deeper portion.

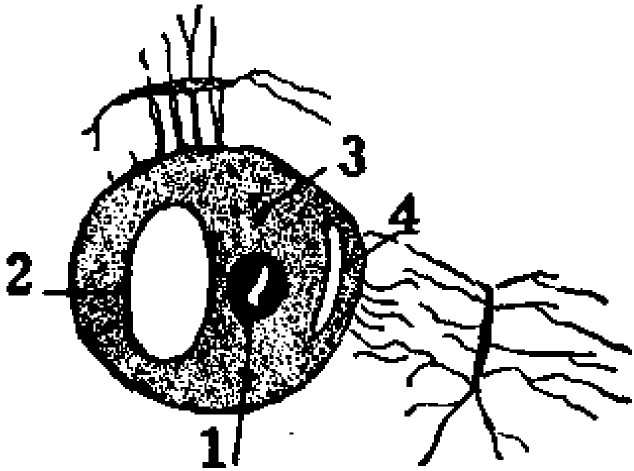

Fig. 95—**Section showing Haversian canal and contents**, highly magnified (after Schäfer). 1. Arterial capillary. 2. Venous capillary. 3. Nerve fibers. 4. Lymph vessel.

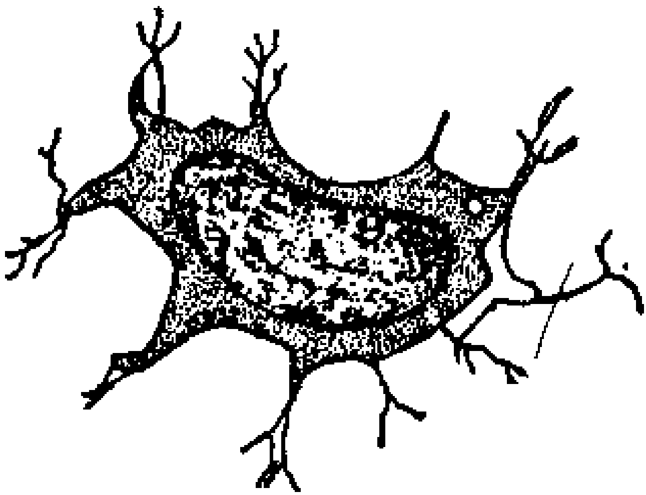

Fig. 96—**Bone cell** removed from the lacuna and very highly magnified. (From Quain's *Anatomy*.)

How the Bone Cells are Nourished.—The bone cells, like all the other cells of the body, are nourished by the lymph that escapes from the blood. This passes through the canaliculi to the cells in the different parts of the bone, as follows:

1. The cells in the surface layer of the bone receive lymph from the capillaries in the periosteum.[79] It gets to them through the short canaliculi that run out to the surface. [221]

2. The cells within the interior of the bone receive their nourishment from the small blood vessels in the Haversian canals. Lymph from these vessels is conveyed to the cells through the canaliculi that connect with the Haversian canals.

Plan and Purpose of the Skeleton.—The framework of the body is such as to adapt it to a *movable* structure. Obviously the different parts of the body cannot be secured to a foundation, as are those of a stationary building, but must be arranged after a plan that is conducive to motion. A moving structure, as a wagon or a bicycle, has within it some strong central part to which the remainder is joined. The same is true of the skeleton. That part to which the others are attached is a long, bony axis, known as the *spinal column*. Certain parts, as the ribs and the skull, are attached directly to the spinal column, while others are attached indirectly to it. The arrangement of all the parts is such that the spinal column is made the central, cohering portion of the skeleton and also of the whole body.

Besides the general arrangement of the parts of the skeleton, there is such a grouping of the bones in each of its main divisions as will enable them to serve definite purposes. In most places they form mechanical devices for supplying special movements, and in certain places they provide for the support or protection of

[79] The dependence of the outer layers of bone cells upon the periosteum for nourishment causes a destruction of this membrane to affect seriously the bone beneath, producing in many instances a decay of the bone substance.

important organs. In most cases there is a definite combination of different bones, forming what is called the bone group.

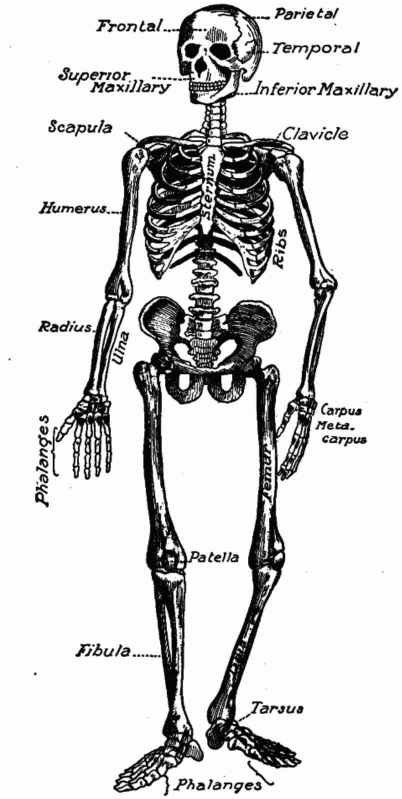

Fig. 97—The human skeleton.

[223] **Bone Groups.**—On account of the close relation between the bones of the same group, they cannot profitably be studied as individual bones, but each must be considered as a part of the group to which it belongs. By first making out the relation of

a given bone to its group, its value to the whole body can be determined. The most important of the groups of bones are as follows:

1. *The Spinal Column.*—This group consists of twenty-four similarly shaped bones, placed one above the other, called the *vertebræ*, and two bones found below the vertebræ, known as the sacrum and the coccyx (Fig. 98). These twenty-six bones supply the central axis of the body, support the head and upper extremities, and inclose and protect the spinal cord.

The upper seven vertebræ form the neck and are called the *cervical* vertebræ. They are smaller and have greater freedom of motion than the others. The first and second cervical vertebræ, known as the *atlas* and the *axis*, are specially modified to form a support for the head and provide for its movements. The head rests upon the atlas, forming with it a hinge joint (used in nodding to indicate "yes"); and the atlas turns upon an upward projection of the axis forming a pivot joint (used in shaking the head to indicate "no").

The next twelve vertebræ, in order below the cervical, are [224]
known as the *thoracic* vertebræ. They form the back part of the framework of the thorax and have little freedom of motion. The five vertebræ below the thoracic are known as the *lumbar* vertebræ. These bones are large and strong and admit of considerable motion. Below the last lumbar vertebra is a wedge-shaped bone which has the appearance of five vertebræ fused together. This bone, known as the *sacrum*, connects with the large bones which form the pelvic girdle. Attached to the lower end of the sacrum is a group of from two to four small vertebræ, more or less fused, called the *coccyx*.

The Joining of the Vertebræ.—A typical vertebra consists

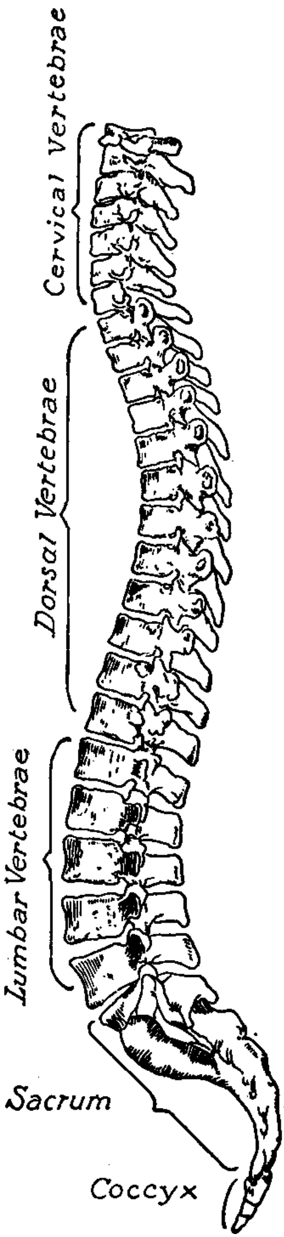

Fig. 98—The spinal column.

of a heavy, disk-shaped portion in front, called the *body*, which is connected with a ring-like portion behind, called the *neural arch*. The body and the neural arch together encircle a round opening which is a part of the canal that contains the spinal cord (Fig. 99). From the neural arch are seven bony projections, or processes, three of which serve for the attachment of muscles and ligaments, while the other four, two above and two below, are for the interlocking of the vertebræ with each other. The separate vertebræ are joined together in the spinal column, as follows:

a. Between the bodies of adjacent vertebræ are disks of elastic cartilage. Each disk is about one fourth of an inch thick and is grown tight onto the face of the vertebra above and also onto the [225]
face of the vertebra below. By means of these disks a very close connection is secured between the vertebræ on the front side of the column.

b. On the back of the column, the downward projections from the neural arch of each vertebra above fit into depressions found in the neural arch of the vertebra below. This *interlocking* of the vertebræ, which is most marked in the lumbar region, strengthens greatly the back portion of the column.

c. To further secure one bone upon the other, numerous ligaments pass from vertebra to vertebra on all sides of the column.

2. *The Skull.*—The skull is formed by the close union of twenty-two irregular bones. These fall naturally into two subgroups—the cranium and the face (Fig. 100). The *cranium* consists of eight thin, curved bones which inclose the space, called the *cranial cavity*, that holds the brain. The *face group*, consisting of fourteen bones, provides cavities and supports for the different organs of the face, and supplies a movable part (the inferior maxillary) which, with the bones above (superior maxillary), forms the machine for masticating the food.

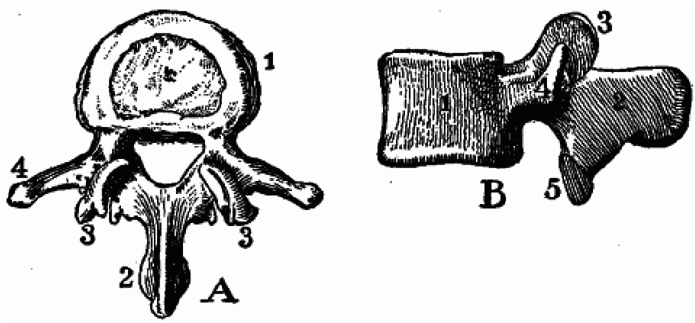

Fig. 99—**Two views of a lumbar vertebra.** *A.* From above. *B.* From the side. 1. Body. 2, 3, 4, 5. Projections from the neural arch.

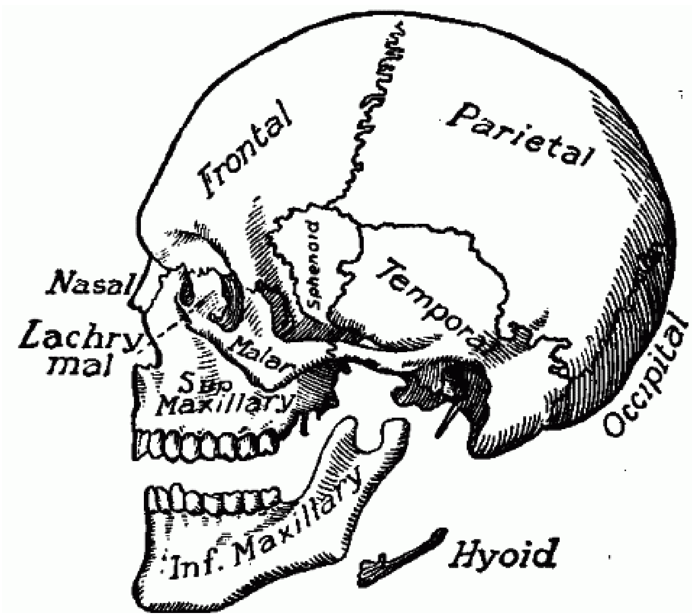

Fig. 100—**The skull (Huxley).** The illustration shows most of the bones of the skull.

3. *The Thorax.*—This group contains twenty-four bones of similar form, called *ribs*, and a straight flat bone, called the *sternum*, or breastbone (Fig. 101). The ribs connect with the spinal column behind, and all but the two lowest ones connect with the sternum in front, and, by so doing, inclose the thoracic cavity. As already stated (page 85), the bones of the thorax form [226] a mechanical device, or machine, for breathing. The ribs are so arranged that the volume of the thorax is increased by elevating them and diminished by depressing them, enabling the air to be forced into and out of the lungs.

4. *The Shoulder and Pelvic Girdles.*—These groups form two bony supports—one at the upper and the other at the lower portion of the trunk—which serve for the attachment of the arms and legs (Fig. 101). The *shoulder girdle* is formed by four bones—two clavicles, or collar bones, and two scapulæ, or shoulder blades. The clavicle on either side connects with the upper end of the sternum and serves as a *brace* for the shoulder, while the scapula forms a socket for the humerus (the large bone of the arm) and supplies many places for the attachment of muscles.

The *pelvic girdle* consists of two large bones of irregular shape, called the *innominate* bones. They connect behind with the sacrum and in front they connect, through a small pad of cartilage, with each other. On the inside of the girdle is a smooth, basin-shaped support for the contents of the abdomen, but on the outside the bones are rough and irregular and provide [227] many places for the attachment of muscles and ligaments. Each innominate bone has a deep, round socket into which the end of the femur (the long bone of the leg) accurately fits.

5. *The Arm and Hand Groups.*—A long bone, the *humerus*, connects the arm with the shoulder and gives form to the upper arm. In the forearm are two bones, the *radius* and the *ulna*, which connect at one end with the humerus and at the other with the

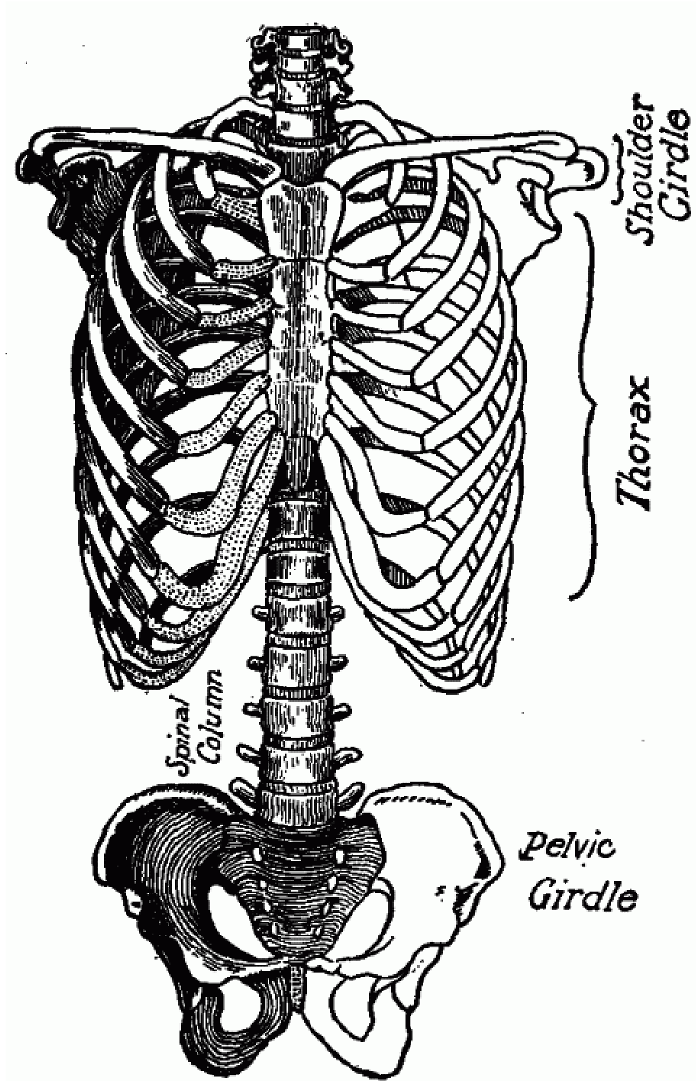

Fig. 101—**Bone groups of trunk.**

bones of the wrist (Fig. 102).

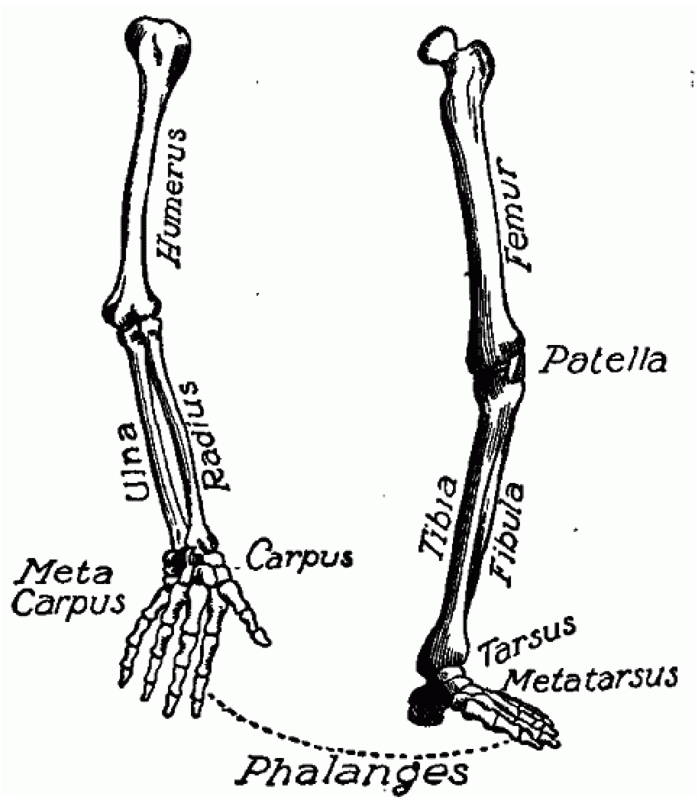

Fig. 102—**Bone groups of arm and leg.**

A group of eight small, round bones is found in the wrist, known as the *carpal* bones. These are arranged in two rows and are movable upon one another. Five straight bones, the *metacarpals*, connect with the wrist bones and form the framework for the palm of the hand. Attached to the metacarpals are the bones of the fingers and thumb. These form an interesting group of fourteen bones, called the *phalanges of the fingers* (Fig. 102).

The bones of the hand provide a mechanical device, or machine, for grasping, and the arm serves as a device for moving this grasping machine from place to place. The work of the arm, in this respect, is not unlike that of a revolving crane upon the end of which is a grab-hook. The hand without the arm to move it about would be of little use.

[228] 6. *The Leg and Foot Groups.*—These correspond in form and arrangement to the bones of the arm and hand. Since, however, the leg and foot are used for purposes different from those of the arm and hand, certain differences in structure are to be found. The *patella*, or kneepan, has no corresponding bone in the arm; and the *carpus*, or ankle, which corresponds to the wrist, contains seven instead of eight bones. The bones of the foot and toes are the same in number as those of the hand and fingers, but they differ greatly in size and form and have less freedom of motion. The *femur*, which gives form to the thigh, is the longest bone of the body. The *tibia*, or shin bone, and the *fibula*, the slender bone by its side, give form to the lower part of the leg (Fig. 102).

The legs are mechanical devices (walking machines) for moving the body from place to place. The feet serve both as supports for the body and as levers for pushing the body forward. By their attachment to the legs they may be placed in all necessary positions for supporting and moving the body.

The different bone groups are shown in Fig. 97 and named in Table IV.

Adaptation to Special Needs.—When any single bone is studied in its relation to the other members of the group to which it belongs or with particular reference to its purpose in the body, its adaptation to some special place or use is at once apparent. Each bone serves some special purpose, and to this purpose it is adapted by its form and structure. Long bones, like the humerus and femur, are suited to giving strength, form, and stiffness to certain parts, while irregular bones, like the vertebræ and the pelvic bones, are fitted for supporting and protecting organs. Others, like the wrist and ear bones, make possible a peculiar kind of motion, and still others, like the ribs, are adapted to more than one purpose. The vast differences in shape, size, structure, and surface among the various bones are but the conditions that adapt them to particular forms of service in the body.

TABLE IV - The Principal Bones and their Grouping in the Body [229]

I. AXIAL SKELETON

A. *Skull*, 28.

1. Cranium, 8.

a. Frontal, forehead 1
b. Parietal 2
c. Temporal, temple 2
d. Occipital 1
e. Sphenoid 1
f. Ethmoid 1

2. Face, 14.

a. Inferior maxillary 1
b. Superior maxillary 2
c. Palatine, palate 2
d. Nasal bones 2
e. Vomer 1
f. Inferior turbinated 2
g. Lachrymal 2
h. Malar, cheek bones 2

3. Bones of the Ears, 6.

a. Malleus 2
b. Incus 2

c. Stapes 2

B. *Spinal Column*, 26.

1. Cervical, or neck, vertebræ 7
2. Dorsal, or thoracic, vertebræ 12
3. Lumbar vertebræ 5
4. Sacrum 1
5. Coccyx 1

C. *Thorax*, 25.

1. Ribs 24
2. Sternum 1

D. *Hyoid*, 1 (at base of tongue).

II. APPENDICULAR SKELETON

A. *Shoulder girdle* 4.

1. Clavicle, collarbone. 2
2. Scapula, shoulder blade 2

B. *Upper extremities*, 60.

1. Humerus 2
2. Radius 2
3. Ulna 2
4. Carpal, wrist bones 16
5. Metacarpal 10
6. Phalanges of fingers 28

C. *Pelvic girdle*, 2.

1. Osinnominatum 2

D. *Lower extremities*, 60.

1. Femur, thigh bone 2
2. Tibia, shin bone 2
3. Fibula 2
4. Patella, kneepan 2

5. Tarsal, ankle bones 14
6. Metatarsal, instep bones 10
7. Phalanges of toes 28

[230]

ARTICULATIONS

Any place in the body where two or more bones meet is called an articulation, or joint. At the place of meeting the bones are firmly attached to each other, thereby securing the necessary coherence of the skeleton. The large number of bones, and consequently of articulations, are necessary for the different movements of the body and also on account of the manner in which the skeleton develops, or grows. Articulations are classed with reference to their freedom of motion, as *movable*, *slightly movable*, and *immovable* articulations.

Most of the *immovable* articulations are found in the skull. Here irregular, tooth-like projections from the different bones enable them to interlock with one another, while they are held firmly together by a thin layer of connective tissue. The wavy lines formed by articulations of this kind are called *sutures* (Fig. 100).

The best examples of joints that are *slightly*, but not freely, *movable* are found in the front of the spinal column. The cartilaginous pads between the vertebræ permit, by their elasticity, of a slight bending of the column in different directions. These movements are caused, not by one bone gliding over another, but by compressions and extensions of the cartilage. Between the vertebræ in the back of the spinal column, however, there is a slight movement of the bone surfaces upon one another.

Structure of the Movable Joints.—By far the most numerous and important of the joints are those that are freely movable. Such joints are strongly constructed and endure great strain without dislocation, and yet their parts move over each other easily and without friction. The ends of the bones are usually enlarged [231] and have specially formed projections or depressions which fit into corresponding depressions or elevations on the bones with which they articulate. In addition to this the articular surfaces are quite smooth and dense, having no Haversian canals, and they are covered with a layer of cartilage. Strong ligaments pass from one bone to the other to hold each in its place (*A*, Fig. 103). Some of these consist simply of bands, connecting the joint on its different sides, while others form continuous sheaths around the joint.

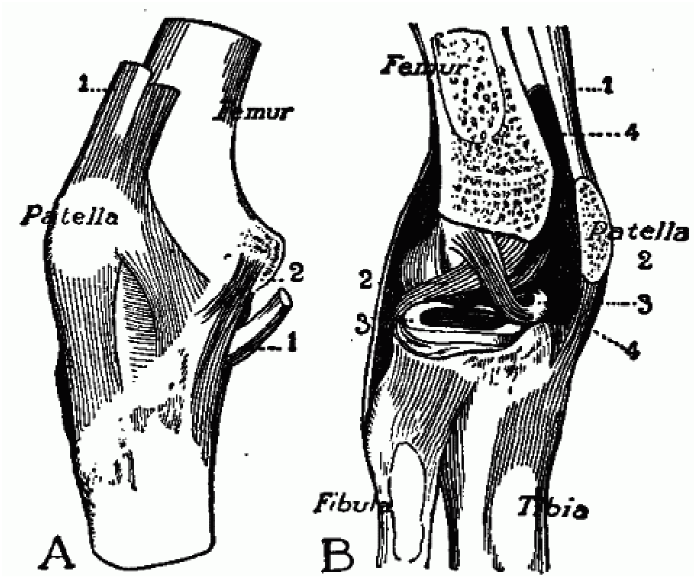

Fig. 103—**Outside and inside view of knee joint.** 1. Tendons. 2. Ligaments. 3. Cartilage. 4. Space containing synovial fluid. This space is lined, except upon the articular surfaces, by the synovial membrane.

The interior of the joint, except where the bone surfaces rub upon each other, is covered with a serous lining, called the *synovial membrane* (*B*, Fig. 103). This secretes a thick, viscid liquid, the *synovial fluid*, which prevents friction. The synovial membrane does not cover the ends of the bones, but passes around the joint and connects with the bones at their edges so as to form a closed sac in which the fluid is retained.

Kinds of Movable Joints.—The different kinds of movable joints are the ball and socket joint, the hinge joint, the pivot joint, the condyloid joint, and the gliding joint. These are constructed and admit of motion, as follows:

1. In the *ball and socket* joint the ball-shaped end of one bone fits into a cup-shaped cavity in another bone, called the socket. The best examples of such joints are found at the hips [232]
and shoulders. The ball and socket joint admits of motion in all directions.

2. In the *hinge* joint the bones are grooved and fit together after the manner of a hinge. Hinge joints are found at the elbows and knees and also in the fingers. The hinge joint gives motion in but two directions—forward and backward.

3. A *pivot* joint is formed by the fitting of a pivot-like projection of one bone into a ring-like receptacle of a second bone, so that one, or the other, is free to turn. A good example of the pivot joint is found at the elbow, where the radius turns upon the humerus. Another example is the articulation of the atlas with the axis vertebra as already noted. The pivot joint admits of motion around an axis.

4. The *condyloid* joint is formed by the fitting of the ovoid (egg-shaped) end of one bone into an elliptical cavity of a second bone. Examples of condyloid joints are found at the knuckles and where the wrist bones articulate with the radius and ulna. They move easily in two directions, like hinge joints, and slightly in other directions.

5. *Gliding* joints are formed by the articulation of plain

(almost flat) surfaces. Examples of gliding joints are found in the articulations between the bones of the wrist and those of the ankle. They are the simplest of the movable joints and are formed by one bone gliding, or slipping, upon the surface of another.

The Machinery of the Body.—A machine is a contrivance for directing energy in doing work. A sewing machine, for example, so directs the energy of the foot that it is made to sew. Through its construction the machine is able to produce just that form of motion needed for its work, and no other forms, so that energy is not wasted in the production of useless motion. The places
[233] in machines where parts rub or turn upon each other are called *bearings*, and extra precautions are taken in the construction and care of the bearings to prevent friction.

The body cannot properly be compared to any single machine, but must be looked upon as a complex organization which employs a number of different kinds of machines in carrying on its work. The majority of these machines are found in the skeleton. The bones are the parts that are moved, and the joints serve as bearings. Connected with the bones are the muscles that supply energy, and attached to the muscles are the nerves that control the motion. Other parts also are required for rendering the machines of the body effective in doing work. These are supplied by the tissues connected with the bones and the muscles.

HYGIENE OF THE SKELETON

Of chief concern in the hygiene of the skeleton is the proper *adjustment* of its parts. The efficiency of any of the body machines is impaired by lack of proper adjustment. Not only this, but because of the fact that the skeleton forms the groundwork of the whole body—muscles, blood vessels, nerves, everything in fact, being arranged with reference to it—any lack of proper adjustment of the bones interferes generally with the arrangement and work of tissues and organs. The displaced bones may even compress blood vessels and nerves and interfere, in this way, with the nourishment and control of organs remote from the places where the displacements occur. For these reasons the proper adjustment of the different parts of the skeleton supplies one of the essential conditions for preserving the health.

Hygienic Importance of the Spinal Column.—What has been said about the adjustment of the skeleton in general applies with particular force to the spinal column. The spinal column serves both as the central axis of the body and as the container of the spinal cord. Thirty-one pairs of nerves pass between the [234] vertebræ to connect the spinal cord with different parts of the body, and two important arteries (the vertebral) pass through a series of small openings in the bones of the neck to reach the brain. Unnatural curves of the spine throw different parts of the body out of their natural positions, diminish the thoracic and abdominal cavities, and, according to the belief of certain physicians, compress the nerves that pass from the cord to other parts of the body. Slightly misplaced vertebræ in the neck, by compressing the vertebral arteries, may also interfere with the supply of blood

How the Skeleton becomes Deformed—We are accustomed to look upon the skeleton as a rigid framework which can get out of its natural form only through severe strain or by violence. This view is far from being correct. On account of their necessary freedom of motion, the bones, especially those of the spinal column, are easily slipped from their normal positions; and where improper attitudes are frequently assumed, or continued [235] through long periods of time, the skeleton gradually becomes deformed (Fig. 104). For example, the habit of always sleeping on the same side with a high pillow may develop a bad crook in

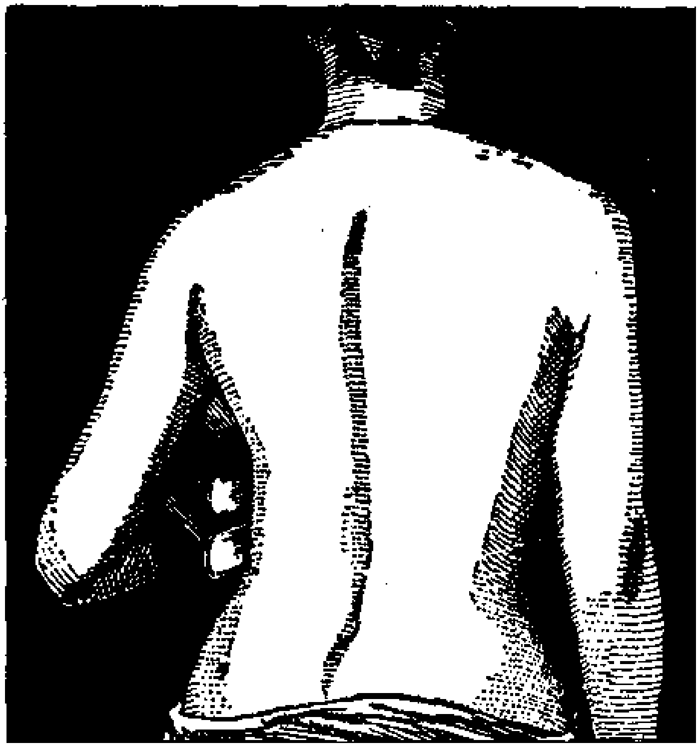

Fig. 104—A tendency toward spinal curvature (after Mosher)

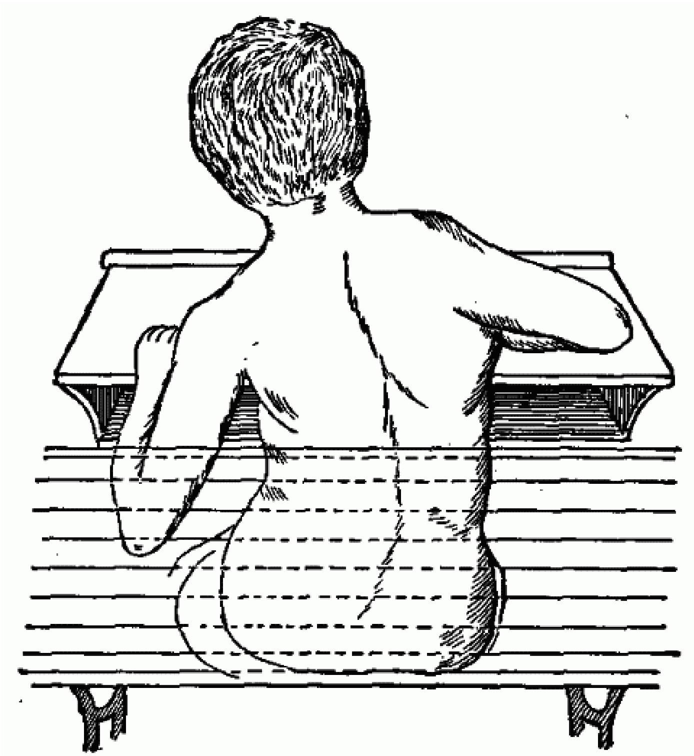

Fig. 105—Effect on spinal column of improper position in writing. (From Pyle's *Personal Hygiene.*)

the neck; and the ugly curves, assumed so frequently in writing [80] (Fig. 105), and also in standing, when the weight is shifted too much on one foot, may become permanent. Then the habit of reclining in a chair with the hips resting on the front of the seat often deforms the back and causes a drooping of the shoulders. In fact, slight displacements of the vertebræ come about so easily *through incorrect positions*, that they may almost be said to "occur of themselves" where active measures are not taken to preserve the natural form of the body. The very few people who have perfectly formed bodies show to what an extent has been overlooked an essential law of hygiene.

Prevention of Skeletal Deformities.—Those deformities of the skeleton that are acquired through improper positions are prevented by giving sufficient attention to the positions assumed in sitting, standing, and sleeping, and also to the posture in various kinds of work. In sitting the trunk should be erect and the hips should touch the back of the chair. One should not lounge in the ordinary chair. In standing the body should be erect, the shoulders back and down, the chest pushed slightly up and forward, and the chin slightly depressed, while the weight should, as a rule, rest about equally on the two feet. The habit of
[236] leaning against some object when standing (the pupil in reciting often leans on his desk) should be avoided. In sleeping the pillow should be of the right thickness to support the head on a level with the spinal column and should not be too soft. If one sleeps on his back, no pillow is required. It is best not to acquire the habit of sleeping always on the same side.

Where one is compelled by his work to assume harmful

[80] It has been claimed that the introduction of vertical writing has reduced the number of cases of spinal curvature originating in the schoolroom, and statistics appear to prove the claim. It is shown, on the other hand, that unnatural positions also are unnecessary in the slanting system of writing, and that in either system the pupil who is permitted to do so is liable to assume an improper position.

positions, these should be corrected by proper exercises, and by cultivating opposing positions during the leisure hours. Much is to be accomplished through those forms of physical exercise which develop the muscles whose work it is to keep the body in an upright position.

School Furniture.—It has long been observed that school children are more subject to curvature of the spine and other deformities of the skeleton than the children who do not attend school. While this is due largely to faulty positions assumed by the pupils at their work, it has been suggested that the school furniture may be in part to blame for these positions. Investigations of this problem have shown that most of the school desks and seats in use in our public schools are unhygienically constructed, in that they *force* pupils into unnatural positions. School seats should support the pupil in a natural position, both in the use of his books and in writing, and there are many arguments in favor of the so-called "adjustable" school furniture. Fig. 106 shows the seat and desk designed by the Boston, Mass., Schoolhouse Commission after much study and experimenting and used in the Boston schools. This furniture, which provides a seat adjustable for height, having a back rest also adjustable for height, and a desk which is likewise provided with a vertical adjustment, supplies all essential hygienic requirements. It is to be hoped that school furniture of this character may in the near future come into general use.

Correction of Skeletal Deformities.—It is, of course, easier [237]
to prevent deformities of the skeleton by giving attention to proper positions, than to correct them after they have occurred. It should also be noted that severe deformities cannot be corrected by the individual for himself, but these must come under the treatment of specialists in this line of medical work. In mild cases of spinal curvature, drooping of the head, and round

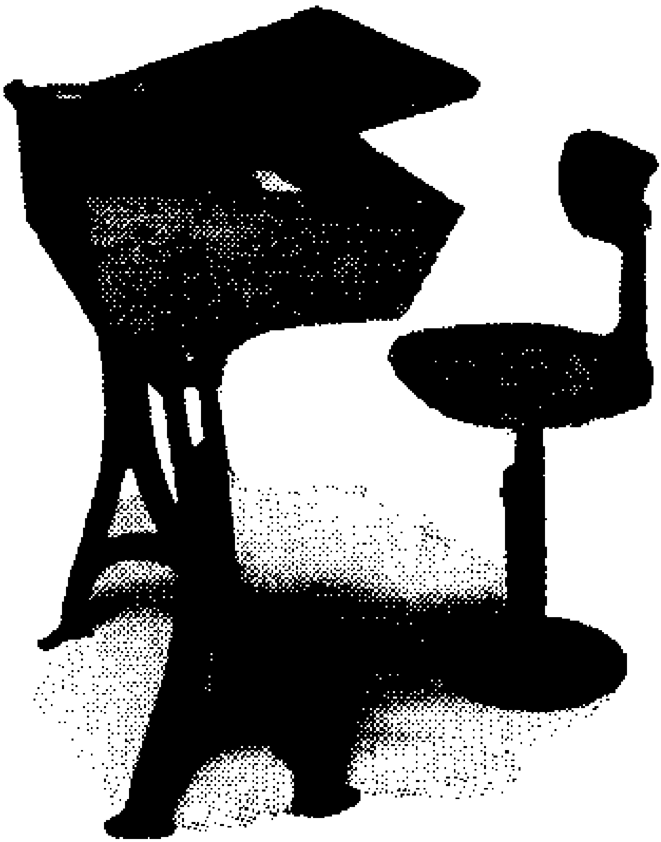

Fig. 106—Adjustable seat and desk used in schools of Boston, Mass.

shoulders, the individual *can* benefit his condition. By working to "substitute a correct attitude for the faulty one,"[81] he can by persistence bring about marked improvements. It is better, however, to have the advice and aid of a physical director, where this is possible. It should also be borne in mind that the correction of skeletal deformities requires effort through a long period of time, especially where the deformities are pronounced; and one lacking the will power to persist will not secure all the results which he seeks.

"Setting Up" Exercises.—The splendid carriage of students from military schools shows what may be accomplished in securing erectness of form where proper attention is given to this matter. The military student gets his fine form partly through his exercises in handling arms, but mainly through his so-called "setting up" drill. As a suggestion to one desiring to improve the form of his body, a modification of the usual "setting up" drill is here given:

1. Standing erect, with the heels together, the feet at an angle of 45°, and hands at the sides, bring the arms to a horizontal position in front, little fingers touching and nails down. From this position raise the hands straight over the head, bringing the palms gradually together. Then with a backward sweeping movement, return the hands again to the sides. Repeat several times.

2. With the feet as in the above exercise, bring the hands and the arms to a level with the shoulders, palms down, elbows bent, middle fingers of the two hands touching, and the extended thumbs touching the chest. Keeping the palms down and the arms on a level with the shoulders, extend the hands as far [238] sideward and backward as possible, returning each time to the first position. As the hands move out, inhale deeply (through the nose), and as they are brought back, exhale quickly (through the mouth). Repeat several times.

[81] Lovett, *Lateral Curvature of the Spine and Round Shoulders*.

3. With the arms at the sides and the feet side by side and touching, bring the hands in a circular movement to a vertical position over the head, and lock the thumbs. Keeping the knees straight and the thumbs locked, bend forward, letting the hands touch the ground if possible, and then bring the body and hands again to the vertical position. Then by a backward sweeping movement, return the hands again to the sides. Repeat.

While these exercises may be practiced whenever convenient, it is best to set apart some special time each day for them, as on retiring at night or on rising in the morning.

Hygienic Footwear.—A necessary aid to erectness of position in standing and walking is a properly fitting shoe. Heels that are too high tilt the body unnaturally forward, and shoes that cause any kind of discomfort in walking lead to unnatural positions in order to protect the feet. Shoes should fit snugly, being neither too large nor too small. Many shoes, however, are unhygienically constructed, and no attempt should be made to wear them. Certainly is this true of styles that approach the "French heel" or the "toothpick toe" (Fig. 107). However, many styles of shoes are manufactured that are both hygienic and neat fitting. Rubber heels, on account of their elasticity, are to be preferred to those made of leather.

The Skeleton in Childhood and Old Age.—Certain peculiarities are found to exist in the bones of children and of old people which call for special care of the skeleton during the first and last periods of life. The bones of children are soft, lacking
[239] mineral matter, and are liable to become bent For this reason, children who are encouraged to walk at too early an age may bend the thigh bones, causing the too familiar "bow-legs." These bones may also be bent by having children sit on benches and chairs which are too high for the feet to reach the floor, and which do not provide supports for the feet. Wholesome food,

fresh air, sunlight, and exercise are also necessary to the proper development of the bones of children. Where these natural conditions are lacking, as in the crowded districts of cities, children often suffer from a disease known as "rickets," on account of which their bones are unnaturally soft and easily bent.

On account of the accumulation of mineral matter, the bones of elderly people become brittle and are easily broken, and from lack of vigor of the bone cells they heal slowly after such injuries occur. This makes the breaking of a bone by an aged person a serious matter. Old people should, as far as possible, avoid liabilities to falls, such as going rapidly up and down stairs, or walking on icy sidewalks, and should use the utmost care in getting about. In old people also the cartilage between the bones softens, increasing the liability of getting misshaped. Special attention, therefore, should be given to erectness of form, and to such exercises as tend to preserve the natural shape of the body.

Treatment of Fractures.—A fractured bone always requires the aid of a surgeon, and no time should be lost in securing his services. In the meantime the patient should be put in a comfortable position, and the broken limb supported above the rest of the body. Though the breaking of a bone is not, as a rule, a serious mishap, it is necessary that the very best skill be employed in setting it. Any failure to bring the ends of the broken bone into their normal relations permanently deforms the limb [240]
and interferes with its use.

Dislocations and Sprains.—Dislocations, if they be of the larger joints, also require the aid of the surgeon in their reduction and sometimes in their subsequent treatment. Simple dislocations of the finger joints, however, may be reduced by pulling the parts until the bones can be slipped into position.

A sprain, which is an overstrained condition of the ligaments surrounding a joint, frequently requires very careful treatment. When the sprain is at all serious, a physician should be called. Because of the limited supply of blood to the ligaments, they are slow to heal, and the temptation to use the joint before it is fully recovered is always great. Massage[82] judiciously applied to a sprained joint, by bringing about a more rapid change in the blood and the lymph, is beneficial both in relieving the pain, and in hastening recovery.

Summary.—The skeleton, or framework of the body, is a structure which is movable as a whole and in most of its parts. It preserves the form of the body, protects important organs, and supplies the mechanical devices, or machines, upon which the muscles act in the production of motion. The skeleton is adapted to its purposes through the number and properties of the bones, and through the cartilage and connective tissue associated with the bones. The places where the different bones connect one with another are known as joints, and most of these admit of motion. The preservation of the natural form of the skeleton is necessary, both for its proper action and for the health of the body.

[241] **Exercises.**—1. State the main purpose of the skeleton. What is the necessity for so many bones in its construction?

2. How may the per cent of animal and of mineral matter in a bone be determined?

3. What properties are given the bones by the animal matter? What by the mineral matter?

4. Locate the bone cells. What is their special function?

5. State the plan by which nourishment is supplied to the bone cells in different parts of the bone.

6. Give the uses of the periosteum.

7. State the purpose of the Haversian canals. Of the canaliculi.

8. Give functions of the spinal column.

9. Name the different materials used in the construction of a joint and the purpose served by each.

10. Name four mechanical devices, or machines, found in the skeleton and state the purpose served by each.

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[82] See "Hygiene of Muscles," Chapter XV.

11. Name one or more of the body machines not located in the skeleton.

12. Of what advantage is the peculiar shape of the lower jaw? Of the ribs? Of the bones of the pelvic girdle?

13. State the importance of preserving the natural form of the skeleton. How are unnatural curves produced in the spinal column?

14. How may slight deformities of the skeleton be corrected?

15. What different systems are employed in the body in the production of motion? What is the special function of each?

PRACTICAL WORK

To obtain clear ideas of the form and functions of the bones, a careful examination of a prepared and mounted skeleton is necessary. Many of the bones, however, may be located and their general form made out from the living body. Bones of the lower animals may also be studied to advantage.

Experiments to show the Composition of Bone.—1. Examine a slender bone, like that in a chicken's leg. Note that it resists bending and is difficult to break. Note also that it is elastic—that, when slightly bent, it will spring back.

2. Soak such a bone over night in a mixture of one part hydrochloric acid and four parts water. Then ascertain by bending, stretching, and twisting what properties the bone has [242]
lost. The acid has dissolved out the mineral matter.

3. Burn a small piece of bone in a clear gas flame, or on a bed of coals, until it ceases to blaze and turns a white color. Can the bone now be bent or twisted? What properties has it lost and what retained? What substance has been removed from the bone by burning?

Observation on the Gross Structure of Bone.—1. Procure a long, dry bone. (One that has lain out in the field until it has bleached will answer the purpose excellently.) Test its hardness, strength, and stiffness. Saw it in two a third of the distance from one end, and saw the shorter piece in two lengthwise. Compare the structure at different places. Find rough elevations on the outside for the attachment of muscles, and small openings into the bone for the entrance of blood vessels and nerves. Make drawings to represent the sections.

2. Procure a fresh bone from the butcher shop. Note the difference between it and the dry bone. Examine the materials surrounding the sides and covering the ends of the bone. Saw through the enlarged portion at the end and examine the red marrow. Saw through the middle of the bone and observe the yellow marrow.

To show the Minute Structure of the Bone.—Prepare a section of bone for microscopic study as follows: With a jeweler's saw cut as thin a slice as possible. Place this upon a good-sized whetstone, not having too much grit, and keeping it wet rub it under the finger, or a piece of leather, until it is thin enough to let the light shine through. The section may then be washed and examined with the microscope. If the specimen is to be preserved for future study, it may be mounted in the usual way, but with *hard* balsam. Prepare and study both transverse and longitudinal sections, making drawings. The sections should be prepared from bones that are thoroughly dry but which have not begun to decay.

To show the Structure of a Joint.—Procure from a butcher the joint of some small animal (hog or sheep). Cut it open and locate the cartilage, synovial membrane, and ligaments. Observe the shape and surface of the rubbing parts and the strength of the ligaments.

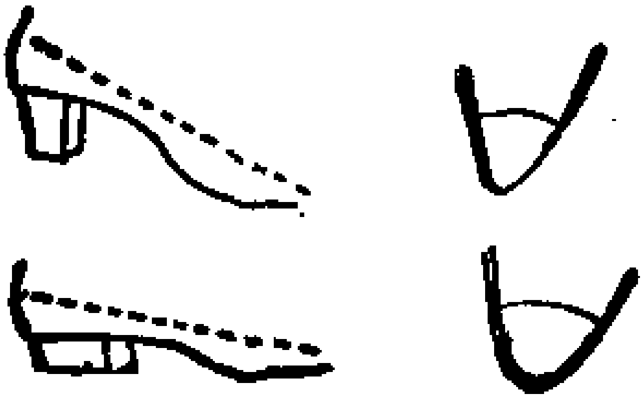

Fig. 107—Heels and toes of unhygienic and of hygienic footwear.

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CHAPTER XV - THE MUSCULAR SYSTEM

As already stated, the skeleton, the nervous system, and the muscular system are concerned in the production of motion. The skeleton and the nervous system, however, serve other purposes in the body, while the muscular system is devoted exclusively to the production of motion. For this reason it is looked upon as the special *motor* system. The muscular tissue is the most abundant of all the tissues, forming about 41 per cent of the weight of the body.

Properties of Muscles.—The ability of muscular tissue to produce motion depends primarily upon two properties—the property of irritability and the property of contractility. *Irritability* is that property of a substance which enables it to respond to a stimulus, or to act when acted upon. *Contractility* is the property which enables the muscle when stimulated to draw up, thereby becoming shorter and thicker (a condition called contraction), and when the stimulation ceases, to return to its former condition (of relaxation). The property of contractility enables the muscles to produce motion. Irritability is a condition necessary to their control in the body.

Kinds of Muscular Tissue.—Three kinds of muscular tissue are found in the body. These are known as the *striated*, or striped, muscular tissue; the *non-striated*, or plain, muscular tissue; and the *muscular tissue of the heart*. These are made up of different kinds of muscle cells and act in different ways to cause motion.
[244] The striated muscular tissue far exceeds the others in amount and forms all those muscles that can be felt from the surface of the body. The non-striated muscle is found in the walls of the food canal, blood vessels, air passages, and other tubes of the body;

while the muscular tissue of the heart is confined entirely to that organ.

Striated Muscle Cells.—The cells of the striated muscles are slender, thread-like structures, having an average length of 1-1/2 inches (35 millimeters) and a diameter of about 1/400 of an inch (60 µ). Because of their great length they are called fibers, or fiber cells. They are marked by a number of dark, transverse bands, or stripes, called striations,[83] which seem to divide them into a number of sections, or disks (Fig. 108). A thin sac-like covering, called the *sarcolemma*, surrounds the entire cell and just beneath this are a number of nuclei.[84]

Within the sarcolemma are minute fibrils and a semiliquid substance, called the *sarcoplasm*. At each end the cell tapers to a point from which the sarcolemma appears to continue as a fine thread, and this, by attaching itself to the inclosing sheath, holds the cell in place. Most of the muscle cells receive, at some portion of their length, the termination of a nerve fiber. This penetrates the sarcolemma and spreads out upon a kind of disk, having several nuclei, known as the *end plate*.

The "Muscle-organ."—We must distinguish between the term "muscle" as applied to the muscular tissue and the term as applied to a working group of muscular tissue, which is an organ. In the muscle, or muscle-organ, is found a definite grouping of muscle fibers such as will enable a large number of them to act together in the production of the same movement. An examination of one of the striated muscles shows the individual fibers to lie parallel in small bundles, each bundle being surrounded by a thin layer of connective tissue. (See Practical Work.) These small bundles are bound into larger ones by thicker sheaths and [245]

[83] On account of the striations of these cells the muscles which they form are called striated muscles.

[84] The striated muscle cells, having many nuclei, are said to be multi-nucleated.

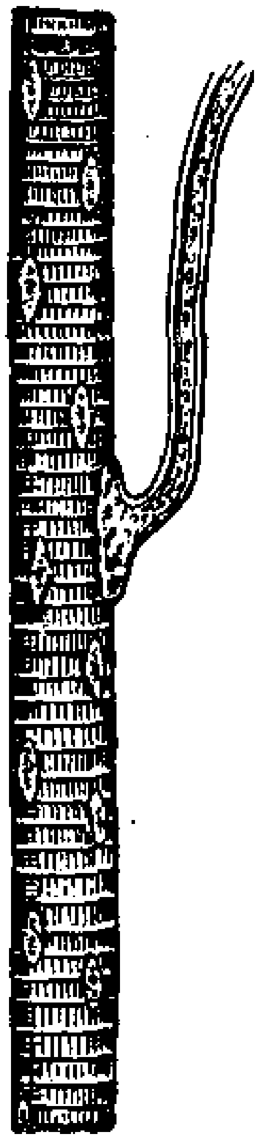

Fig. 108—**A striated muscle cell** highly magnified, showing striations and nuclei. Attached to the cell is the termination of a nerve fiber.

these in turn may be bound into bundles of still larger size (Fig. 109). The sheaths surrounding the fiber bundles are connected with one another and also with the outer covering of the muscle, known as

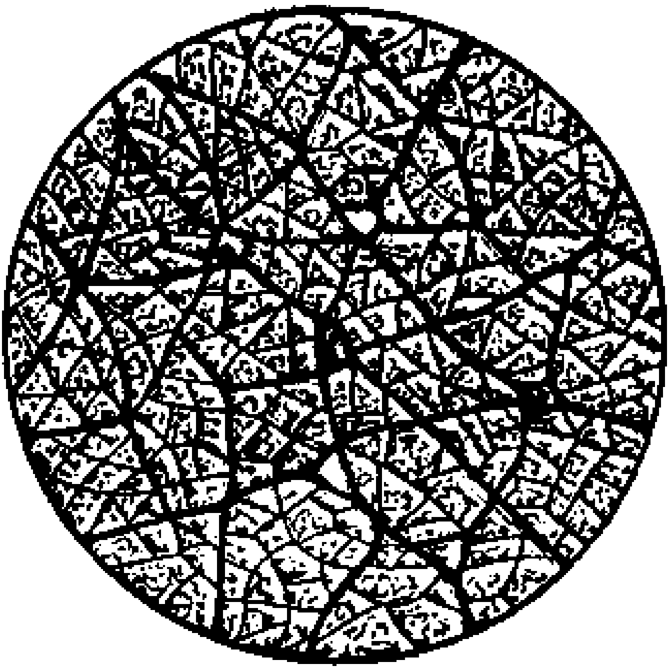

Fig. 109—**Diagram** of a section of a muscle, showing the perimysium and the bundles of fiber cells.

The Perimysium.—The plan of the muscle-organ is revealed through a study of the perimysium. This is not limited to the

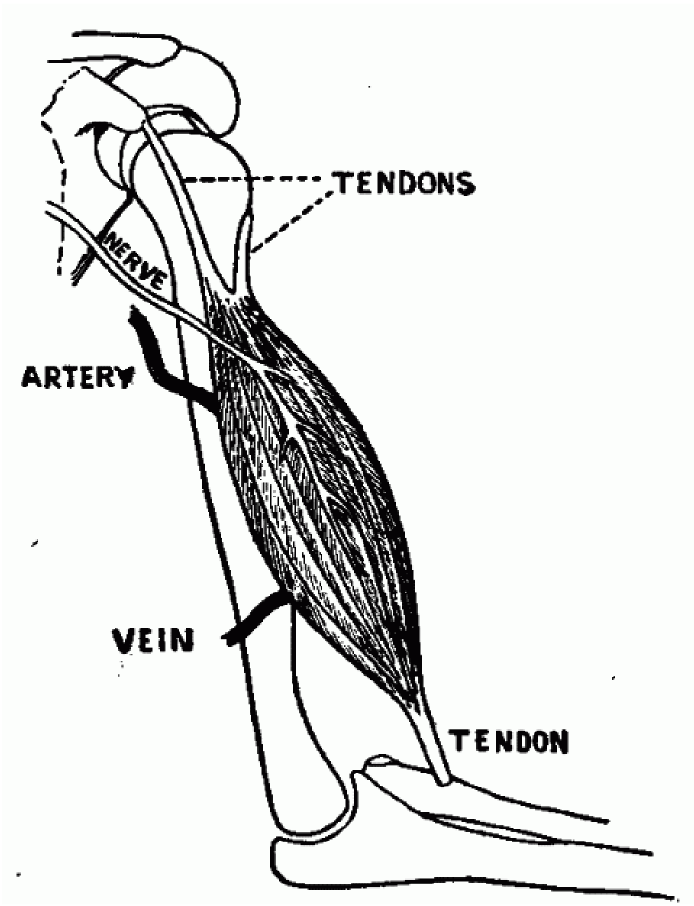

Fig. 110—**A muscle-organ in position.** The tendons connect at one end with the bones and at the other end with the fiber cells and perimysium. (See text.)

surface of the muscle, as the name suggests, but properly includes the sheaths that surround the bundles of fibers. Furthermore, [246] the surface perimysium and that within the muscle are both continuous with the strong, white cords, called *tendons*, that connect the muscles with the bones. By uniting with the bone at one end and blending with the perimysium and fiber bundles at the other, the tendon forms a very secure attachment for the muscle. The perimysium and the tendon are thus the means through which the fiber cells in any muscle-organ are made to *pull together* upon the same part of the body (Fig. 110).

Purpose of Striated Muscles.—The striated muscles, by their attachments to the bones, supply motion to all the mechanical devices, or machines, located in the skeleton. Through them the body is moved from place to place and all the external organs are supplied with such motion as they require. Because of the attachment of the striated muscles to the skeleton, and their action upon it, they are called *skeletal* muscles. As most of them are under the control of the will, they are also called *voluntary* muscles. They are of special value in adapting the body to its surroundings.

Structure of the Non-striated Muscles.—The cells of the non-striated muscles differ from those of the striated muscles in being decidedly spindle-shaped and in having but a single well-defined nucleus (Fig. 111). Furthermore, they have no striations, and their connection with the nerve fibers is less marked. They are also much smaller than the striated cells, being less than one one-hundredth of an inch in length and one three-thousandth of an inch in diameter.

In the formation of the non-striated muscles, the cells are attached to one another by a kind of muscle cement to form thin sheets or slender bundles. These differ from the striated muscles in several particulars. They are of a pale, whitish color, and they have no tendons. Instead of being attached to the bones, they [247] usually form a distinct layer in the walls of small cavities or of tubes (Fig. 111). Since they are controlled by the part of the nervous system which acts independently of the will, they are said to be *involuntary*. They contract and relax slowly.

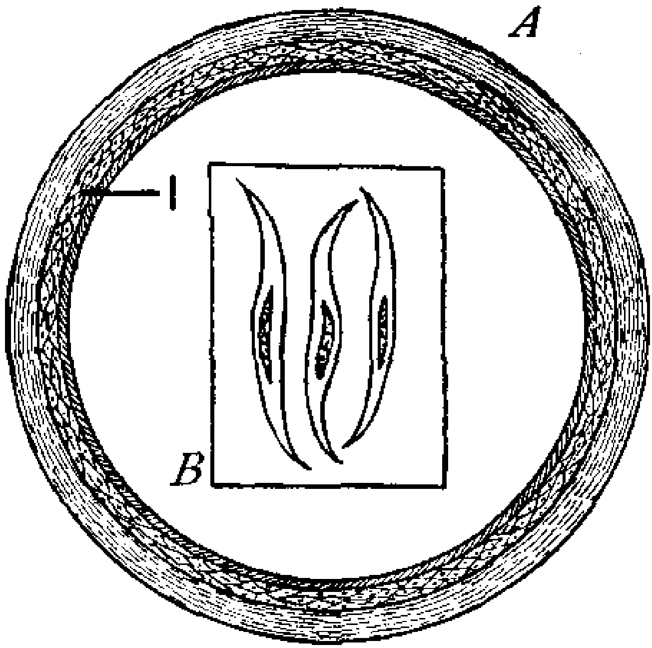

Fig. 111—**Non-striated muscle cells.** *A.* Cross section of small artery magnified, showing (1) the layer of non-striated cells. *B.* Three non-striated cells highly magnified.

Work of the Non-striated Muscles.—The work of the non-striated muscles, both in purpose and in method, is radically different from that of the striated. They do not change the *position* of parts of the body, as do the striated muscles, but they alter the *size* and *shape* of the parts which they surround.

Their purpose, as a rule, is to move, or control the movement of, materials within cavities and tubes, and they do this by means of the *pressure* which they exert. Examples of their action have already been studied in the propulsion of the food through the alimentary canal and in the regulation of the flow of blood through the arteries (pages 159 and 49). While they do not contract so quickly, nor with such great force as the striated muscles, their work is more closely related to the vital processes.

Structure of the Heart Muscle.—The cells of the heart combine the structure and properties of the striated and the non-striated muscle cells, and form an intermediate type between the two. They are cross-striped like the striated cells, and are nearly as wide, but are rather short (Fig. 112). Each cell has a well-defined nucleus, but the sarcolemma is absent. They are placed end to end to form fibers, and many of the cells have [248] branches by which they are united to the cells in neighboring fibers. In this way they interlace more or less with each other, but are also cemented together. They contract quickly and with great force, but are not under control of the will. Muscular tissue of this variety seems excellently adapted to the work of the heart.

The Muscular Stimulus.—The inactive, or resting, condition of a muscle is that of relaxation. It does work through contracting. It becomes active, or contracts, only when it is being acted upon by some force outside of itself, and it relaxes again when this force is withdrawn. Any kind of force which, by acting on muscles, causes them to contract, is called a *muscular stimulus*. Electricity, chemicals of different kinds, and mechanical force may be so applied to the muscles as to cause them to contract. These are *artificial* stimuli. So far as known, muscles are stimulated *naturally* in but one way. This is through the nervous system. The nervous system supplies a stimulus called the *nervous impulse*, which reaches the muscles by the nerves,

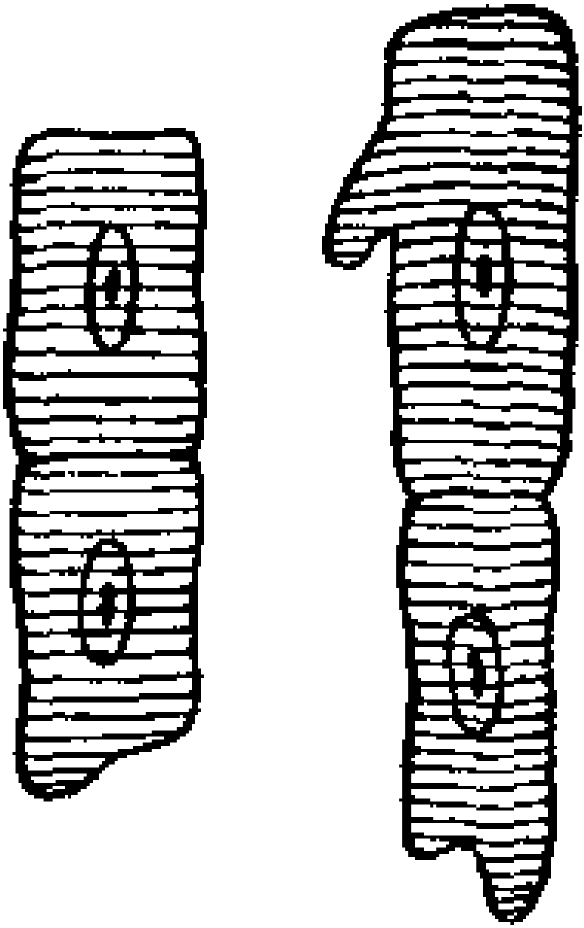

Fig. 112—**Muscle cells from the heart**, highly magnified (after Schäfer).

causing them to contract. By means of nervous impulses, all of the muscles (both voluntary and involuntary) are made to contract as the needs of the body for motion require.

Energy Transformation in the Muscle.—The muscle serves as a kind of engine, doing work by the transformation of potential into kinetic energy. Evidences of this are found in the changes that accompany contraction. Careful study shows that during any period of contraction oxygen and food materials are consumed, waste products, such as carbon dioxide, are produced, and heat is liberated. Furthermore, the *blood supply to the muscle* is [249] such that the materials for providing energy may be carried rapidly to it and the products of oxidation as rapidly removed. Blood vessels penetrate the muscles in all directions and the capillaries lie very near the individual cells (Fig. 113). Provision is made also, through the nervous system, for *increasing* the blood supply when the muscle is at work. From these facts, as well as from the great force with which the muscle contracts, one must conclude that the muscle is a *transformer of energy*—that within its protoplasm, chemical changes take place whereby the potential energy of oxygen and food is converted into the kinetic energy of motion.

Plan of Using Muscular Force.—Two difficulties have to be overcome in the using of muscular force in the body. The first of these is due to the fact that the muscles exert their force *only when they contract*. They can pull but not push. Hence, in order to bring about the opposing movements[85] of the body, each muscle must work against some force that produces a result directly opposite to that which the muscle produces. Some of the muscles (those of breathing) work against the elasticity of

[85] Every movement in the body has its opposing movement. This is necessary both on account of the work to be accomplished and for preserving the natural form of the body.

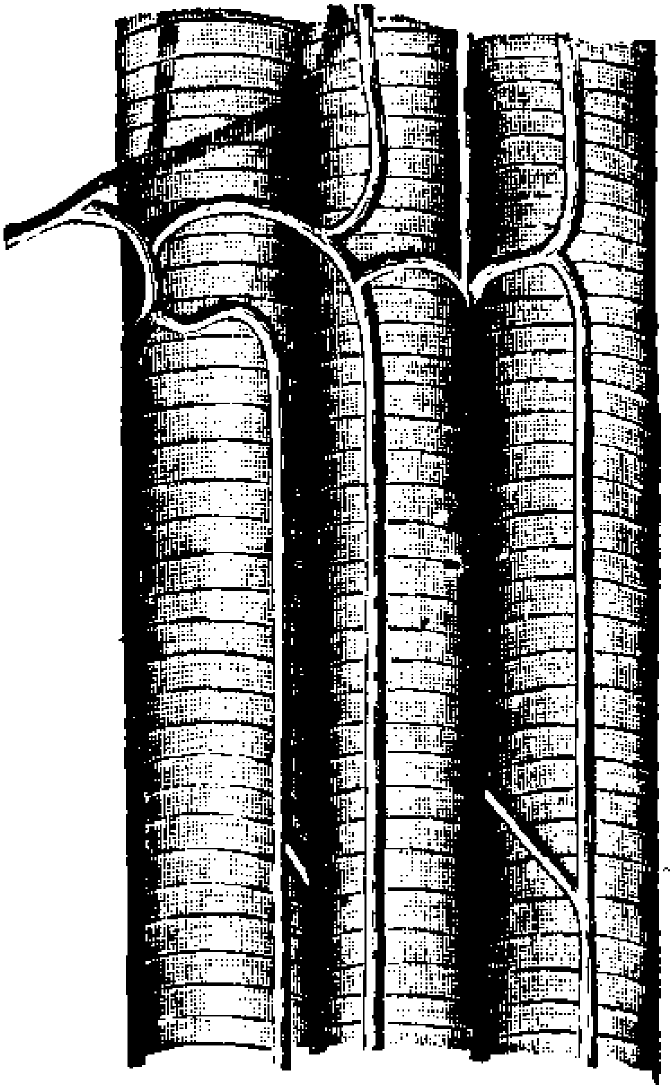

Fig. 113—**Capillaries** of muscles.

certain parts of the body; others (those that hold the body in an upright position), to some extent against gravity; and others (the [250] non-striated muscle in arteries), against pressure. But in most cases, *muscles work against muscles*.

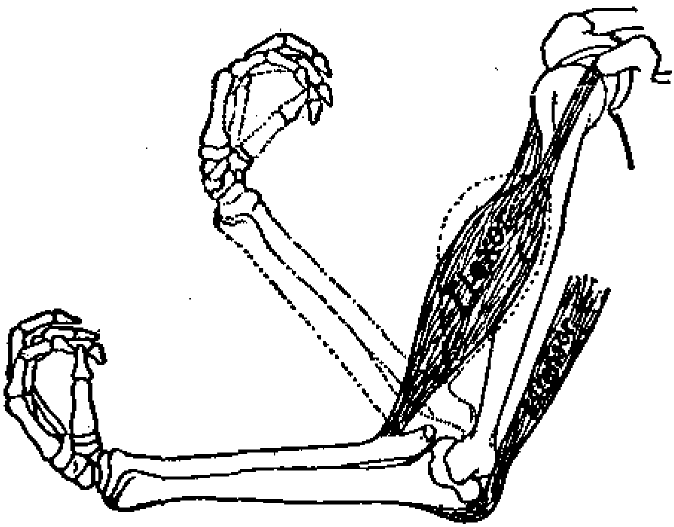

Fig. 114—**The muscle pair** that operates the forearm. For names of these muscles, see Fig. 119.

The striated, or skeletal, muscles are nearly all arranged after the last-named plan. As a rule a pair of muscles is so placed, with reference to a joint, that one moves the part in one direction, and the other moves it in the opposite direction. From the kinds of motion which the various muscle pairs produce, they are classified as follows:

1. *Flexors and Extensors.*—The flexor muscles bend and the extensors straighten joints (Fig. 114).

2. *Adductors and Abductors.*—The adductors draw the limbs into positions parallel with the axis of the body and the abductors draw them away.

3. *Rotators* (two kinds).—The rotators are attached about pivot joints and bring about twisting movements.

4. *Radiating and Sphincter Muscles.* —The radiating muscles open and the sphincter muscles close the natural openings of the body, such as the mouth.

The pupil should locate examples of the different kinds of muscle pairs in his own body.

Exchange of Muscular Force for Motion.—The second difficulty to be overcome in the use of muscular force in the body is due to the fact that the muscles contract through *short* distances, while it is necessary for most of them to move portions of the body through *long* distances. It may be easily shown that the longest muscles of the body do not shorten more than three
[251] or four inches during contraction. To bring about the required movements of the body, which in some instances amount to four or five feet, requires that a large proportion of the muscular force be exchanged for motion. The machines of the skeleton, while providing for motion in definite directions, also provide the means whereby *strong forces*, acting through *short distances*, are made to produce movements of *less force*, through *long distances*. The mechanical device employed for this purpose is known as

The Lever.—The lever may be described as a stiff bar which turns about a fixed point of support, called the *fulcrum*. The force applied to the bar to make it turn is called the *power*, and that which is lifted or moved is termed the *weight*. The weight, the power, and the fulcrum may occupy different positions along the bar and this gives rise to the three kinds of levers, known as levers of the first class, the second class, and the third class (Fig. 115). In levers of the *first class* the fulcrum occupies a position somewhere between the power and the weight. In the *second* *class* the weight is between the fulcrum and the power. In the *third class* the power is between the fulcrum and the weight.

Application to the Body.—In the body the bones serve as levers; the turning points, or fulcrums, are found at the joints; the muscles supply the power; and parts of the body, or things to be [252] lifted, serve as weights. For these levers to *increase* the motion of the muscles, it is necessary that the muscles be attached to the bones *near the joints*, and that the parts to be moved be located at some distance from the joints. In other words the (muscle) power-arm must be *shorter* than the (body) weight-arm.[86]

Examining Fig. 116, it is seen that the distances moved by the power and weight vary as their respective distances from the fulcrum. That is to say, if the weight is twice as far from the fulcrum as the power, it will move through twice the distance, and if three times as far, through three times the distance. Thus the muscles, by acting through short distances (on the short arms of levers), are able to move portions of the body (located on the long arms) through long distances. Can all three classes of levers be used in this way in the body?

Classes of Levers found in the Body.—Practically all of the levers of the body belong either to the first class or the third class. In both of these the muscle power can be applied to the short arm of the lever, thereby moving the body weight through a longer distance than the muscle contracts (Fig. 116). In the levers of the second class, however, the weight occupies this position, being situated *between* the power and fulcrum (Fig. 117). The weight, [253] therefore, *cannot* move farther than the power in this lever. It must always move a shorter distance. While such a lever is of

[86] The distance from the fulcrum to the power is called the *power-arm* and the distance from the fulcrum to the weight is called the *weight-arm* (Fig. 115).

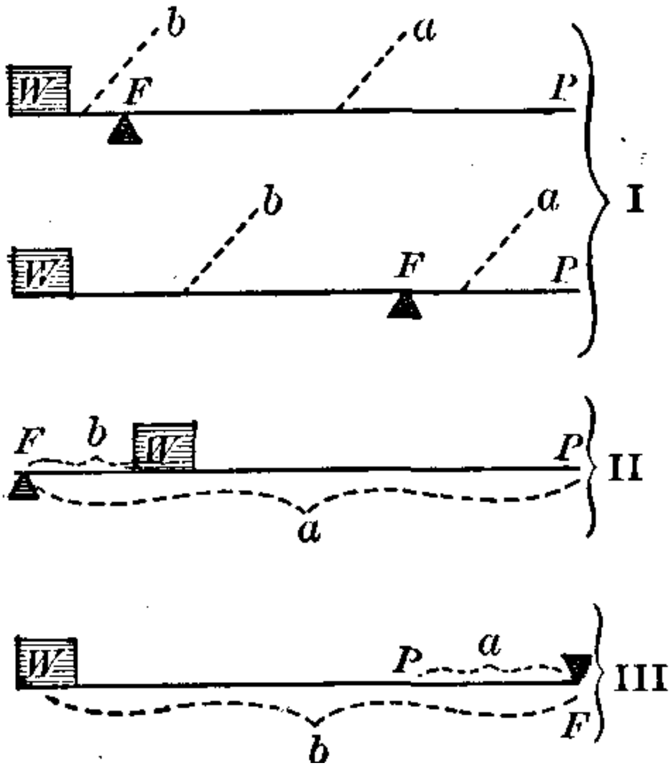

Fig. 115—**Classes of levers. I.** Two levers of first class showing fulcrums in different positions. II. Lever of second class. III. Lever of third class. *F*. Fulcrum. *P*. Power. *W*. Weight. *a*. Power-arm. *b*. Weight-arm.

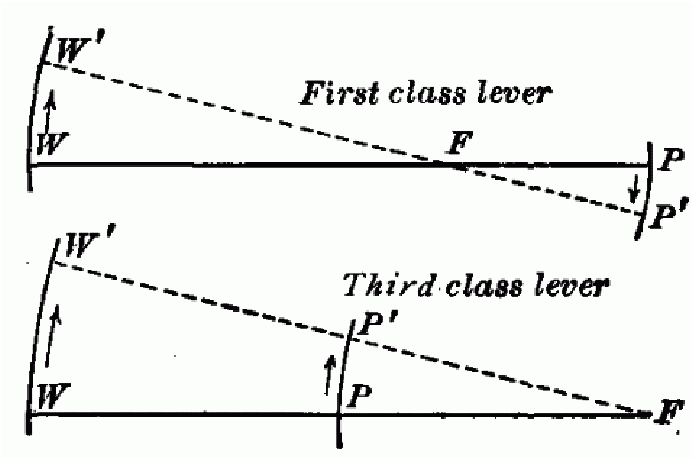

Fig. 116—**Motion producing levers.** Diagrams show relative distances moved by the power and weight in levers having the power nearer the fulcrum than is the weight. *F*. Fulcrum. *P*, *P'*. Power. *W*, *W'*. Weight.

great advantage in lifting heavy weights outside of the body, it cannot be used for increasing the motion of the muscles. For this reason no well-defined levers of the second class are present in the body.[87]

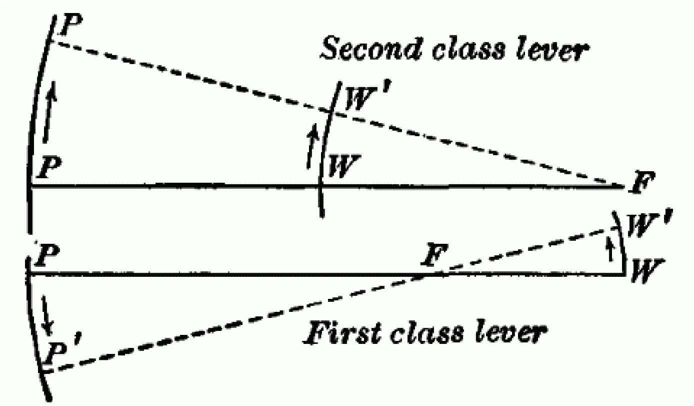

Fig. 117—**Weight lifting levers.** Diagrams show relative distances moved by the power and weight in levers having the weight nearer the fulcrum than is the power. *F.* Fulcrum. *P, P'.* Power. *W, W'.* Weight.

[87] The foot in lifting the body on tiptoe appears at first thought to be a lever of the second class, the body being the weight and the toe serving as the fulcrum. However, if the distance which the body is raised is compared with the distance which the muscle shortens, it is found that the *supposed* weight has moved *farther* than the power (Fig. 118). It will also be noted that the muscle which furnishes the power is attached at its upper end to the "weight." These facts show clearly that we are not here dealing with a lever of the second class. The foot in this instance acts as a lever of the first class with the fulcrum at the ankle joint and the toe pressing against the earth, which is the *actual* weight. Since the earth is immovable, the body is lifted or pushed upward, somewhat as a fulcrum support is made to move when it is too weak to hold up the weight that is being lifted. In other words, we have the same lever action in the foot in lifting the body as we have when one lies face downward, and, bending the knee, lifts some object on the toes.

Loss of Muscular Force.—Using a small spring balance for measuring the power, a light stick for a lever, and a small piece of metal for a weight, and arranging these to represent some lever of the body (as the forearm), it is easily shown that the gain [254] in motion causes a corresponding loss in muscular power. (See Practical Work.) If, for example, the balance is attached two inches from the fulcrum and the weight twelve inches, the pull on the balance is found to be six times greater than the weight that is being lifted. If other positions are tried, it is found that the power exerted in each case is as many times greater than the weight as the weight-arm is times longer than the power-arm.

Applying this principle to the levers of the body, it is seen that the gain in motion is at the expense of muscular force, or, as we say, *muscular force is exchanged for motion*. This exchange is greatly to the advantage of the body; for while the ability to lift heavy weights is important, the ability to move portions of the body rapidly and through long distances is much more to be desired.

Important Muscles.—There are about five hundred separate muscles in the body. These vary in size, shape, and plan of attachment, to suit their special work. Some of those that are prominent enough to be felt at the surface are as follows:

Of the head: The *temporal*, in the temple, and the *masseter*, in the cheek. These muscles are attached to the lower jaw and are the chief muscles of mastication.

Of the neck: The *sterno-mastoids*, which pass between the mastoid processes, back of the ears, and the upper end of the sternum. They assist in turning the head and may be felt at the sides of the neck (Fig. 119).

Of the upper arm: The *biceps* on the front side, the *triceps* behind, and the *deltoid* at the upper part of the arm beyond the

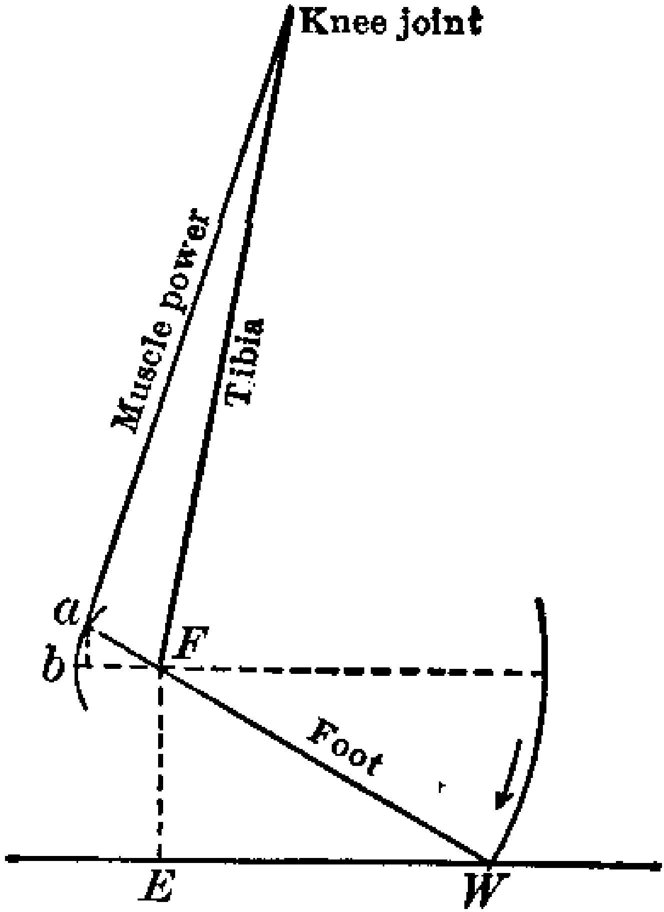

Fig. 118—**Diagram of the foot lever.** *F.* Fulcrum at ankle joint. *W.* Body weight expressed as pressure against the earth. While the muscle power acts through the distance *ab*, the fulcrum support (body) is forced through the distance *FE*.

projection of the shoulder.

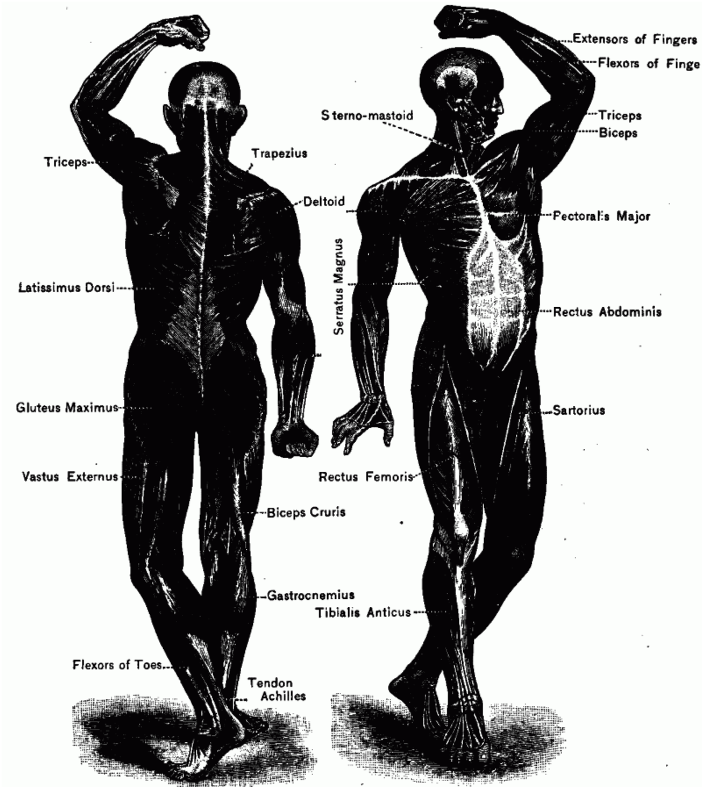

Fig. 119—Back and front views of important muscles.

Of the forearm: The *flexors* of the fingers, on the front side, [256]
and the *extensors* of the fingers, on the back of the forearm (Fig. 119).

Of the hand: The *adductor pollicis* between the thumb and the palm.

Of the trunk: The *pectoralis major*, between the upper front part of the thorax and the shoulder; the *trapezius*, between the back of the shoulders and the spine; the *rectus abdominis*, passing over the abdomen from above downward; and the *erector spinæ*, found in the small of the back.

Of the hips: The *glutens maximus*, fastened between the lower back part of the hips and the upper part of the femur.

Of the upper part of the leg: The *rectus femoris*, the large muscle on the front of the leg which connects at the lower end with the kneepan.

Of the lower leg: The *tibialis anticus* on the front side, exterior to the tibia, and the *gastrocnemius*, the large muscle in the calf of the leg. This is the largest muscle of the body, and is connected with the heel bone by the *tendon of Achilles* (Fig. 119).

The use of these muscles is, in most instances, easily determined by observing the results of their contraction.

HYGIENE OF THE MUSCLES

The hygiene of the muscles is almost expressed by the one word *exercise*. It is a matter of everyday knowledge that the muscles are developed and strengthened by use, and that they become weak, soft, and flabby by disuse. The effects of exercise are, however, not limited to the large muscles attached to the skeleton, but are apparent also upon the involuntary muscles, whose work is so closely related to the vital processes. While it is true that exercise cannot be applied directly to the involuntary muscles, it
[257] is also true that exercise of the voluntary muscles causes a greater activity on the part of those that are involuntary and is indirectly a means of exercising them.

Exercise and Health.—In addition to its effects upon the muscles themselves, exercise is recognized as one of the most fundamental factors in the preservation of the health. Practically every process of the body is stimulated and the body as a whole invigorated by exercise properly taken. On the other hand, a lack of exercise has an effect upon the entire body somewhat similar to that observed upon a single muscle. It becomes weak, lacks energy, and in many instances actually loses weight when exercise is omitted. This shows exercise to supply an actual need and to be in harmony with the nature and plan of the body.

How Exercise benefits the Body.—In accounting for the healthful effects of exercise, it must be borne in mind that the body is essentially a motion-producing structure. Furthermore, its plan is such that the movements of its different parts aid indirectly the vital processes. The student will recall instances of such aid, as, for example, the assistance rendered by muscular contractions in the circulation of the blood and lymph, due to the valves in veins and lymph vessels, and the assistance rendered by abdominal movements in the propulsion of materials through the food canal. A fact not as yet brought out, however, is that *exercise stimulates nutritive changes in the cells,* thereby imparting to them new vigor and vitality. While this effect of exercise cannot be fully accounted for, two conditions that undoubtedly influence it are the following:

1. Exercise causes the blood to circulate more rapidly.

2. Exercise increases the movement of the lymph through the lymph vessels.

The increase in the flow of the blood and the lymph causes [258]
changes to take place more rapidly in the liquids around the cells, thereby increasing the supply of food and oxygen, and hastening the removal of waste.

One should plan for Exercise.—Since exercise is demanded by the nature and plan of the body, to neglect it is a serious matter. People do not purposely omit exercise, but from lack of time or from its interference with the daily routine of duties, the needed amount is frequently not taken. Especially is this true of students and others who follow sedentary occupations. People of this class should plan for exercise as they plan for the other great needs of the body—food, sleep, clothing, etc. It is only by making a sufficient amount of muscular work or play a regular part of the daily program that the needs of the body for exercise are adequately supplied.

Amount and Kind of Exercise.—The amount of exercise required varies greatly with different individuals, and definite recommendations cannot be made. For each individual also the amount should vary with the physical condition and the other demands made upon the energy. One in health should exercise sufficiently to keep the muscles firm to the touch and the body in a vigorous condition.

Of the many forms of exercise from which one may choose, the question is again one of individual adaptability and convenience. While the different forms of exercise vary in their effects and may be made to serve different purposes, the consideration of these is beyond the scope of an elementary text. As a rule one will not go far wrong by following his inclinations, observing of course the conditions under which exercise is taken to the best advantage.

General Rules for Healthful Exercise.—That exercise may secure the best results from the standpoint of health, a number
[259] of conditions should be observed: 1. It should not be excessive or carried to the point of exhaustion. Severe physical exercise is destructive to both muscular and nervous tissues. 2. It should, if possible, be of an interesting nature and taken in the open air. 3. It should be counter-active, that is, calling into play those parts of the body that have not been used during the regular work.[88] 4. It should be directed toward the weak rather than toward the strong parts of the body. 5. When one is already tired from study, or other work, it should be taken with moderation or omitted for the time being. (For exercise of the heart muscle and the muscular coat of the blood vessels see pages 55 and 57.)

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[88] *Walking* is considered one of the very best forms of counter-active exercise for the brain worker (page 328).

Massage.—In lieu of exercise taken in the usual way, similar effects are sometimes obtained by a systematic rubbing, pressing, stroking, or kneading of the skin and the muscles by one trained in the art. This process, known as massage, may be gentle or vigorous and is subject to a variety of modifications. Massage is applied when one is unable to take exercise, on account of disease or accident, and also in the treatment of certain bodily disorders. A weak ankle, wrist, or other part of the body, or even a bruise, may be greatly benefited by massage. The flow of blood and lymph is stimulated, causing new materials to be passed to the affected parts and waste materials to be removed. Massage, however, should never be applied to a boil, or other infected sore. The effect in this case would be to spread the infection and increase the trouble.

Summary.—Motion is provided for in the body mainly through the muscle cells. These are grouped into working parts, called muscles, which in turn are attached to the movable parts of the body. The striated muscles, as a rule, are attached [260] to the mechanical devices found in the skeleton, and bring about the voluntary, movements. The non-striated muscles surround the parts on which they act, and produce involuntary movements. Both, however, are under the control of the nervous system. To bring about the opposing movements of the body, the striated muscles are arranged in pairs; and to increase their motion, the bones are used as levers. Physical exercise is necessary both for the development of the muscles and for the health and vigor of the entire body.

Exercises.—1. Compare the striated and non-striated muscles with reference to structure, location, and method of work.

2. In what respects is the muscular tissue of the heart like the striated, and in what respects like the non-striated, muscular tissue?

3. If muscles could push as well as pull, would so many be needed in the body? Why?

4. Locate muscles that work to some extent against elasticity and gravity.

5. Locate five muscles that act as flexors; five that act as extensors; two that act as adductors; and two as abductors. Locate sphincter and radiating muscles.

6. By what means does the nervous system control the muscles?

7. Give proofs of the change of potential into kinetic energy during muscular contraction.

8. Define the essential properties of muscular tissue and state the purpose served by each.

9. Describe a lever. For what general purpose are levers used in the body? What other purpose do they serve outside of the body?

10. Why are levers of the second class not adapted to the work of the body?

11. Name the class of lever used in bending the elbow; in straightening the elbow; in raising the knee; in elevating the toes; and in biting. Why is one able to bite harder with the back teeth than with the front ones when the same muscles are used in both cases?

12. Measure the distance from the middle of the palm of the hand to the center of the elbow joint. Find the attachment of the tendon of the biceps muscle to the radius and measure its
[261] distance to the center of the elbow joint. From these distances calculate the force with which the biceps contracts in order to support a weight of ten pounds on the palm of the hand.

13. How does exercise benefit the health? How does a short walk "clear the brain" and enable one to study to better advantage?

14. When exercisers taken for its effects upon the health, what conditions should be observed?

PRACTICAL WORK

The reddish muscle found in a piece of beef is a good example of striated muscle. The clear ring surrounding the intestine of a cat (shown by cross section) and the outer portion of the preparation from the cow's stomach, sold at the butcher shop under the name of *tripe*, are good examples of non-striated muscular tissue. The heart of any animal, of course, shows the heart muscle.

To show the Structure of Striated Muscle.—Boil a tough piece of beef, as a cut from the neck, until the connective tissue has thoroughly softened. Then with some pointed instrument, separate the main piece into its fiber bundles and these in turn into their smallest divisions. The smallest divisions obtainable are the muscle cells or fibers.

To show Striated Fibers.—Place a small muscle from the leg of a frog in a fifty-per-cent solution of alcohol and leave it there for half a day or longer. Then cover with water on a glass slide, and with a couple of fine needles tease out the small muscle threads. Protect with a cover glass and examine with a microscope, first with a low and then with a high power. The striations, sarcolemma, and sometimes the nuclei and nerve plates, may be distinguished in such a preparation.

To show Non-striated Cells.—Place a clean section of the small intestine of a cat in a mixture of one part of nitric acid and four parts of water and leave for four or five hours. Thoroughly wash out the acid with water and separate the muscular layer from the mucous membrane. Cover a small portion of the muscle with water on a glass slide and tease out, with needles, until it is as finely divided as possible. Examine with a microscope, first with a low and then with a high power. The cells appear as very fine, spindle-shaped bodies.

To illustrate Muscular Stimulus and Contraction.—Separate the muscles at the back of the thigh of a frog which has just been killed and draw the large sciatic nerve to the surface. Cut this as high up as possible and, with a sharp knife and a small pair of scissors, dissect it out to the knee. [262]

Now cut out entirely the large muscle of the calf of the leg (the gastrocnemius), but leave attached to it the nerve, the lower tendon, and the bones of the knee. Mount on an upright support, as shown in Fig. 120, and fasten the tendon to a lever below by a thread or small wire hook:

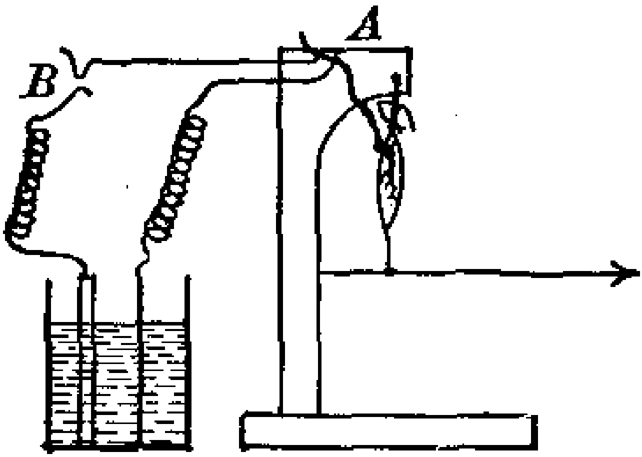

Fig. 120—**Apparatus** for demonstrating properties of muscles.

1. Lay the nerve over the ends of the wires from a small battery which are attached to the support at *A*, and arrange a second break in the circuit at *B*. At this place the battery circuit is made and broken either by a telegraph key or by simply touching and separating the wires. Note that the muscle gives a single contraction, or twitch, both when the current is made and when it is broken.

2. Remove the current and pinch the end of the nerve, noting the result. With very fine wires, connect the battery directly to the ends of the muscle. Stimulate by making and breaking the current

as before. In this experiment the muscle cells are stimulated by the direct action of the current and not by the current acting on the nerve.

3. With the wires attached to either the muscle or the nerve, make and break the current in rapid succession. This causes the muscle to enter into a second contraction before it has relaxed from the first, and if the shocks follow in rapid succession, to continue in the contracted state. This condition, which represents the method of contraction of the muscles in the body, is called *tetanus*.

NOTE.—In these experiments a twitching of the muscle is frequently observed when no stimulus is being applied. This is due to the drying out of the nerve and is prevented by keeping it wet with a physiological salt solution. (See footnote, page 38.)

To show the Action of Levers.—With a light but stiff wooden bar, a spring balance, and a wedge-shaped fulcrum, show:

1. The position of the weight, the fulcrum, and the power in the different classes of levers, and also the weight-arm and the power-arm in each case.

2. The direction moved by the power and the weight respectively in the use of the different classes of levers.

3. That when the power-arm and weight-arm are equal, the power equals the weight and moves through the same distance.

4. That when the power-arm is longer than the weight-arm, [263]
the weight is greater, but moves through a shorter distance than the power.

5. That when the weight-arm is longer than the power-arm, the power is greater and moves through a shorter distance than the weight.

To show the Loss of Power in the Use of the Body Levers.—Construct a frame similar to, but larger than, that shown in Fig. 120, (about 12 inches high), and hang a small spring balance (250 grams capacity) at the place where the muscle is attached. Fasten the end of a lever to the upright piece, at a point on a level with the end of the balance hook. (The nail or screw used for this purpose must pass loosely through the lever, and serve as a pivot upon which it can turn.) The lever should consist of a light piece of wood, and should have a length at least three times as great as the distance from the hook to the turning point. Connect the balance hook with the lever by a thread or string, and then hang upon it a small body of known weight. Note the amount of force exerted at the balance in order to support the weight at different places on the lever. At what point is the force just equal to the weight? Where is it twice as great? Where three times? Show that the force required to support the weight increases proportionally as the weight-arm and as the distance through which the weight may be moved by the lever. Apply to the action of the biceps muscle in lifting weights on the forearm.

A Study of the Action of the Biceps Muscle.—Place the fingers upon the tendon of the biceps where it connects with the radius of the forearm. With the forearm resting upon the table, note that the tendon is somewhat loose and flaccid, but that with the slightest effort to raise the forearm it quickly tightens. Now transfer the fingers to the body of the muscle, and sweep the forearm through two or three complete movements, noting the changes in the length and thickness of the muscle. Lay the forearm again on the table, back of hand down, and place a heavy weight (a flatiron or a hammer) upon the hand. Note the effort required to raise the weight, and then shift it along the arm. Observe that the nearer it approaches the elbow the lighter it seems. Account for the difference in the effort required to raise the weight at different places. Does the effort vary as the distance from the tendon?

[264]

CHAPTER XVI - THE SKIN

Protective coverings are found at all the exposed surfaces of the body. These vary considerably at different places, each being adapted to the conditions under which it serves. The most important ones are the *skin*, which covers the entire external surface of the body; the *mucous membrane*, which lines all the cavities that communicate by openings with the external surface; and the *serous membrane*, which, including the synovial membranes, lines all the closed cavities of the body. In addition to the protection which it affords, the skin is one of the means by which the body is brought into proper relations with its surroundings. It is because of this function that we take up the study of the skin at this time.

The Skin is one of the most complex structures of the body, and serves several distinct purposes. It is estimated to have an area of from 14 to 16 square feet, and to have a thickness which varies from less than one eighth to more than one fourth of an inch. It is thickest on the palms of the hands and the soles of the feet, the places where it is most subject to wear. It is made up of two distinct layers—an outer layer called the *epidermis*, or cuticle, and an inner layer called the *dermis*, or cutis vera (Fig. 121).

The Dermis.—This is the thicker and heavier of the two layers, and is made up chiefly of connective tissue. The network of tough fibers which this tissue supplies, forms the essential [265]
body of the dermis and gives to it its power of resistance. It is on account of the connective tissue that the skins of animals can be converted into leather by tanning. A variety of structures, including blood and lymph vessels, oil and perspiratory glands, hair follicles, and nerves, are found embedded in the connective

tissue (Fig. 122). These aid in different ways in the work of the skin.

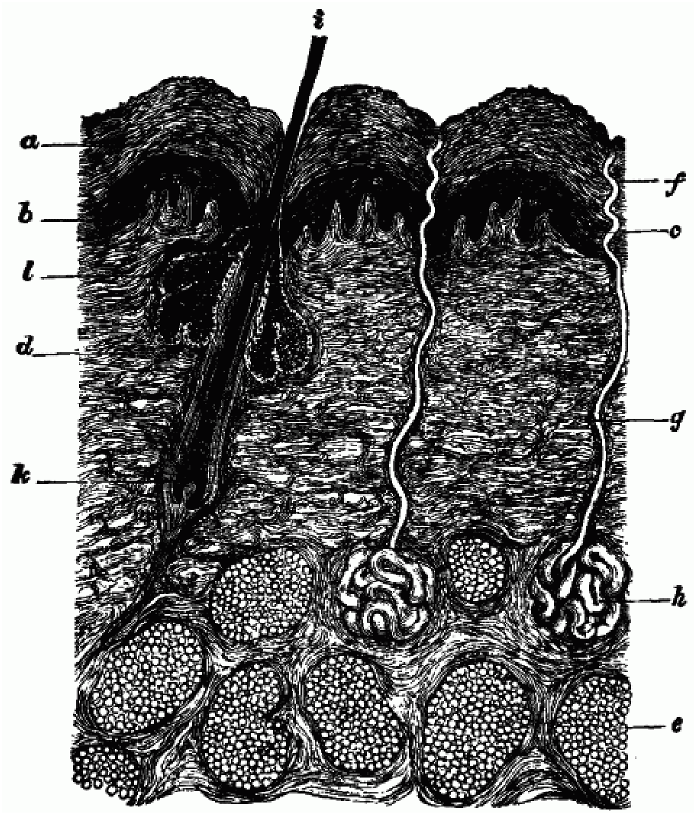

Fig. 121—**Section of skin** magnified, *a, b.* Epidermis, *b.* Pigment layer. *c.* Papillæ, *d.* Dermis. *e.* Fatty tissue. *f, g, h.* Sweat gland and duct. *i, k.* Hair and follicle. *l.* Oil gland.

[266] On the outer surface of the dermis are numerous elevations, called *papillæ*. These average about one one-hundredth of an

inch in height, and one two hundred and fiftieth of an inch in diameter. They are most numerous on the palms of the hands, the soles of the feet, and the under surfaces of the fingers and toes. At these places they are larger than in other parts of the body, and are closely grouped, forming the parallel curved ridges which cover the surfaces. Each papilla contains a loop of capillaries and a small nerve, and many of them are crowned with touch corpuscles (page 342).

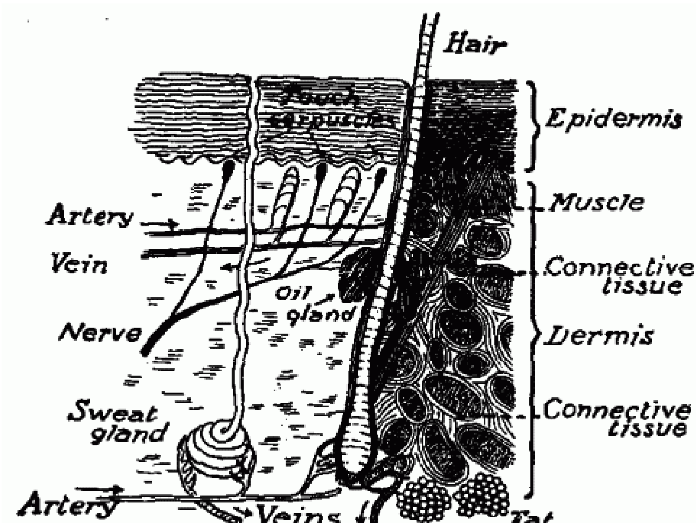

Fig. 122—**Diagram** of section of skin showing its different structures.

The Epidermis is much thinner than the dermis. It is made up of several layers of cells which are flat and scale-like at the surface, but are rounded in form where the epidermis joins the dermis. The epidermis has the appearance of being *moulded onto* the dermis, filling up the depressions between the papillæ

and having corresponding irregularities (Fig. 121). No blood vessels are found in the epidermis, its nourishment being derived from the lymph which reaches it from the dermis. Only the part next to the dermis is made up of *living* cells. These are active, however, in the formation of new cells, which take the place of those that are worn off at the surface. Some of the cells belonging to the inner layer of epidermis contain *pigment granules*, which
[267] give the skin its color (Fig. 121). The epidermis contains no nerves and is therefore non-sensitive. The hair and the nails are important modifications of the epidermis.

A Hair is a slender cylinder, formed by the union of epidermal cells, which grows from a kind of pit in the dermis, called the *hair follicle*. The oval and somewhat enlarged part of the hair within the follicle is called the *root*, or *bulb*, and the uniform cylinder beyond the follicle is called the *shaft*. Connected with the sides of the follicles are the *oil*, or *sebaceous*, *glands* (Figs. 121 and 122). These secrete an oily liquid which keeps the hair and cuticle soft and pliable. Attached to the inner ends of the follicles are small, involuntary muscles whose contractions cause the roughened condition of the skin that occurs on exposure to cold.

A Nail is a tough and rather horny plate of epidermal tissue which grows from a depression in the dermis, called the *matrix*. The back part of the nail is known as the *root*, the middle convex portion as the *body*, and the front margin as *the free edge* (Fig. 123). Material for the growth of the nail is derived from the matrix, which is lined with active epidermal cells and is richly supplied with blood vessels. Cells added to the root cause the nail to grow in length (forward) and cells added to the under surface cause it to grow in thickness. The cuticle adheres to the nail around its entire circumference so that the covering over the dermis is complete.

Functions of the Skin.—The chief function of the skin is that of protection. It is able to protect the body on account of the tough connective tissue in the dermis, the non-sensitive cells of the epidermis, and also by the touch corpuscles and their [268] connecting nerve fibers. This protection is of at least three kinds, as follows:

1. *From mechanical injuries* such as might result from contact with hard, rough, or sharp objects. The main quality needed for resisting mechanical injuries is *toughness*, and this is supplied both by the epidermis and by the connective tissue of the dermis.

2. *From chemical injuries* caused by contact with various chemical agents, as acids, alkalies, and the oxygen of the air. The epidermis, being of such a nature as to resist to a considerable extent the action of chemical agents, affords protection from these substances. [89]

3. *From disease germs* which are everywhere present. The epidermis is the main protective agent against attacks of germs, but should the epidermis be broken, they meet with further resistance from the fluids of the dermis and the white corpuscles of the blood.

4. *From an excessive evaporation of liquid from the surface of the body*. In the performance of this function, the skin is an important means of keeping the tissues soft and the blood and lymph from becoming too concentrated.

Other Functions of the Skin.—Through the perspiratory glands the skin is an *organ of excretion*. While the secretion from a single gland is small, the waste that leaves the body through all of the perspiratory glands is considerable [90] (page 206). By

[89] The epidermis does not afford complete protection against chemicals, many of them being able to destroy it quickly. The rule of washing the skin immediately after contact with strong chemical agents should always be followed.

[90] "Rough calculations have placed the number of sweat glands on the entire body at about 2,000,000." Rettger, *Studies in Advanced Physiology*.

means of the nerves terminating in the touch corpuscles, the skin serves as the *organ of touch*, or feeling (Chapter XX). To
[269] a slight extent also the skin may absorb liquid substances, these being taken up by the blood and lymph vessels, and perform a respiratory function, throwing off carbon dioxide. But the most important function of the skin, in addition to protection, is that of serving as

An Organ of Adaptation.—Forming, as it does, the boundary between the body and its physical environment, the skin is perhaps the most important agent through which the body is adapted to its immediate surroundings. Evidence of this is found in the great variety of influences which are able to affect the body through their action upon the nerves in the skin, and in the changes which the epidermis undergoes on exposure. The latter function is especially marked in the lower animals, the coverings of epidermal tissue (hair, scales, feathers, etc.) adapting each species to the physical conditions under which it lives. In man the most striking example of adaptation through the skin is seen in the variations in the quantity of blood circulating through it, corresponding to the changes in the temperature outside of the body. These variations are of great importance, having to do with the

Maintenance of the Normal Temperature.—It is necessary to the continuance of life that the temperature of the body be kept at a nearly uniform degree, called the *normal temperature,* which is about 98.6° F. The maintenance of the normal temperature depends mainly upon four conditions: the chemical changes at the cells, the circulation of the blood, the nervous system, and *the skin*. The chemical changes produce the heat, the blood in its circulation distributes the heat over the body, and the nervous system controls the heat-producing and distributing processes
[270] (page 320). The skin is the chief means by which the body gets rid of an excess of heat and, by so doing, avoids overheating. [91]

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[91] Heat also leaves the body by the lungs, partly by the respired air and partly

How the Skin cools the Body.—The skin is a means of ridding the body of an excess of heat in at least two ways:

1. *By the conduction and radiation of heat from its surface* as from a stove. This goes on all the time, but varies with the amount of heat brought to the surface by the blood.

2. *By the evaporation of the perspiration.* It is a well-established and easily demonstrated principle that liquids in evaporating use up heat.(See Practical Work.) It is also a matter of everyday experience that the perspiration has a cooling effect upon the body and that its flow increases with the amount of heat to be gotten rid of. The quantity of perspiration secreted, and of heat disposed of through its evaporation, also varies with the amount of blood circulating through the skin.

Temperature Regulation by the Skin.—Variations in the quantity of blood circulating through the skin enable this organ to throw off just the right amount of heat for keeping the body at the normal temperature. If it is necessary for the body to rid itself of an excess of heat, the quantity of blood circulating in the skin is increased. This brings the blood near the surface, where more heat can be radiated and where it may cause an increase in the perspiration. On the other hand, if the body is in danger of losing too much heat, the circulation diminishes in the skin and increases in the internal organs. This stops the rapid loss of heat from the surface. The skin in this work is of course made [271] to cooperate with other parts of the body. That it is not the only organ concerned in regulating the escape of heat is seen in the results that follow sensations either of chilliness or of heat at the surface.

Effects of Heat and Cold Sensations.—Sensations, or feelings, of heat and cold are made possible through the nerves which connect the brain with the *temperature corpuscles*, found in the skin (page 343). As the warm blood recedes from the

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through the evaporation of moisture from the lung surfaces. Respiration in some animals, as the dog, is the chief means of cooling the body.

skin, a sensation of cold is felt, but when the blood returns, there is again the feeling of warmth. The sensation of cold prompts one to seek a warmer place, or to put on more clothing; while the sensation of heat, if it be oppressive, leads to activities of an opposite kind. Prompted in this way by the sensations from the skin, one voluntarily supplies the external conditions, such as clothing and heat, that affect the body temperature.

Alcohol and the Regulation of Temperature.—Alcohol, through its effect upon the nervous system, interferes seriously with the regulation of the body temperature. By dilating the capillaries, it increases the circulation in the skin and leads to an undue loss of heat. At the same time the excess of blood in the skin causes a *feeling of warmth* which has led to the erroneous belief that alcohol is a heat producer. If taken on a cold day, it deceives one about his true condition and leads to a wasting of heat when it should be carefully economized. Not only is alcohol of no value in maintaining the body temperature, but if taken during severe exposure to cold, it becomes a menace to life itself. Arctic, explorers and others exposed to severe cold have found that they withstand cold far better when no alcohol at all is used.[92]

[272]

[92] "The story is told of some woodsmen who were overtaken by a severe snowstorm and had to spend the night away from camp; they had a bottle of whisky, and, chilled to the bone, some imbibed freely while others refused to drink. Those who drank soon felt comfortable and went to sleep in their improvised shelter; those who did not drink felt very uncomfortable throughout the night and could get no sleep, but in the morning they were alive and able to struggle back to camp, while their companions who had used alcohol were frozen to death.... This, if true, was of course an extreme case; but it accords with the universal experience of arctic travelers and of lumbermen and hunters in the northern woods, that the use of alcohol during exposure to cold, although contributing greatly to one's comfort for the time being, is generally followed by undesirable or dangerous results."—HOUGH AND SEDGWICK: *The Elements of Hygiene and Sanitation.*

HYGIENE OF THE SKIN

Much of the hygiene of the skin is included in the problems of keeping it warm and clean. It is kept warm by clothing; bathing is the method of keeping it clean.

Clothing should be warm and loose-fitting. Woolen fabrics are to be preferred in winter to cotton because, being poorer conductors of heat, they afford better protection from the cold. But wool fails to absorb the perspiration rapidly from the skin and to pass it to the outside where it is evaporated. This, together with its tendency to irritate, makes woolen clothing somewhat objectionable for wearing next to the skin. This objection, however, is obviated by woolen underwear which is lined by a thin weaving of cotton.

Bathing.—The solid material from the perspiration, which is left on the skin, together with the oil from the oil glands and the dirt from the outside, tends to close up the pores and develop offensive odors. Keeping the skin clean is, for these reasons, necessary from both a health and a social standpoint. While one should always keep clean, the frequency of the bath will depend upon the season, the occupation of the individual, and the nature and amount of the perspiration. As to the kind of bath to be taken and the precautions to be observed, no specific rules can be laid down. These must be determined by the facilities at hand and by [273]
the health and natural vigor of the bather. Severe chilling of the body should be avoided, especially by those in delicate health. If a hot bath is taken, one should dash cold water over the body on finishing. One should then quickly dry and rub the body with a coarse towel. The dash of cold water closes the pores of the skin and lessens the liability of taking cold.

The Tonic Bath.—The cold bath has been found to have a beneficial effect upon the general health beyond its effect upon the skin. When taken with care as to the length of time and the degree of cold, decided tonic effects are observed on the circulation and on the nervous system. The rapid changes of temperature vigorously exercise the non-striated muscles of the blood vessels (page 57) and the nerves controlling them. The irritability of the nervous system in general is also lessened. For this reason the cold bath is one of the best means of keeping both mind and body in good condition during the warm months. Sponging off the body with cold or tepid water before retiring is also an excellent aid in securing sound sleep during the hot summer nights.

Danger from the cold bath arises through the shock to the nervous system and the loss of heat from the body. It is avoided by using water whose temperature is not too low and by limiting the time spent in the bath. A brisk rubbing with a coarse towel should always follow the cold bath. People past middle age are, as a rule, not benefited by the cold bath; and those in delicate health, especially if inclined toward rheumatism, are likely to be affected injuriously by it.

Care of the Complexion.—A good complexion is a natural
[274] accompaniment of good health and depends primarily upon two conditions—a clear skin and an active circulation of the blood through it. Clearness of the skin depends largely upon the elimination of waste material from the body, and where the solid wastes are not effectively removed through the natural channels (the liver, kidneys, and bowels), blotches, sallowness of the skin, and skin eruptions are likely to result. In seeking to clear the complexion, attention must be given to all those agencies that favor the elimination of waste, and especially should there be a free and thorough evacuation of the bowels each day. The general health should also be looked after, attention being given to exercise, fresh air, proper food,[93] sufficient sleep, etc.

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[93] Foods that are difficult to digest, or which cause disturbances of the digestive organs (a coated tongue being one indication), have a bad effect upon the skin. It is in this way that the use of tea and coffee by some people induces a sallow or "muddy" condition of the complexion.

Bathing is the chief means employed for increasing the circulation in the skin, although exercise which is sufficiently vigorous to cause one to perspire freely is a valuable aid. A daily bath of warm or hot water, finished off with a dash of cold, followed by a thorough rubbing of the entire surface, and this by a kneading of the skin with the thumbs and fingers, will in most cases bring about the desired results. A little olive oil, thoroughly worked into the skin during the kneading process, is beneficial where one lacks flesh or where the skin is dry and thin. The olive oil is also beneficial where the baths are exhausting or render one susceptible to cold. In rubbing and kneading, the skin should not be bruised or irritated.

The much advertised "complexion beautifiers" which are applied directly to the face frequently have the effect of clogging the pores and of causing eruptions of the skin. On the other hand, [275] certain authorities state that the cold cream preparations may be of advantage in giving the skin a desired softness, and that when judiciously used (the face being cleansed after each application) they do no harm. Of the different kinds of face powder those prepared from rice are considered the least injurious.

Treatment of Skin Wounds.—Skin wounds which may not be serious in themselves frequently become so through getting infected with germs. Blood poisoning often results from such infections, one of the worst forms being *tetanus*, or lockjaw. A wound should be kept clean, and if it shows signs of infection, it should be washed with some antiseptic solution. Or, it may be cleansed with pure warm water and then covered with some antiseptic ointment,[94] of which there are a number on the market.

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[94] A most valuable antiseptic ointment is prepared by the druggist from the following formula:

Lanolin, 25 grams.
Ichthyol, 6 grams.
Yellow vaseline, 20 grams.

A weak solution of carbolic acid (one part acid to twenty-five parts of water) makes an excellent antiseptic wash. It may be used not only for cleansing wounds, but also in counteracting the poisonous effects that follow the bites of insects.

A wound resulting from the bite of an animal (cat or dog), even though slight, should receive more serious attention, and as soon as possible after the occurrence. Such wounds should be cauterized, and for this purpose pure carbolic, acid (undiluted with water) may be used. A wooden toothpick is dipped into the acid and this is worked about in the wound. The acid is then washed out with warm water. A deep wound from a rusty
[276] nail or a thorn should be treated in the same manner and should be kept open, not being allowed to heal at the surface first. If one has reason to believe he has been bitten by a mad dog, the wound should be cauterized as above, and a physician should be summoned at once. Deep wounds from explosives, or other causes, should also receive the attention of the physician. Many cases of lockjaw result every year from wounds inflicted by the toy pistols, firecrackers, etc., used in our Fourth of July celebrations. These are due to the embedding in the skin or flesh of small solid particles on which are lockjaw germs. Wounds of this nature should, of course, receive the attention of the physician.

Care of the Nails.—Relief from a blood blister under the nail is secured by boring a small hole through the nail with the sharp point of a sterilized penknife (page 38). This simple bit of surgery not only relieves the pain, but is frequently the only means of saving the nail. Ingrown toe nails are relieved by scraping a broad strip in the middle of the nail until very thin. This relieves the pressure, preventing the sides of the nail from being forced into the toe. While the finger nails should be trimmed in a curve,

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This is applied as a thin layer on the surface, except in the case of boils or abscesses. In treating these a heavy layer is spread over the affected part and then covered with absorbent cotton or a thin piece of clean cotton cloth.

corresponding to the end of the finger, it is recommended that the toe nails be cut straight across (Fig. 124), as this method diminishes the pressure from the shoe and keeps the nails from ingrowing. Shoes that pinch the toes should, of course, not be worn (page 238).

Care of the Hair.—Occasional washing of the hair is beneficial, but too much wetting causes decay of the hair roots, which leads to its falling out. The worst enemy of the hair is dandruff. A method of removing dandruff which is highly recommended is that of rubbing olive oil into the scalp and later of removing [277] this with a cleansing shampoo. The olive oil is placed on the scalp with a medicine dropper and thoroughly rubbed in with the fingers. After three or four hours the hair is washed with soap and water (any good toilet soap will do) and rinsed with pure water. The hair is then dried, the surplus water being removed with a coarse towel. Where the dandruff is very troublesome, this treatment may be given once or twice a week; but in mild cases once a month is sufficient. Massage of the scalp, by increasing the circulation at the hair roots, is beneficial, but irritation by a fine-tooth comb, a stiff hair brush, or by other means should be avoided. Frequent brushing and combing, however, are necessary both for the good appearance of the hair and for spreading the oil secreted by the glands at the hair roots.

Summary.—The skin forms the external covering of the body and also serves additional purposes. It is a most important agency in adapting the body to its physical surroundings, as shown by the part which it plays in the regulation of the body temperature. The skin should be kept clean and active, and skin wounds, even though small, should be guarded against infection.

Exercises.—1. Name an example of each of the protective coverings of the body.

2. Compare the dermis and the epidermis with reference to

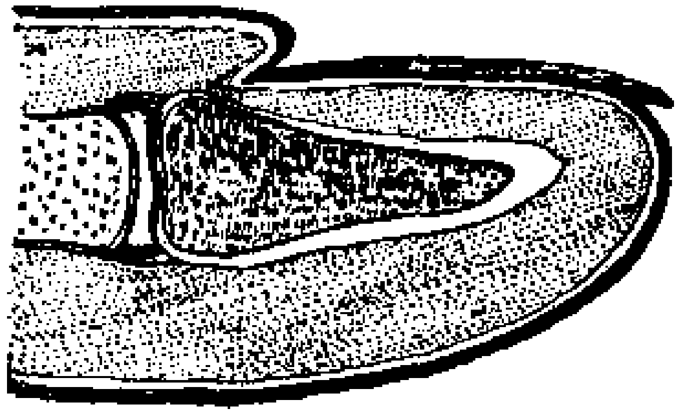

Fig. 123—**Section of end of finger** showing nail in position.

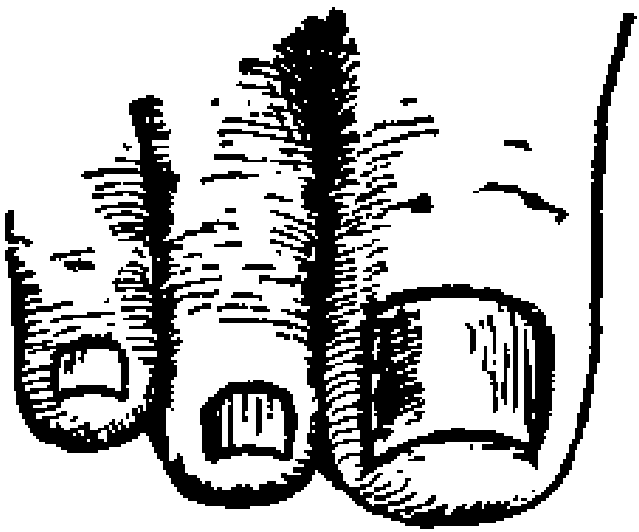

Fig. 124—Proper method of trimming nails of toes.

thickness, composition, and function.

3. To what is the color of the skin due? How is the color of the skin affected by the sunlight?

4. What modifications of the epidermis are found on our bodies? What are found on the body of a chicken?

5. What different kinds of protection are provided by the skin?

6. How does the perspiration cool the body?

7. What change occurs in the circulation in the skin when the body is becoming too cold? When becoming too warm? What is the purpose of these changes?

8. How does alcohol cause one to *feel* warm when he may be [278] losing too much of his heat?

9. What precaution should be observed by one in poor health, in taking a bath?

10. How may the cold bath be a means of improving the general health?

PRACTICAL WORK

Observations on the Skin and its Appendages.—Examine the palm of the hand with a lens. Note the small ridges which correspond to the rows of papillæ beneath the cuticle. In these find small pits, which are the openings of the sweat glands.

2. Examine the epidermis on the back of the hand and palm. At which place is it thickest and most resisting? Is it of uniform thickness over the palm? Try picking it with a pin at the thickest place, noting if pain is felt. Inference?

3. Examine a finger nail. Is the free edge or the root the thickest? Trim closely the thumb nail and the nail of the middle finger of one hand and try to pick up a pin, or other minute object, from a smooth, hard surface. The result indicates what use of the nails? Suggest other uses.

4. Examine with a microscope under a low power hairs from a variety of animals, as the horse, dog, cat, etc., noting peculiarities of form and surface.

To illustrate Cooling Effects of Evaporation.—1. Wet the back of the hand and move it through the air to hasten evaporation. Observe that, as the hand dries, a sensation of cold is felt. Repeat the experiment, using ether, alcohol, or gasolene instead of the water, noting the differences in results. These liquids evaporate faster than water.

2. Wet the bulb of a thermometer with alcohol or water. Move it through the air to hasten evaporation. Note and account for the fall of the mercury.

[279]

CHAPTER XVII - STRUCTURE OF THE NERVOUS SYSTEM

Coördination and Adjustment.—If we consider for a moment the movements of the body, we cannot fail to note the coöperation of organs, one with another. In the simple act of whittling a stick one hand holds the stick and the other the knife, while the movements of each hand are such as to aid in the whittling process. Examples of coöperation are also found in the taking of food, in walking, and in the performance of different kinds of work. Not only is coöperation found among the external organs, but our study of the vital processes has shown that the principle of coöperation is carried out by the internal organs as well. The fact that all the activities of the body are directed toward a common purpose makes the coöperation of its parts a necessity. The term "coördination" is employed to express this coöperation, or working together, of the different parts of the body.

A further study of the movements of the body shows that many of them have particular reference to things outside of it. In going about one naturally avoids obstructions, and if anything is in the way he walks around or steps over it. Somewhat as a delicate instrument (the microscope for example) is altered or adjusted, in order to adapt it to its work, the parts of the body, and the body as a whole, have to be *adjusted* to their surroundings. This is seen in the attitude assumed in sitting and in standing, in the position of the hands for different kinds of work, in the variations [280]
of the circulation of the blood in the skin, and in the movements for protecting the body.[95]

[95] In a larger sense adjustment includes all those activities by means of which the body is brought into proper relations with its environment, including the changes which the body makes in its surroundings to *adapt them* to its purposes.

Work of the Nervous System.—How are the different activities of the body controlled and coördinated? How is the body adjusted to its surroundings? The answer is found in the study of the nervous system. Briefly speaking, the nervous system controls, coördinates, and adjusts the different parts of the body by fulfilling two conditions:

1. It provides a complete system of connections throughout the body, thereby bringing all parts into communication.

2. It supplies a means of controlling action (the so-called impulse) which it passes along the nervous connections from one part of the body to another.

The present chapter deals with the first of these conditions; the chapter following, with the second.

The Nerve Skeleton.—If all the other tissues are removed, leaving only the nervous tissue, a complete skeleton outline of the body still remains. This nerve skeleton, as it has been called, has the general form of the framework of bones, but differs from it greatly in the fineness of its structures and the extent to which it represents every portion of the body. An examination of a nerve skeleton, or a diagram of one (Fig. 125), shows the main structures of the nervous system and their connection with the different parts of the body.

Corresponding to the skull and the spinal column is a central nervous axis, made up of two parts, the *brain* and the *spinal cord*. From this central axis white, cord-like bodies emerge and pass to
[281] different parts of the body. These are called *nerve trunks*, and the smaller branches into which they divide are called *nerves*. The nerves also undergo division until they terminate as fine thread-like structures in all parts of the body. The distribution of nerve terminations, however, is not uniform, as might be supposed, but the skin and important organs like the heart, stomach, and muscles are the more abundantly supplied. On many of the nerves are small rounded masses, called *ganglia*, and from many of these small nerves also emerge. At certain places the nerves

and ganglia are so numerous as to form a kind of network, known as a *plexus*.

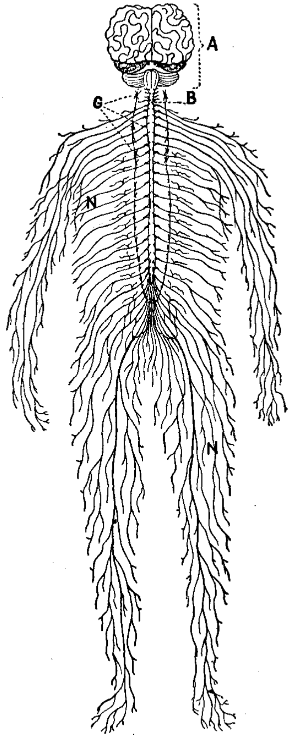

Fig. 125—**Diagram of nerve skeleton.** The illustration shows the extent and general arrangement of the nervous tissue. *A.* Brain. *B.* Spinal cord. *N.* Nerve trunks and nerves. *G.* Ganglia.

It is through these structures—brain and spinal cord, nerve trunks and nerves, ganglia and nerve terminations—that connections are established between all parts of the body, but more especially between the surface of the body and the organs within.

[282] **The Neurons, or Nerve Cells.**—While a hasty examination of the nerve skeleton is sufficient to show the connection of the nervous system with all parts of the body, no amount of study of its gross structures reveals the nature of its connections or suggests its method of operation. Insight into the real nature of the nervous system is obtained only through a study of its minute structural elements. These, instead of being called cells, as in the case of the other tissues, are called *neurons*. The use of this term, instead of the simpler one of nerve cell, is the result of recent advances in our knowledge of the nervous system.[96]

The neurons are in all respects cells. They differ widely, however, from all the other cells of the body and are, in some respects, the most remarkable of all cells. They are characterized by minute extensions, or prolongations, which in some instances extend to great distances. Though the neurons in certain parts of the body differ greatly in form and size from those in other parts of the body, most of them may be included in one or the other of two classes, known as *mon-axonic* neurons and *di-axonic* neurons.

[283] **Mon-axonic Neurons.**—Neurons of this class consist of three distinct parts, known as the cell-body, the dendrites, and the axon (Fig. 126).

The *cell-body* has in itself the form of a complete cell and was at one time so described. It consists of a rounded mass of protoplasm, containing a well-defined nucleus. The protoplasm

[96] Almost to the present time, physiologists have described the nervous system as being made up of two kinds of structural elements which were called *nerve cells* and *nerve fibers*. The nerve cells were supposed to form the ganglia and the fibers to form the nerves. Recent investigators, however, employing new methods of microscopic study, have established the fact that the so-called nerve cell and nerve fiber are but two divisions of the same thing and that the nervous system is made up of, not two, but one kind of structural element. The term "neuron" is used to denote this structural element, or *complete nerve cell*.

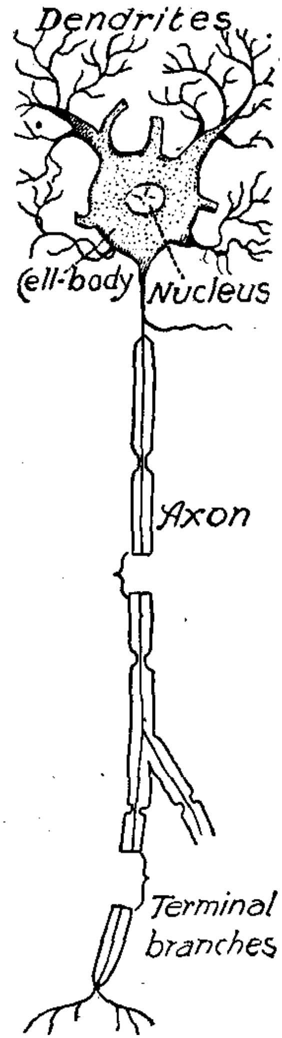

Fig. 126—**Diagram of a mon-axonic neuron** (greatly enlarged except as to length). The central thread in the axon is the axis cylinder.

is similar to that of other cells, but is characterized by the presence of many small granules and has a slightly grayish color.

The *dendrites* are short extensions from the cell-body. They branch somewhat as the roots of a tree and form in many instances a complex network of tiny rootlets. Their protoplasm, like that of the cell-body, is more or less granular. The dendrites increase greatly the surface of the cell-body, to which they are related in function.

The *axon*, or nerve fiber, is a long, slender extension from the cell-body, which connects with some organ or tissue. It was at one time described as a distinct nervous element, but later study has shown it to be an outgrowth from the cell-body. The mon-axonic neurons are so called from their having but a single axon.

Di-axonic Neurons.—Neurons belonging to this class have each a well-defined cell-body and two axons, but no parts just like the dendrites of mon-axonic neurons. The cell-body is smooth and rounded, and its axons extend from it in opposite directions (Fig. 127).

Structure of the Axon.—The axon, or nerve fiber, has practically the same structure in both classes of neurons, being
[284] composed in most cases of three distinct parts. In the center, and running the entire length of the axon, is a thread-like body, called the *axis cylinder* (Fig. 126). The axis cylinder is present in all axons and is the part essential to their work. It may be considered as an extension of the protoplasm from the cell-body. Surrounding the axis cylinder is a thick, whitish-looking layer, known as the *medullary sheath*, and around this is a thin covering, called the *primitive sheath*, or neurilemma. The medullary sheath and the primitive sheath are not, strictly speaking, parts of the nerve cell, but appear to be growths that have formed around it. Certain of the axons have no primitive sheath and others are

without a medullary sheath.[97]

Form and Length of Axons.—Where the axons terminate they usually separate into a number of small divisions, thereby increasing the number of their connections. Certain axons are also observed to give off branches before the place of termination is reached (Fig. 131). These collateral branches, by distributing themselves in a manner similar to the main fiber, greatly extend the influence of a single neuron.

In the matter of length, great variation is found among the axons in different parts of the body. In certain parts of the brain, for example, are fibers not more than one one-hundredth of an inch in length, while the axons that pass all the way from the spinal cord to the toes have a length of more than three feet. Between these extremes practically all variations in length are found.

Arrangements of the Neurons.—Nowhere in the body do the neurons exist singly, but they are everywhere connected with each other to form the different structures observed in the nerve skeleton. Two general plans of connection are to be observed, known as the anatomical and the physiological, or, more simply speaking, as the "side-by-side" and "end-to-end" plans. The side-by-side plan is seen in that disposition of the neurons which [285]
enables them to form the nerves and the ganglia, as well as the brain and spinal cord. The end-to-end connections are necessary to the work which the neurons do.

Side-by-side Connections.—On separating the ganglia and nerves into their finest divisions, it is found that the nerves consist of axons, while the ganglia are made up mainly of cell-bodies and dendrites. The axons lie side by side in the nerve, being surrounded by the same protective coverings, while the

[97] Many of the axons in the brain and spinal cord have no primitive sheath. Axons without the medullary sheath are found in the sympathetic nerves. These are known as non-medullated axons and they have a gray instead of a white color.

cell-bodies form a rounded mass or cluster, which is the ganglion (Fig. 128). But the axons, in order to connect with the cell-bodies, must terminate within the ganglion, so that they too form a part of it. To some extent, also, axons pass through ganglia with which they make no connection. The neurons in the brain and spinal cord also lie side by side, but their arrangement is more complex than that in the nerves and ganglia.

[286] The side-by-side arrangement of the neurons shows clearly the structure of the ganglia and nerves. The nerve is seen to be a bundle of axons, or nerve fibers, held together by connective tissue, while the ganglion is little more than a cluster of cell-bodies. Their connection is necessarily very close, for the same group of neurons will form, with their axons, the nerve, and, with their cell-bodies, the ganglion (Fig. 128).

End-to-end Connections.—These consist of loose end-to-end unions of the fiber branches of certain neurons with the dendrites of other neurons. The purpose of such connections is to provide the means of communication between different parts of the body. There appears to be no actual uniting of the fiber branches with the dendrites, but they come into relations sufficiently close to establish *conduction pathways*, and these extend throughout the body (Fig. 129). They connect all parts of the body with the brain and spinal cord, while connections within the brain and cord bring the parts into communication with each other.

[287] **Nature of the Nervous System.**—The nervous system represents the sum total of the neurons in the body. In some respects it may be compared to the modern telephone system. The neurons, like the electric wires, connect different places with a central station (the brain and spinal cord), and through the central station connections are established between the different places in

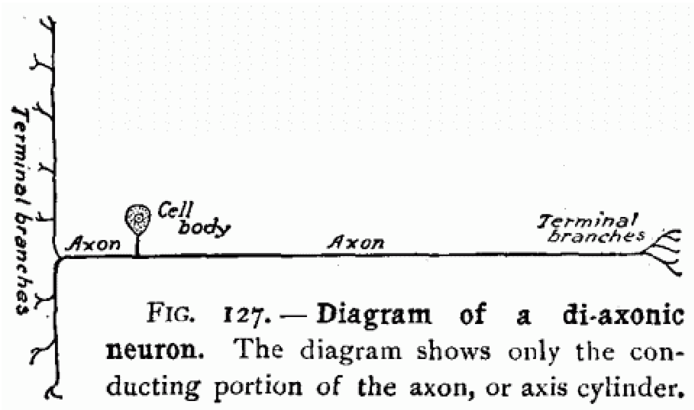

Fig. 127—**Diagram of a di-axonic neuron.** The diagram shows only the conducting portion of the axon, or axis cylinder.

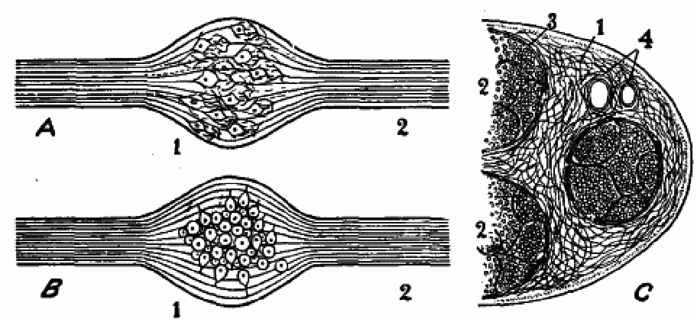

Fig. 128—**Diagrams illustrating arrangement of neurons.** *A, B.* Ganglia and short segments of nerves. 1. Ganglion. 2. Nerve. In the ganglion of *A* are end-to-end connections of different neurons; in the ganglion of *B* are the cell-bodies of di-axonic neurons. *C.* Section of a nerve trunk. 1. Epineurium consisting chiefly of connective tissue. 2. Bundles of nerve fibers. 3. Covering of fiber bundle, or perineurium. 4. Small artery and vein.

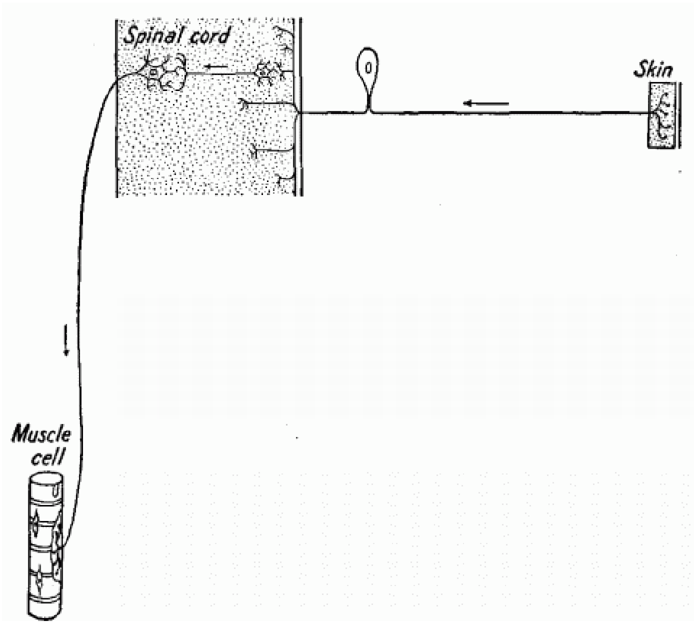

Fig. 129—**Diagram of a nerve path** starting at the skin, extending through the spinal cord, and passing out to muscles. A division of this path also reaches the brain.

the system. As the separate wires are massed together to form cables, the neurons are massed to form the gross structures of the nervous system. The nervous system, however, is so radically different from anything found outside of the animal body that no comparison can give an adequate idea of it. We now pass to a study of the gross structures observed in the nerve skeleton.

Divisions of the Nervous System.—While all of the nervous structures are very closely blended, forming one complete system for the entire body, this system presents different divisions which may, for convenience, be studied separately. As physiologists have become better acquainted with the human nervous system, different schemes of classification have been proposed. The following outline, based upon the location of the different parts, presents perhaps the simplest view of the entire group of nervous structures:

- Nervous System
  - Central
    - Brain
      - Forebrain — Cerebrum
      - Midbrain
      - Hindbrain
        - Pons
        - Cerebellum
        - Bulb
    - Spinal cord
  - Peripheral
    - Ganglia
      - Dorsal-root ganglia
      - Sympathetic ganglia
    - Nerves
      - Cranial nerves
      - Spinal nerves
      - Sympathetic nerves

The Central Division.—This division of the nervous system [288]
lies within the cranial and spinal cavities, and consists of the brain and the spinal cord. The brain occupying the cranial cavity and the spinal cord in the spinal cavity connect with each other through the large opening at the base of the skull to form one continuous structure. The brain and cord are the most

complicated portions of the nervous system, and the ones most difficult to understand.

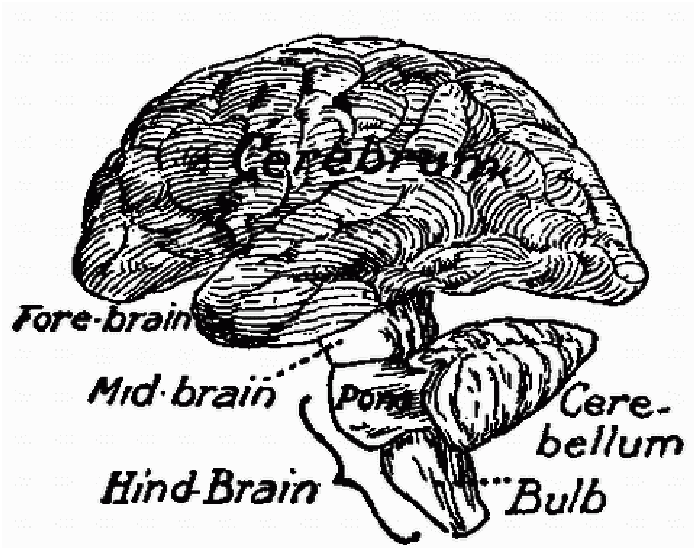

Fig. 130—**Diagram of divisions of brain.**

The Brain.—The brain, which is the largest mass of nervous tissue in the body, weighs in the average sized man about 50 ounces, and in the average sized woman about 44 ounces.[98] It may be roughly divided into three parts, which are named from their positions (in lower animals) the forebrain, the midbrain, and the hindbrain (Fig. 130). The forebrain consists almost entirely of a single part, known as

[98] The difference in weight between the brain of man and that of woman is due mainly to the fact that man's body is, as a rule, considerably larger than that of woman's.

The Cerebrum.—The cerebrum comprises about seven eighths of the entire brain, and occupies all the front, middle, back, and upper portions of the cranial cavity, spreading over and concealing, to a large extent, the parts beneath. The surface layer of the cerebrum is called the *cortex*. This is made up largely of cell-bodies, and has a grayish appearance.[99] The cortex is greatly increased in area by the presence everywhere [289] of ridge-like *convolutions*, between which are deep but narrow depressions, called *fissures*. The interior of the cerebrum consists mainly of nerve fibers, or axons, which give it a whitish appearance. These fibers connect with the cell-bodies in the cortex (Fig. 131).

The cerebrum is a double organ, consisting of two similar divisions, called the *cerebral hemispheres*. These are separated by a deep groove, extending from the front to the back of the brain, known as the *median fissure*. The hemispheres, however, are closely connected by a great band of underlying nerve fibers, called the *corpus callosum*.

At the base of the cerebrum three large masses of cell-bodies are to be found. One of these, a double mass, occupies a central position between the hemispheres, and is called the *optic thalami*. The other two occupy front central positions at the base of either hemisphere, and are known as the *corpora striata*, or the striate bodies.

The Midbrain is a short, rounded, and compact body that

[99] The nervous tissues present, at different places, two colors—one white, and the other a light gray. Great significance was formerly attached to these colors, because it was supposed that they represented two essentially different kinds of nervous matter. It is now known that the protoplasm in all parts of the neuron proper—cell-body, axis cylinder, and dendrites—has a grayish color, while the coverings of most of the fibers are white. Hence gray matter in any part of the nervous system indicates the presence of cell-bodies, and white matter the presence of nerve fibers.

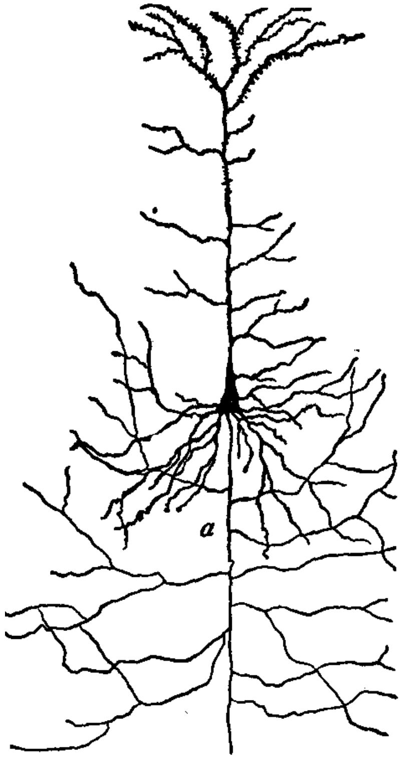

Fig. 131—**Microscope drawing** of a neuron from cerebral cortex. *a.* Short segment of the axis cylinder with collateral branches.

lies immediately beneath the cerebrum, and connects it with [290]
the hindbrain. On account of the great size of the cerebrum, the midbrain is entirely concealed from view when the other parts occupy their normal positions. However, if the cerebrum is pulled away from the hindbrain, it is brought into view somewhat as in Fig. 130.

The midbrain carries upon its back and upper surface four small rounded masses of cell-bodies, called the *corpora quadrigemina*. The upper two of these bodies are connected with the eyes; the lower two appear to have some connection with the organs of hearing. On the front and under surface, the midbrain separates slightly as if to form two pillars, which are called the *crura cerebri*, or cerebral peduncles. These contain the great bundles of nerve fibers that connect the cerebrum with the parts of the nervous system below.

The Hindbrain lies beneath the back portion of the cerebrum, and occupies the enlargement at the base of the skull. It forms about one eighth of the entire brain, and is composed of three parts—the cerebellum, the pons, and the bulb.

The Cerebellum is a flat and somewhat triangular structure with its upper surface fitting into the triangular under surface of the back of the cerebrum. It is divided into three lobes—a central lobe and two lateral lobes—and weighs about two and one half ounces. In its general form and appearance, as well as in the arrangement of its cell-bodies and axons, the cerebellum resembles the cerebrum. It differs from the cerebrum, however, in being more compact, and in having its surface covered with narrow, transverse ridges instead of the irregular and broader convolutions (Fig. 132).

The Pons, or pons Varolii, named from its supposed resemblance to a bridge, is situated in front of the cerebellum, and is readily recognized as a circular expansion which extends forward from that body. It consists largely of bands of nerve fibers, [291]
between which are several small masses of cell-bodies. The

fibers connect with different parts of the cerebellum and with parts above.

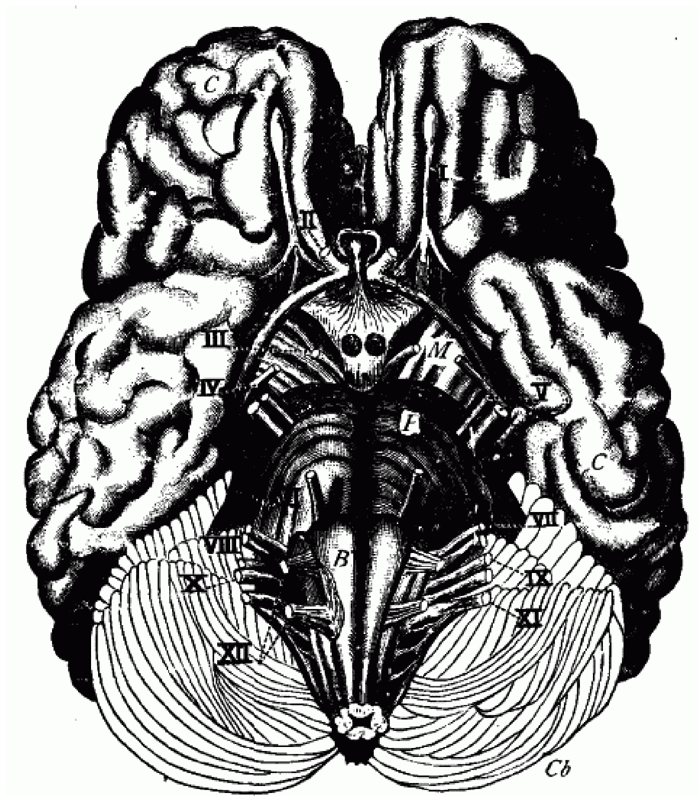

Fig. 132—**Human brain** viewed from below. *C.* Cerebrum. *Cb.* Cerebellum. *M.* Midbrain. *P.* Pons. *B.* Bulb. I-XII. Cranial nerves.

The Bulb, or medulla oblongata, is, properly speaking, an enlargement of the spinal cord within the cranial cavity. It is somewhat triangular in shape, and lies immediately below the cerebellum. It contains important clusters of cell-bodies, as well as the nerve fibers that pass from the spinal cord to the brain.

The Spinal Cord.—This division of the central nervous [292] system is about seventeen inches in length and two thirds of an inch in diameter. It does not extend the entire length of the spinal cavity, as might be supposed, but terminates at the lower margin of the first lumbar vertebra.[100] It connects at the upper end with the bulb, and terminates at the lower extremity in a number of large nerve roots, which are continuous with the nerves of the hips and legs (Fig. 133). Two deep fissures, one in front and the other at the back, extend the entire length of the cord, and separate it into two similar divisions. These are connected, however, along their entire length by a central band consisting of both gray and white matter.

The arrangement of the neurons of the spinal cord is just the reverse of that in the cerebrum—the center being occupied by a [293] double column of cell-bodies, which give it a grayish appearance, while the fibers occupy the outer portion of the cord, giving it a whitish appearance.

The spinal cord is not uniform in thickness, but tapers slightly, though not uniformly, from the upper toward the lower end. At the places where the nerves from the arms and legs enter the cord two enlargements are to be found, the upper being called the *cervical* and the lower the *lumbar enlargement*. These, on account of the difference in length between the cord and the spinal cavity, are above—the lower one considerably above—the places where the limbs which they supply join the trunk (Fig. 133).

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[100] In very early life the spinal cord entirely fills the spinal cavity, but as the body develops the cord grows less rapidly than the spinal column, and, as a consequence, separates at the lower end from the inclosing bony column.

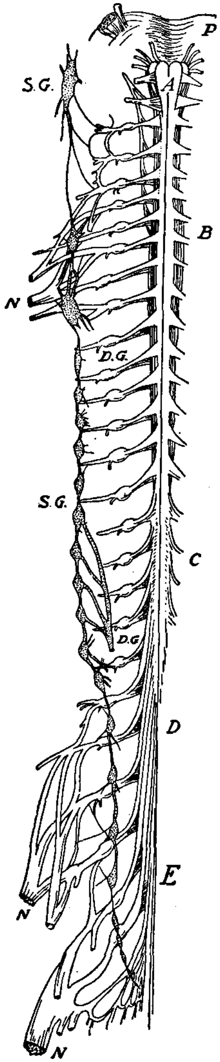

Fig. 133—**Spinal cord**, showing on one side the nerves and ganglia with which it is closely related in function. *A.* Bulb. *B.* Cervical enlargement. *C.* Lumbar enlargement. *D.* Termination of cord. *E.* Nerve roots that occupy the spinal cavity below the cord. *P.* Pons. *D.G.* Dorsal root ganglia. *S.G.* Sympathetic ganglia. *N.* Nerve trunks to upper and lower extremities.

Arrangement of the Neurons of the Brain and Cord.—The cell-bodies in the brain and spinal cord are collected into groups, and their fibers extend from these groups to places that may be near or remote. Guided by the white and gray colors of the nervous tissue, and also by the structures revealed by the microscope, physiologists have made out three general schemes in the grouping of cell-bodies, as follows:

1. *That of surface distribution*, the cell-bodies forming a thin but continuous layer over a given surface. This is the plan in the cerebrum and cerebellum, and here are found devices for increasing the surface: the cerebrum having convolutions, the cerebellum transverse ridges.

2. *That of collections of cell-bodies into rounded masses.* Such masses are found in the bulb, the pons, the midbrain, and the base of the cerebrum.

3. *That of arrangement in a continuous column.* This is the plan in the spinal cord. It matters not at what place the spinal cord be cut, a central area of gray matter, resembling in form the capital letter H, is always found.

The fibers connecting with the cell-bodies in the brain and spinal cord are gathered into bundles or tracts, and these pass through different parts somewhat as follows:

1. *In the cerebrum* they extend in three general directions, forming three classes of fibers. The first connect different localities in the same hemisphere, and are known as *association* fibers (*A*, Fig. 134). The second make connection between the two hemispheres, and form the corpus callosum. These are [294] known as *commissural* fibers (*C*, Fig. 134). The third connect the cerebrum with the parts of the nervous system below, and are called *projection* fibers (*P*, Fig. 134).

2. *In the cerebellum* both association and commissural fibers are found. Bands of fibers, passing upward toward the cerebrum and downward toward the cord, connect this part of the brain with other parts of the nervous system.

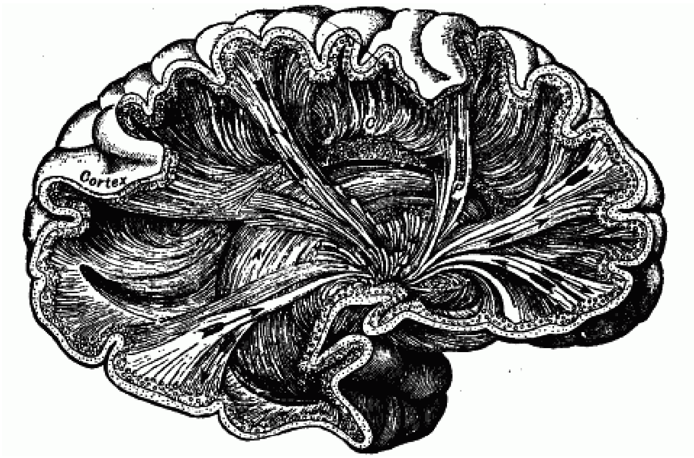

Fig. 134—**Semi-diagrammatic representation of a section through the right cerebral hemisphere**, showing fiber tracts. *A.* Association fibers. *C.* Commissural fibers. *P.* Projection fibers. The cell-bodies with which the fiber bundles connect are in the surface layer or cortex.

3. *In the midbrain, bulb, and spinal cord* fibers are found: first, that connect these parts with the cerebrum[101] and cerebellum
[295] above; second, that pass into and become a part of the nerves of the body; and third, that connect the opposite sides of these parts together.

[101] Fibers passing between the spinal cord and the cerebrum cross to opposite sides—most of them at the bulb, but many within the cord—so that the right side of the cerebrum is connected with the left side of the body, and *vice versa*. This accounts for the observed fact that disease or accidental injury of one side of the cerebrum causes loss of motion or of feeling in the opposite side of the body.

The Peripheral Division.—The peripheral division of the nervous system includes all the nervous structures found outside of the brain and spinal cord. These consist of the cranial, spinal, and sympathetic nerves, and of various small ganglia, all of which are closely connected with the central system.

Spinal Nerves and Dorsal-root Ganglia.—The spinal nerves comprise a group of thirty-one pairs, which connect the spinal cord with different parts of the trunk, with the upper, and with the lower extremities. Each nerve joins the cord by two roots, these being named from their positions the *ventral*, or anterior, root and the *dorsal*, or posterior, root. The two roots blend together within the spinal cavity to form a single nerve trunk, which passes out between the vertebræ. On the dorsal root of each spinal nerve is a small ganglion which is named, from its position, the *dorsal-root ganglion*. (Consult Figs. 133 and 135, and also Fig. 125.)

Double Nature of Spinal Nerves.—Charles Bell, in 1811, made the remarkable discovery that each spinal nerve is double in function. He found the portion connecting with the cord by the dorsal root to be concerned in the *production of feeling* and the portion connecting by the ventral root to be concerned in the *production of motion*. In keeping with these functions, the two divisions of the nerve are made up of different kinds of fibers, as follows:

1. The dorsal-root divisions, of the fibers of di-axonic neurons, the cell-bodies of which form the dorsal-root ganglia (Fig. 135).

2. The ventral-root divisions, of the fibers of mon-axonic [296]
neurons, the cell-bodies of which are in the gray matter of the cord.

The first convey impulses to the cord and are called *afferent* neurons;[102] the second convey impulses from the cord and

[102] In general, *afferent* neurons or fibers are those that convey impulses *toward* the central nervous system (brain and cord), while *efferent* neurons or fibers are those that convey impulses *from* the central system.

are known as *efferent* neurons. Thus, by forming a part of the nerve pathways between the skin and the brain, the dorsal divisions of these nerves aid in the production of feeling; and by completing pathways to the muscles, the ventral divisions aid in the production of motion (Figs. 129, 135, and 141).

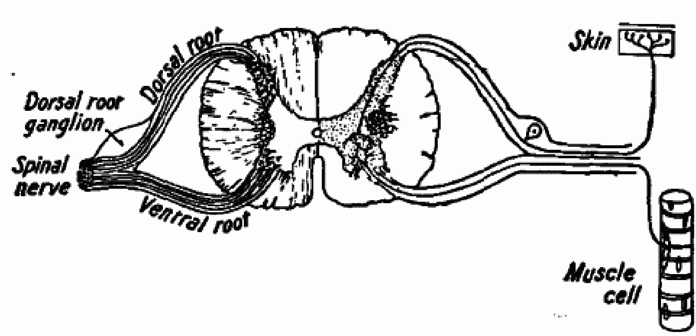

Fig. 135—**Connection of spinal nerves with the cord.** On the right is shown a nerve pathway from the skin to the muscle. A division of this pathway reaches the brain.

The Cranial Nerves.—From the under front surface of the brain, twelve pairs of nerves emerge and pass to the head, neck, and upper portions of the trunk. These, the cranial nerves, have names suggestive of their function or distribution and, in addition, are given numbers which indicate the order in which they leave the brain (Fig. 136). Unlike the spinal nerves, the cranial nerves present great variety among themselves, scarcely any two of them being alike in function or in their connection with different parts of the body. Several of them have to do with
[297] the special senses, and are for this reason very important. They connect the brain with the different parts of the head, neck, and trunk, as follows:

1. The first pair (*olfactory* nerves; nerves of smell; afferent) connect with the mucous membrane of the nostrils (Fig. 136).

2. The second pair (*optic* nerves; nerves of sight; afferent) connect with the retina of the eyes.

3. The third, fourth, and sixth pairs (*motores oculi;* control muscles of the eyes; efferent) connect with the internal and external muscles of the eyeballs (Fig. 136).

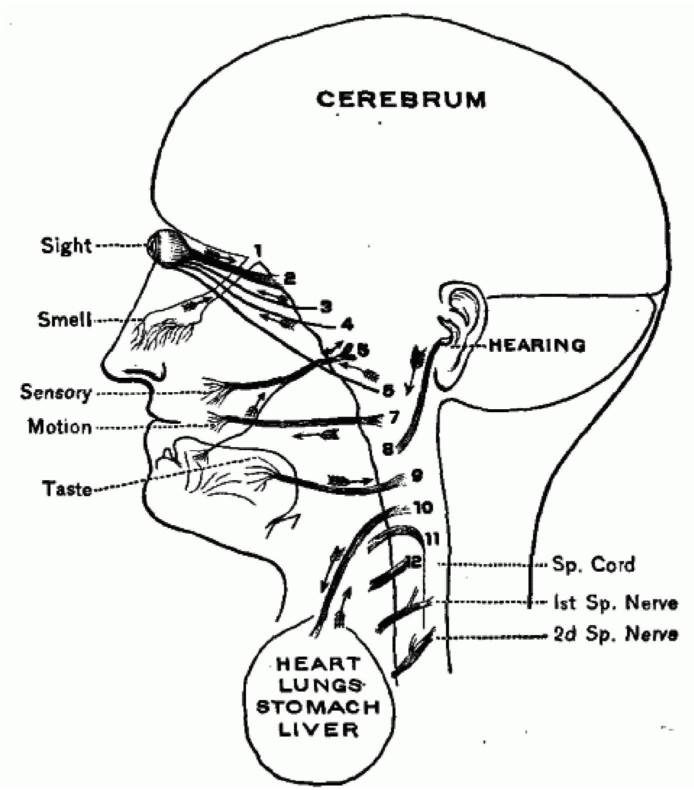

Fig. 136—**Diagram suggesting the distribution and functions of the cranial nerves** (Colton). See also Fig. 132.

[298] 4. The fifth pair (*trigeminal* nerves; nerves of feeling to the face, of taste to the front of the tongue, and of control of muscles of mastication; afferent and efferent) connect with the skin of the face, the mucous membrane of the mouth, the teeth, and the muscles of mastication.

5. The seventh pair (*facial* nerves; control muscles that give the facial expressions; efferent) connect with the muscles just beneath the skin of the face.

6. The eighth pair (*auditory* nerves; nerves of hearing; afferent) connect with the internal ear.

7. The ninth pair (*glossopharyngeal* nerves; nerves of taste to back of tongue and of muscular control of pharynx; afferent and efferent) connect with the back surface of the tongue and with the muscles of the pharynx.

8. The tenth pair (*vagus*, or pneumogastric, nerves; nerves of feeling and of muscular control; afferent and efferent) connect with the heart, larynx, lungs, and stomach. They have the widest distribution of any of the cranial nerves.

9. The eleventh pair (*spinal accessory* nerves; control muscles of neck; efferent) connect with the muscles of the neck.

10. The twelfth pair (*hypoglossal* nerves; control muscles of the tongue; efferent) connect with the muscles of the tongue.

Sympathetic Ganglia and Nerves.—The sympathetic ganglia are found in different parts of the body, and vary in size from those which are half an inch in diameter to those that are smaller than the heads of pins. The largest and most important ones are found in two chains which lie in front, and a little to either side, of the spinal column, and extend from the neck to the region of the pelvis (Figs. 125 and 133). The number of ganglia in
[299] each of these chains is about twenty-four. They are connected on either side by the right and left sympathetic nerves which extend vertically from ganglion to ganglion. In addition to the ganglia forming these chains, important ones are found in the

head (outside of the cranial cavity) and in the plexuses of the thorax and the abdomen.

The sympathetic ganglia receive nerves from the central division of the nervous system, but connect with glands, blood vessels, and the intestinal walls through fibers from their own cell-bodies. Some of these latter fibers join the spinal nerves, and some blend with each other to form small sympathetic nerves.

Protection of Brain and Spinal Cord.—On account of their delicate structure, the brain and spinal cord require the most complete protection. In the first place, they are surrounded by the bones of the head and spinal column; these not only shield them from the direct effects of physical force, but by their peculiar construction prevent, to a large degree, the passage of jars and shocks to the parts within. In the second place, they are surrounded by three separate membranes, as follows:

1. The *dura*, or dura mater, a thick, dense, and tough membrane which lines the bony cavities and forms supporting partitions.

2. The *pia*, or pia mater, a thin, delicate membrane, containing numerous blood vessels, that covers the surface of the brain and cord.

3. The *arachnoid*, a membrane of loose texture, that lies between the dura and the pin.

Finally, within the spaces of the arachnoid is a lymph-like liquid which completely envelops the brain and the cord, and which, by serving as a watery cushion, protects them from jars and shocks. Thus the brain and cord are directly shielded by bones, by membranes, and by the liquid which surrounds them. [300]
They are also protected from jars resulting from the movements of the body by the general elasticity of the skeleton.

Summary.—The nervous system establishes connections between all parts of the body, and provides a stimulus by means of which they are controlled. It is made up of a special form of cells, called neurons. The neurons form the different divisions of the nervous system, and also serve as the active agents in carrying on its work. Through a side-by-side method of joining they form the nerves, ganglia, spinal cord, and brain; and by a method of end-to-end joining they connect places remote from each other, and provide for nervous movements through the body. The nervous system, may in some respects be compared to a complicated system of telephony, in which the chains of neurons correspond to the wires, and the brain and spinal cord to the central station.

Exercises.—1. Give the meaning of the term "coördination." Supply illustrations.

2. What two general conditions are supplied in the body by the nervous system?

3. Compare the skeleton outline of the nervous system with the bony skeleton.

4. Sketch outlines of mon-axonic and di-axonic neurons.

5. Give two differences between the neurons and the other cells of the body.

6. Describe the two general methods of connecting neurons in the body. What purpose is accomplished by each method?

7. Name and locate the principal divisions of the nervous system.

8. Draw an outline of the brain (side view), locating each of its principal divisions.

9. If a pencil were placed over the ear, what portions of the brain would be above it and what below?

10. Describe briefly the cerebrum, the cerebellum, the mid-brain, the pons, and the bulb.

[301] 11. Locate and describe the cortex. State purpose of the convolutions.

12. State the general differences between the cranial and the spinal nerves.

13. Locate and give the number of the dorsal-root ganglia. Locate and give the approximate number of the sympathetic ganglia.

14. Show how the two portions of the spinal nerves are formed—the one from the mon-axonic and the other from the di-axonic neurons.

15. Enumerate the different agencies through which the brain and spinal cord are protected.

16. What cranial nerves contain afferent fibers? What ones contain efferent fibers? What ones contain both afferent and efferent fibers?

17. In what respects is the nervous system similar to a system of telephony? In what respects is it different?

PRACTICAL WORK

Examine a model of the brain, identifying the different divisions and noting the position and relative size of the different parts (Fig. 137). Observe the convolutions of the cerebrum and compare these with the parallel ridges of the cerebellum. If the model is dissectible, study the arrangement of the cell-bodies (gray matter) and the distribution of the fiber bundles (white matter). Note the connection of the cranial nerves with the under side.

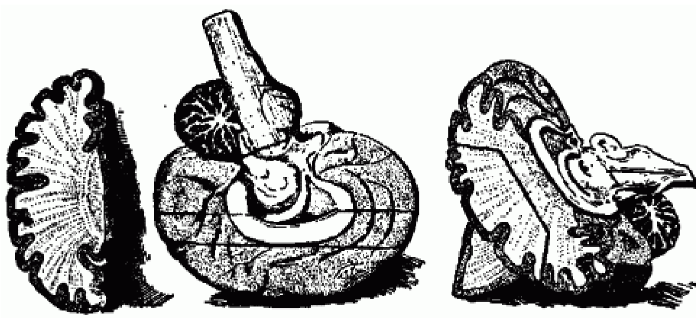

Fig. 137—Model for demonstrating the brain (dissectible).

A prepared nervous system of a frog (such as may be obtained from supply houses) should also be examined. Observe the appearance and general distribution of the nerves and their connection with the brain and spinal cord. If such a preparation is not at hand, some small animal may be dissected to show the main divisions of the nervous system, as follows:

Dissection of the Nervous System (by the teacher).—For this purpose a half-grown cat is generally the best available material. [302] This should be killed with chloroform and secured to a board as in the dissection of the abdomen (page 169). Open the abdominal cavity and remove the contents, tying the alimentary canal where it is cut, and washing out any blood which may escape. Dissect for the nervous system in the following order:

1. Cut away the front of the chest, exposing the heart and lungs. Find on each side of the heart a nerve which passes by the side of the pericardium to the diaphragm. These nerves assist in controlling respiration and are called the *phrenic* nerves. Find other nerves going to different parts of the thorax.

2. Remove the heart and lungs. Find in the back part of the thoracic cavity, on each side of the spinal column, a number of small "knots" of nervous matter joined together by a single nerve. These are sympathetic ganglia. Where the neck joins the thorax, find two sympathetic ganglia much larger than the others.

3. Cut away the skin from the shoulder and upper side of the fore leg. By separating the muscles and connective tissue where the leg joins the thorax, find several nerves of considerable size. These connect with each other, forming a network called the *brachial plexus*. From here nerves pass to the thorax and to the fore leg.

4. From the brachial plexus trace out the nerves which pass to different parts of the fore leg. In doing this separate the muscles with the fingers and use the knife only where it is necessary to

expose the nerves. Note that some of the branches pass into the muscles, while others connect with the skin.

5. Remove the skin from the upper portion of one of the hind legs and separate the muscles carefully until a large nerve is found. This is one of the divisions of the *sciatic* nerve. Carefully trace it to the spinal cord, cutting away the bone where necessary, and find the connections of its branches with the cord. Then trace it toward the foot, discovering its branches to different muscles and to the skin.

6. Unjoint the neck and remove the head. Examine the spinal cord where exposed. Cut away the bone sufficiently to show the connection between the cord and one of the spinal nerves. On the dorsal root of one of the nerves find a small ganglion. What is it called?

7. Fasten the head to a small board and remove the scalp. Saw through the skull bones in several directions. Pry off the small pieces of bones, exposing the upper surface of the brain. Study its membranes, convolutions, and divisions.

8. With a pair of bone forceps, or nippers, break away the skull [303]
until the entire brain can be removed from the cavity. Examine the different divisions, noting the relative position and size of the parts.

9. With a sharp knife cut sections through the different parts, showing the positions of the "gray matter" and of the "white matter."

NOTE.—If the entire class is to examine one specimen, it is generally better to have the dissecting done beforehand and the parts separated and tacked to small boards. This will permit of individual examination. Sketches of the sciatic nerve, brachial plexus, and of sections through the brain and spinal cord should be made.

Location of Nerves in the Body.—Several of the nerves of the body lie sufficiently near the surface to be located by pressure and are easily recognized as sensitive cords. Slight pressure from the fingers reveals the presence of nerves in the grooves of the elbow (the crazy bone), between the muscles on the inner side of the arm near the shoulder, and in the hollow part of the leg back of the knee. These are all large nerves. Small nerves may be located in the same manner in the face and neck.

[304]

CHAPTER XVIII - PHYSIOLOGY OF THE NERVOUS SYSTEM

In the preceding chapter was pointed out the method by which the different parts of the body are brought into communication by the neurons or nerve cells. We are now to study the means whereby the neurons are made to control and coördinate the different parts of the body and bring about the necessary adjustment of the body to its surroundings. This work of the neurons naturally has some relation to their properties.

Properties of Neurons.—The work of the neurons seems to depend mainly upon two properties—the property of irritability and the property of conductivity. *Irritability* was explained, in the study of the muscles (page 243), as the ability to respond to a stimulus. It has the same meaning here. The neurons, however, respond more readily to stimuli than do the muscles and are therefore more irritable. Moreover, they are stimulated by all the forces that induce muscular contraction and by many others besides. They are by far the most irritable portions of the body.

Conductivity is the property which enables the effect of a stimulus to be transferred from one part of a neuron to another. On account of this property, an excitation, or disturbance, in any part of a neuron is conducted or carried to all the other parts. Thus a disturbance at the distant ends of the dendrites causes a movement toward the cell-body and, reaching the cell-body, the disturbance is passed through it into the axon. This movement [305]
through the neuron is called the *nervous impulse*.

Purpose of the Impulse. —Though the nature of the nervous impulse is not understood, [103] its purpose is quite apparent. It is

[103] At different times the nervous impulse has been regarded as a current of

the means employed by the nervous system for controlling and coördinating the different parts of the body. The arrangement of the neurons enables impulses to be started in certain parts of the nervous system, and the property of conductivity causes them to be passed *as stimuli* to other parts. This enables excitation at one place to bring about action at another place.

Acting as stimuli, the impulses seem able to produce two distinct effects: first, to throw resting organs into action and to increase the activity of organs already at work; and second, to diminish the rate, or check entirely, the activity of organs. Impulses producing the first effect are called *excitant* impulses; those producing the second effect, *inhibitory* impulses.

Functions of the Parts of Neurons.—The *cell-body* serves as a nutritive center from which the other parts derive nourishment. Proof of this is found in the fact that when any part of the neuron is separated from the cell-body, it dies, while the cell-body and
[306] the parts attached to the cell-body may continue to live. In addition to this the cell-body probably reënforces the nervous impulse.

The *dendrites* serve two purposes: first, they extend the surface of the cell-body, thereby enabling it to absorb a greater amount of nourishment from the surrounding lymph; second, they act as *receivers of stimuli* from other neurons. The same impulse does not pass from one neuron to another. An impulse in one neuron,

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electricity; as a progressive chemical change, likened to that in a burning fuse; as a mechanical vibration, such as may be passed over a stretched rope; and as a molecular disturbance accompanied by an electrical discharge. The velocity of the nervous impulse, which is only about one hundred feet per second, proves that it is not a current of electricity. It takes place with little or no exhaustion of the cell protoplasm and consequently is not due to chemical action. And the loose, relaxed condition of the nerves prevents their transmission of physical vibrations, like those on a stretched rope. The view that the impulse is a progressive molecular disturbance, accompanied by an electrical discharge, has much evidence in its favor, but it has only recently been proposed and is likely to be modified upon fuller investigation.

however, is able to excite the neuron with which it makes an end-to-end connection, so that a series of impulses is produced along a given nerve path (Fig. 129).

The special *function of the axon* is to transmit the impulse. By its length, structure, and property of conductivity it is especially adapted to this purpose. The axis cylinder, however, is the only part of the axon concerned in the transmission. The primitive sheath and the medullary layer protect the axis cylinder, and, according to some authorities, serve to insulate it. The medullary sheath may also aid in the nourishment of the axis cylinder.

Nerve Stimuli.—While the properties of irritability and conductivity supply a necessary cause for the production and transmission of nervous impulses, these alone are not sufficient to account for their origin. An additional cause is necessary—a force not found in the nerve protoplasm, but one which, by its action on the protoplasm, makes it produce the impulse. In this respect, the neuron does not differ essentially from the cell of a muscle. Just as the muscle cell requires a stimulus to make it contract, so does the neuron require a stimulus to start the impulse. Hence, in accounting for the activities of the body, it is not sufficient to say they are caused by nervous impulses. We must also investigate the *nerve stimuli*—the means through which the nervous impulses are started. Most of these are found [307]
outside of the body and are known as external stimuli.

Action of External Stimuli.—In the arrangement of the nervous system the most favorable conditions are provided for the reception of external stimuli. Not only do vast numbers of neurons terminate at the surface of the body,[104] but they connect there with delicate structures, called *sense organs*. The purpose of the sense organs is to *sensitize* (make sensitive) the terminations of the neurons. This they do by supplying special structures through which the stimuli can act to the best advantage

[104] The surface of the body includes the linings of the air passages, food canal, and certain cavities, as well as the external covering or skin.

upon the nerve endings. Moreover, there are different kinds of sense organs, and these cause the neurons to be sensitive to different kinds of stimuli. Acting through the sense organs adapted for receiving them, light, sound, heat, cold, and odors all act as stimuli for starting impulses. Indeed, the arrangement is so complete that the nervous system is subjected to the action of external stimuli in some form practically all the time. The work of the sense organs is further considered in Chapters XX, XXI, and XXII.

How External Stimuli act on Internal Organs.—For stimulating the neurons not connected with the body surface we are dependent, so far as known, upon the nervous impulses. An impulse started by the external stimulus goes only so far as its neuron extends. But it serves as a stimulus for the neuron with which the first connects and starts an impulse in this connecting neuron, the point of stimulation being where the fiber terminations of the first neuron make connection with the dendrites of the second. This impulse in turn stimulates the next neuron, and
[308] so on, producing a series of impulses along a given nerve path. In this way the effect of an external stimulus may reach and bring about action in any part of the body. This is in brief the general plan of inducing action in the various organs of the body. This plan, however, is varied according to circumstances, and at least three well-defined forms of action are easily made out. These are known as *reflex action*, *voluntary action*, and *secondary reflex action*.

Reflex Action.—When some sudden or strong stimulus acts upon the nerve terminations at the surface of the body, an immediate response is frequently observed in some quick movement. The jerking away of the hand on accidentally touching a hot stove, the winking of the eyes on sudden exposure to danger, and the quick movements from slight electrical shocks are familiar examples. The explanation of reflex action is that external stimuli start impulses in neurons terminating at the surface of the body and these, in turn, excite impulses in neurons which pass from the spinal cord or brain to the muscles (Fig. 138). Since there is an apparent turning back of the impulses by the cord or brain, the resulting movements are termed *reflex*.[105]

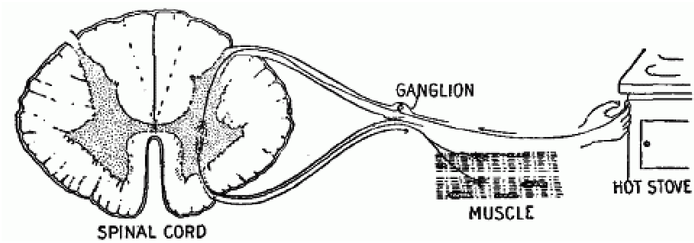

Fig. 138—**Diagram illustrating reflex action of an external organ.**

Reflex Action and the Mind.—If one carefully studies the reflex actions of his own body, he will find that they occur [309] at the time, or even a little before the time, that he realizes what has happened. If a feather is brought in contact with the more sensitive parts of the face of a sleeping person, there is a twitching of the skin and sometimes a movement of the hand to remove the offending substance. Surgeons operating upon patients completely under the influence of chloroform, and therefore completely unconscious, have observed strong reflex actions. These and other similar cases indicate clearly that reflex action occurs *independently* of the mind—that the mind neither causes nor controls it. If a further proof of this fact were needed, it

[105] Derived from the Latin *re*, back, and *flectere*, to turn or bend.

is supplied by experiments upon certain of the lower animals,[106] which live for a while after the removal of the brain. These experiments show that the nervous impulses that produce reflex action need only pass through the spinal cord and do not reach the cerebrum, the organ of the mind.

The Reflex Action Pathway.—By study of the impulses that produce any reflex action, a rather definite pathway may be made out, having the following divisions:

1. *From the surface of the body to the central nervous system* (usually the spinal cord). This, the *afferent* division, is made up of di-axonic neurons, and these have (in the case of the spinal nerves) their cell-bodies in the dorsal root ganglia (page 295). They are acted upon by external stimuli, while their impulses in turn act on the neurons in the spinal cord.

[310] 2. *Through the central system* (spinal cord or base of brain). This, the *intermediate* division, may be composed of mon-axonic neurons, or it may consist of branches from the afferent neurons. In the case of separate neurons, these are acted upon by impulses from the afferent neurons, while their impulses serve in turn as stimuli to other neurons within the cord (Fig. 129).

3. *From the central nervous system to the muscles.* This, the *efferent* division, is made up of mon-axonic neurons. Most of these have their cell-bodies in the gray matter of the cord, while their fibers pass into the spinal nerves by the ventral roots.[107] They may be stimulated by impulses either from the intermediate

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[106] A frog from which the brain has been removed is suspended with its feet downward and free to move. If a toe is pinched, the foot is drawn away, and if dilute acid, or a strong solution of salt, is placed on the tender skin, the feet are moved as if to take away the irritating substance. This of course shows that reflex action can take place independently of the brain.

Now if the spinal cord is also destroyed, there is no response when the irritation of the skin is repeated. The animal remains perfectly quiet, because the destruction of the cord has interrupted the reflex action pathway. This shows that some part of the central nervous system is necessary to reflex action.

[107] Review description of the spinal nerves, page 295.

neurons, or from branches of the afferent neurons. Their impulses reach and stimulate the muscles.

Reflex Action in Digestion.—The flowing of the saliva, when food is present in the mouth, is an example of reflex action. In this case, however, the organ excited to activity is a gland instead of a muscle. The food starts the impulses, and these, acting through the bulb, reach and stimulate the salivary glands. In a similar manner food excites the glands that empty their fluids into the stomach and intestines, and stimulates the muscular coats of these organs to do their part in the digestive process. To a considerable extent, neurons having their cell-bodies in the sympathetic ganglia are concerned in these actions (Fig. 139).

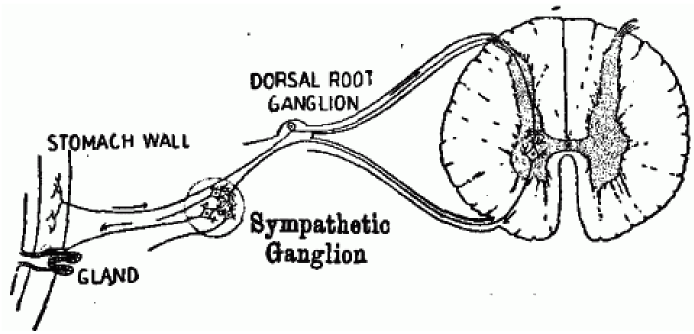

Fig. 139—Diagram illustrating reflex action in its relation to the food canal. The nerve path in this case includes sympathetic neurons.

Reflex Action in the Circulation of the Blood.—On sudden exposure to cold, the small arteries going to the skin quickly [311] diminish in size, check the flow of blood to the surface, and prevent too great a loss of heat. In this case, impulses starting at the surface of the body are transmitted to the bulb and then through the efferent neurons to the muscles in the walls of the arteries. In a somewhat similar manner, heat leads to a relaxation of the arterial walls and an increase in the blood supply to the skin. Other changes in the blood supply to different parts of the body are also of the nature of reflex actions. As in the work of digestion, neurons having their cell-bodies in the sympathetic ganglia aid in the control of the circulation.

Purposes of Reflex Action.—The examples of reflex action so far considered illustrate its two main purposes—(1) protection, and (2) a means of controlling important processes.

The pupil has but to study carefully the reflex actions of his own body for a period, say of two or three weeks, in order to be convinced of their protective value. He will observe that portions of his body have, on exposure to danger, been moved to places of safety, while in some instances, like falling, his entire body has been adjusted to new conditions. He will also find that reflex action is quicker, and for that reason offers in some cases better protection, than movements directed by the mind. In digestion and circulation are found the best examples of the control of important processes through reflex action.

Voluntary Action.—It is observed that reflex action, in the sense that it has so far been considered, is not the usual mode of action of the external organs, but is, instead, a kind of emergency action, due to unusual conditions and excitation by strong stimuli. Voluntary actions, on the other hand, represent the ordinary, or normal, action of these organs. They comprise the movements of the body of which we are conscious and which are *controlled*
[312] *by the mind*. But while they are of a higher order than reflex actions and are under *intelligent* direction, they are brought about in much the same manner.

Voluntary Action Pathways differ in but one essential respect from those of reflex action. They pass through the cerebrum, the organ of the mind (Fig. 140). This is necessary in order that the mind may control the action. From all portions of the body surface, afferent pathways may be traced to the cerebrum; and from the cerebrum efferent pathways extend to all the voluntary organs. A complex system of intermediate neurons, found mostly in the brain, join the afferent with the efferent pathways. The voluntary pathways are not distinct from, but include, reflex pathways, a fact which explains why the same external stimulus may excite both reflex and voluntary action (Fig. 141).

Choice in Voluntary Action.—In reflex action a given stimulus, acting in a certain way; produces each time the same result. This is not the case with voluntary action, the difference being *due to the mind*. In these actions the external stimulus first excites the mind, and the resulting mental processes—perhaps as memory of previous experiences—supply a variety of facts, any of which may act as stimuli to action. Before the action takes place, however, some one fact must be singled out from among [313]
the mental processes excited. This fact becomes the *exciting stimulus* and leads to action. It follows, therefore, that the action which finally occurs is not necessarily the result of an immediate external stimulus, but of a *selected* stimulus—one which is the result of choice.

Not only does the element of choice enter into the selection of the proper stimulus, but it also enters into the time, nature, and intensity of the action. For these reasons it is frequently impossible to trace voluntary actions back to their actual stimuli. The pupil will recognize the element of choice in such simple acts as picking up some object from the street, complying with a request, and purchasing some article from a store.

Reflex and Voluntary Action Compared.—Certain likenesses and differences, already suggested in these two forms of action, may now be more fully pointed out. Reflex and voluntary

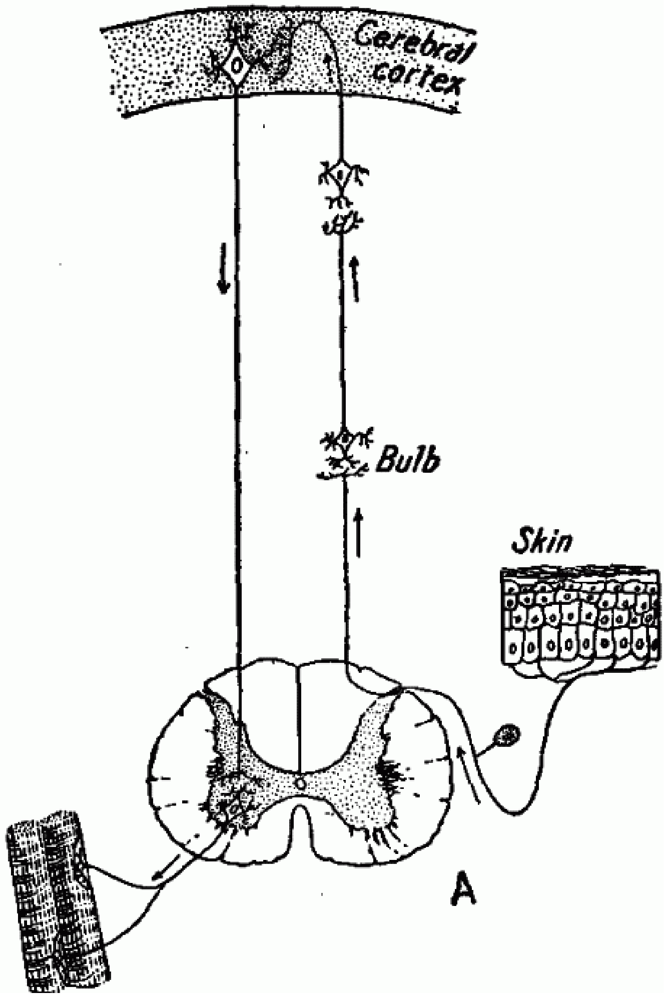

Fig. 140—**Diagram of a voluntary action pathway.**

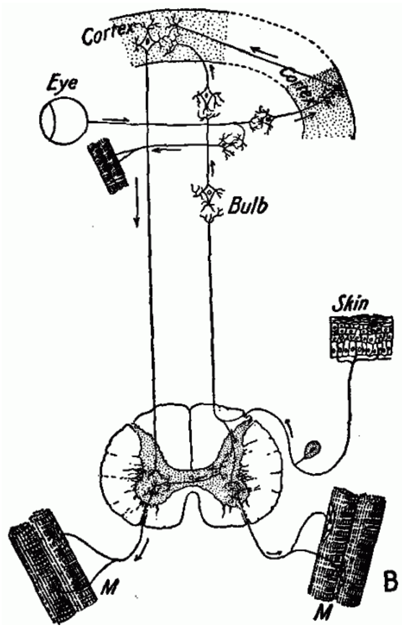

Fig. 141—**Diagram of voluntary action pathways** including reflex pathways.

action are alike in that the primary cause of each is some outside force or condition which has impressed itself upon the nervous system. They are also alike in the general direction taken by the impulses in producing the action. The impulses are, first, from [314] the surface of the body to the central nervous system; second, through the central system; and third, from the central nervous system to the active tissues of the body.

Their chief differences are to be found, first, in the pathways followed by the impulses, which are through the cerebrum (the organ of the mind) in voluntary action, but in reflex action are only through the spinal cord or the lower parts of the brain; and second, in the fact that voluntary action is under the direction of the mind, while reflex action is not. It would seem, therefore, that the statement sometimes made that "voluntary action is reflex action plus the mind" is not far from correct. Mind, however, is the important factor in this kind of action.

Secondary Reflex Action.—Everyday experience teaches that any voluntary action becomes easier by repetition. A given act performed a number of times under conscious direction establishes a condition in the nervous system that enables it to occur without that direction and very much as reflex actions occur. Actions of this kind are known as secondary reflex actions, or as *acquired reflexes*. Walking, writing, and numerous other movements pertaining to the occupation which one follows are examples of such reflexes. These activities are at first entirely voluntary, but by repetition they gradually become reflex, requiring only the stimulus to start them.

The advantages to the body of its acquired reflexes are quite apparent. The mind does not have to attend to the selection and direction of stimuli and, to that extent, is left free for other work. A good example of this is found in writing, where the mind apparently gives no heed to the movements of the hand and is only concerned in what is being written. The student will easily supply other illustrations of the advantages of secondary reflex action.

The development of secondary reflexes probably consists in the establishment of fixed pathways for impulses through the nervous system. Through the branching of the nerve fibers many pathways are open to the impulses. But in repeating the same kind of action the impulses are guided into particular paths, or channels. In time these paths become so well established that the impulses flow along them without conscious direction and it is then simply necessary that some stimulus starts the impulses. By following the established pathways, these reach the right destination and produce the desired result. According to this view, secondary reflex action is but a higher phase of ordinary reflex action—a kind of reflex action, the conditions of which have been established by the mind through repetition. (See functions of the cerebellum, page 317.) [315]

Habits.—People are observed to act differently when exposed to the same conditions, or when acted upon by the same stimuli. This is explained by saying they have different habits. By *habits* are meant certain general modes of action that have been acquired by repetition. Certain acts repeated again and again have established conditions in the nervous system which enable definite forms of action to be excited, somewhat after the manner of reflex action. On account of habits, therefore, the actions of the individual are more or less *predisposed*. What he will do under certain conditions may be foretold from his habits. Habits simply represent, a higher order of secondary reflexes—those more closely associated with the mental life and character than are the lower forms.

Habits, in common with other forms of secondary reflex action, serve the important purpose of *economizing the nervous energy*. However, if pernicious habits are formed instead of those that are useful, they are detrimental from both a moral and physical standpoint. Youth is recognized as the period in which fundamental habits are formed and character is largely

[316] determined. Therefore parents and teachers do wisely when they insist upon the formation of right habits by the young.

Functions of Divisions of the Nervous System.—The relationship between the different parts of the nervous system is very close and one part does not work independently of other parts. At the same time the general work of the nervous system requires that its different divisions serve different purposes:

1. The peripheral divisions of the nervous system are concerned in the transmission of impulses between the surface of the body and the central system and between the central system and the active tissues. The nerves are the carriers of the impulses. The ganglia contain the cell-bodies which serve as nutritive centers; and, in the case of the sympathetic ganglia, these cell-bodies are the places where the fiber terminations of one neuron connect with, and stimulate, other neurons.

2. The gray matter in the spinal cord, bulb, pons, and midbrain (through the cell-bodies, fiber terminations, and short neurons which they contain) completes the reflex action pathways between the surface of the body and the voluntary muscles, and also between the surface of the body and the organs of circulation and digestion.

3. The white matter of the spinal cord, bulb, pons, and midbrain (by means of the fibers of which they are largely composed) forms connections with, and passes impulses between, the various parts of the central nervous system.

4. The bulb, because of certain special reflex-action pathways completed through it, is the portion of the central nervous system concerned in the control of respiration, circulation, and the secretion of liquids.

Work of the Sympathetic Ganglia and Nerves.—The neurons which form these ganglia aid in controlling the vital pro-
[317] cesses, especially digestion and circulation. These neurons are controlled for the most part by fibers from the bulb and spinal cord, and cannot for this reason be looked upon as forming an

independent system. Their chief purpose seems to be that of spreading the influence of neurons from the central system over a wider area than they would otherwise reach. For example, a single neuron passing out from the spinal cord may, by terminating in a sympathetic ganglion, stimulate a large number of neurons, each of which will in turn stimulate the cells of muscles or of glands. Because of this function, the sympathetic neurons are sometimes called *distributing* neurons.

Functions of the Cerebellum.—Efforts to discover some *special* function of the cerebellum have been in the main unsuccessful. Its removal from animals, instead of producing definite results, usually interferes in a mild way with a number of activities. The most noticeable results are a general weakness of the muscles and an inability on the part of the animal to balance itself. This and other facts, including the manner of its connection with other parts of the nervous system, have led to the belief that the cerebellum is the chief organ for the *reflex* coördination of muscular movements, especially those having to do with the balancing of the body. In this connection it is subordinate to and under the control of the cerebrum. Of the relations which the cerebellum sustains to the cerebrum and to the different parts of the body, the following view is quite generally held:

In the development of secondary reflexes, as already described, conditions are established in the cerebellum, such that given stimuli may act *reflexively* through it and produce definite results in the way of muscular contraction. After the establishment of these conditions, afferent impulses from the eyes, ears, skin, and other places, under the general direction of the cerebrum, may cause such actions as the balancing of the body, walking, etc., as well as the delicate and varied movements of the hand. This view of its functions makes of the cerebellum the great center of secondary reflex action.

Functions of the Cerebrum.—While the work of the cerebrum is closely related to that of the general nervous system, it,

more than any other part, exercises functions peculiar to itself. The cerebrum is the part of the nervous system upon which our varied experiences leave their impressions and through which
[318] these impressions are made to influence the movements of the body. But the power to alter, postpone, or entirely inhibit, nervous movements is but a part of the general work ascribed to the cerebrum as *the organ of the mind*. Numerous experiments performed upon the lower animals, together with observations on man, show the cerebrum to be the seat of the mental activities, and to make possible, in some way, the processes of consciousness, memory, volition, imagination, emotion, thought, and sensation.

Localization of Cerebral Functions.—Many experiments have been performed with a view to determining whether the entire cerebrum is concerned in each of its several activities or whether special functions belong to its different parts. These experiments have been made upon the lower animals and the results thus obtained compared with observations made upon injured and imperfectly developed brains in man. The results have led to the conclusion that certain forms of the work of the cerebrum are *localized* and that some of its parts are concerned in processes different from those of others.

The work of locating the functions of different parts of the cerebrum forms one of the most interesting chapters in the history of brain physiology. The portions having to do with sight, voluntary motion, speech, and hearing have been rather accurately determined, while considerable evidence as to the location of other functions has been secured. Much of the cerebral surface, however, is still undetermined (Fig. 142).

NERVOUS CONTROL OF IMPORTANT PROCESSES

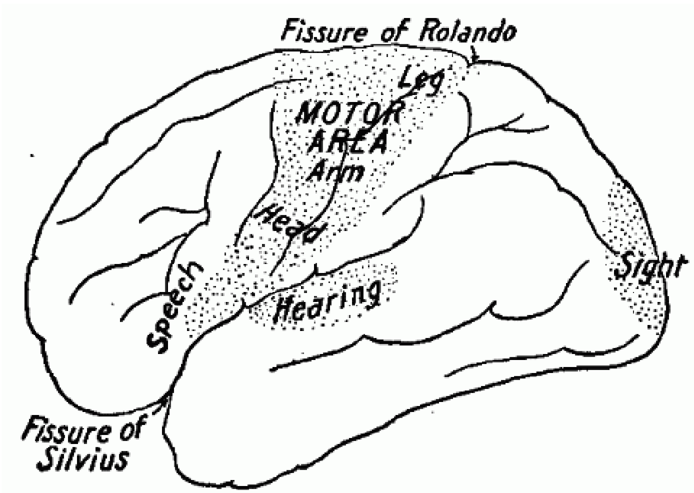

Fig. 142—**Location of cerebral functions.** Diagram of cerebrum, showing most of the areas whose functions are known.

Circulation of the Blood.—1. *Control of the Heart.*—The ability to contract at regular intervals has been shown to reside [319] in the heart muscle. Among other proofs is that furnished by cold-blooded animals, like the frog, whose heart remains active for quite a while after its removal from the body. These automatic contractions, however, are not sufficient to meet all the demands made upon the circulation. The needs of the tissues for the constituents of the blood vary with their activity, and it is therefore necessary to vary frequently the force and rapidity of the heart's contractions. Such changes the heart itself is unable to bring about.

For the purpose of controlling the rate and force of its contractions, the heart is connected with the central nervous system by two kinds of fibers:

a. Fibers that convey *excitant* impulses to the heart to quicken its movements.

b. Fibers that convey *inhibitory* impulses to the heart to retard its movements.

The cell-bodies of the excitant fibers are found in the sympathetic ganglia, but fibers from the bulb connect with and control them. The cell-bodies of the inhibitory fibers are located in the bulb, from where their fibers pass to the heart as a part of the vagus nerve.

In addition to the fibers above mentioned, are those that convey impulses *from* the heart to the bulb. These connect with neurons that in turn connect with blood vessels and with them act reflexively, when the heart is likely to be overstrained, to cause a dilation of the blood vessels. This lessens the pressure which the heart must exert to empty itself of blood. These fibers serve, in this way, as a kind of safety valve for the heart.

2. *Control of Arteries.*—Changes in the rate and force of the heart's contractions can be made to correspond only to the *general* needs of the body. When the blood supply to a particular organ is to be increased or diminished, this is accomplished

through the muscular coat in the arteries. The connection of the arterial muscle with the sympathetic ganglia and the method by which they vary the flow of blood to different organs has already been explained (pages 311 and 49), so that only the location of the controlling neurons need be noted here. These, like the controlling neurons of the heart, have their cell-bodies in the bulb. It thus appears that the entire control of the circulation is effected in a reflex manner through the nerve centers in the bulb. These centers are stimulated by conditions that relate to the movement of the blood through the body.

Respiration.—Efferent fibers connect the different muscles [320]
of respiration with a cluster of cell-bodies in the bulb, called the *respiratory center*. This center together with the nerves and muscles in question form an automatic, or self-acting, mechanism similar in some respects to that of the heart. Through the impulses passing from the respiratory center to the muscles, a rhythmic action is maintained sufficient to satisfy the usual needs of the body for oxygen. The demand of the body for oxygen, however, varies with its activities, and to such variations the respiratory center alone is unable to respond. The regulating factor in the respiratory movements has been found to be the condition of the blood with reference to the presence of oxygen and carbon dioxide. If the blood contains much carbon dioxide and little oxygen, it acts as a strong stimulus to the respiratory center, causing it, in turn, to stimulate the respiratory muscles with greater intensity and frequency. On the other hand, if the blood contains much oxygen and little carbon dioxide, it acts only as a mild stimulus. This explains how physical exercise increases the breathing, since the muscles at work consume more oxygen than when resting and give more carbon dioxide and other wastes to the blood.

The respiratory center is also connected by afferent nerves with the mucous membrane of the air passages. Irritation of the nerve endings in this membrane causes impulses to pass to the center, and this leads, by reflex action, to such modifications of the respiratory acts as sneezing and coughing. There is also a connection between the cerebrum and the respiratory center. This is shown by the fact that one can voluntarily change the rate and force of the respiratory movements, and further by the fact that emotions affect the breathing.

Regulation of the Body Temperature.—As explained in the study of the skin (page 270), the nervous system regulates the body temperature by controlling the circulation of the blood through the skin and the internal organs. This is accomplished by stimulating in a reflex manner the muscles in the walls of certain arteries. To prevent the body from getting too hot, muscles in the arteries going to the skin relax, thereby allowing more blood to flow to the surface, where the heat can be disposed of through radiation and through the evaporation of the perspiration. On the other hand, if the body is in danger of losing too much heat, the muscles in the walls of arteries going to the skin are made to contract and those to internal organs relax, so that less blood
[321] flows to the skin and more to the internal organs. In this way the nervous system adjusts the circulation to suit the conditions of temperature outside of and within the body and, in so doing, maintains the normal body temperature.

Summary.—The nervous system is able to control, coördinate, and adjust the different organs of the body through its intimate connection with all parts and through a stimulus (the nervous impulse) which it supplies and transmits. Nervous impulses, excited by external stimuli, follow definite paths and cause activity in the different parts of the body. All such pathways are through the central nervous system. In reflex action the impulses are mainly through the spinal cord, but to some extent through the bulb, pons, and midbrain. In voluntary action they pass through the cerebrum—a condition that leads to important modifications in the results. The cerebrum, in addition to controlling the voluntary movements, is able to establish the necessary conditions for secondary reflex actions, such as walking, writing, etc. Although certain of the divisions of the nervous system exercise special functions, all parts of it are closely related.

Exercises.—1. Give the function of each of the parts of a neuron.

2. State the purpose of the nervous impulse.

3. Show that the exciting cause of bodily action is outside of the nervous system and, to a large extent, outside of the body.

4. Describe the arrangement that enables stimuli outside of the body to cause action within the body.

5. Describe a reflex action and show how it is brought about.

6. Distinguish between afferent, efferent, and intermediate neurons.

7. Draw diagrams showing the impulse pathways in voluntary and in reflex action.

8. What purposes are served by the sympathetic neurons?

9. Describe the method of control of the circulatory and digestive processes. How do reflex actions protect the body?

10. Compare voluntary and reflex action. In what sense are [322]
all the activities of the body reflex?

11. In what sense is walking voluntary? In what sense is it reflex?

12. How does secondary reflex action lessen the work of the nervous system?

13. State the special functions of the nerves, ganglia, spinal cord, bulb, cerebellum, and cerebrum.

14. State the importance of the formation of correct habits.

PRACTICAL WORK

To demonstrate Nerve Pathways.—A smooth board, 2x6 ft., is painted black, and upon this is drawn in white a life-size outline

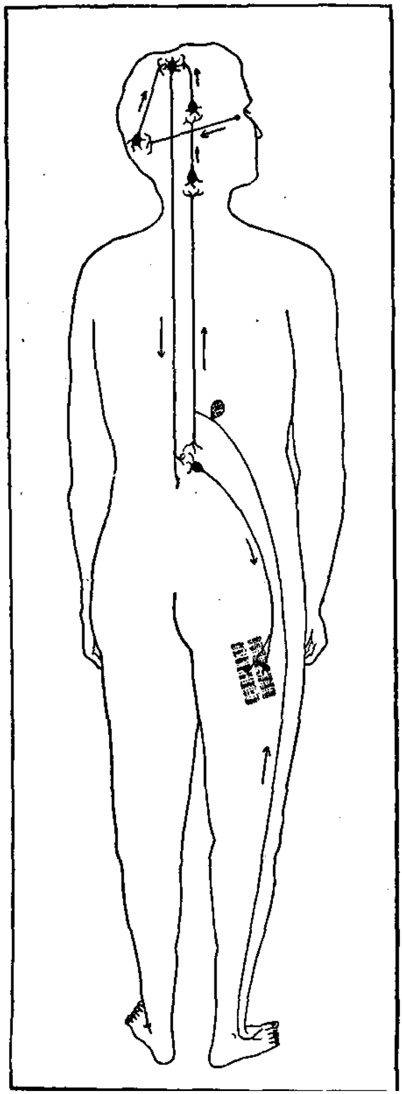

Fig. 143—Nerve board for demonstrating nerve pathways.

of the body. Pieces of cord of different colors and lengths are knotted to represent mon-axonic and di-axonic neurons. These are then pinned or tacked to the board in such a manner as to represent the connections in the different kinds of nerve pathways. Fig. 143 shows such a board with connections for a reflex action and a voluntary action of the same muscle.

Study of the "Knee Jerk" Reflex.—A boy is seated on a chair with the legs crossed. With a small pointer he is given a light, quick blow on the upper margin of the patella at the point of connection of the tendon. The stroke will usually be followed by a reflex movement of the foot. Does this take place independently of the mind? (The one upon whom the experiment is being performed should assume a relaxed condition and make no effort either to cause or prevent the movement.) Can the movement be inhibited (prevented)? Repeat the experiment, effort being [323] made to prevent the movement, but not by contracting opposing muscles.

Other reflex actions adapted to class study are those of the eyes, such as the closing of the lids on moving objects near them and the dilating of the pupils when the eyes are shaded. The involuntary jerking of the head on bringing the prongs of a vibrating tuning fork in contact with the end of the nose is also a reflex action which can be studied to advantage.

To determine the Reaction Time.—Have several pupils join hands, facing outwards, making a complete circle, excepting one gap. Give a signal by touching the hand of one pupil at the end of the line. Let this pupil communicate the signal, by pressure of the other hand, to the next pupil and so on around, having the last pupil raise the free hand at close of the experiment. Note carefully the time, preferably with a stop watch, required to complete the experiment and divide this by the number of pupils, to get the average reaction time. The experiment may be repeated with boys only and then with girls, comparing their average reaction time.

Reflex Action of the Salivary Glands.—Place a small pinch of salt upon the tongue and note the flow of saliva into the mouth. Try other substances, as starch, bits of wood, and sugar. What appears to be the natural stimulus for these glands? Compare with reflex actions of the muscles.

[324]

CHAPTER XIX - HYGIENE OF THE NERVOUS SYSTEM

The far-reaching effects and serious nature of disorders of the nervous system are sufficient reasons for considering carefully those conditions that make or mar its efficiency. Controlling all the activities of the body and affecting through its own condition the welfare of all the organs, the hygiene of the nervous system is, in a large measure, the hygiene of the entire body. Moreover, it is known that some of our worst diseases, including paralysis and insanity, are disorders of the nervous system and are prevented in many instances by a proper mode of living.

The Main Problem.—Many of our nervous disorders are undoubtedly due to the age in which we live. Our modern civilization, with all its facilities for human advancement and enjoyment, throws an extra strain upon the nervous system. Educational and social standards are higher than ever before and life in all its phases is more complex. Since we can hardly change the conditions under which we live, and probably would not if we could, we must learn to adapt or adjust ourselves to them so as to secure for the nervous system such relief as it requires. This adjustment is sometimes difficult, even when the actual needs of the nervous system are known.

The healthful action of the nervous system requires, on the one hand, exercise, but on the other hand, a certain condition of quietude, or *poise*—a state which is directly opposed to that of restlessness. The conditions of modern life seem able to force [325] upon the nervous system all the exercise that it needs, and more (whether it be of the right kind or not), so that the main problem of to-day seems to be that of conserving, or economizing, the nervous energy and of preventing nervous waste.

Wasteful Forms of Nervous Activity.—There are without doubt many forms of activity that waste the vital forces of the body and lead to nervous exhaustion. Take, for example, the rather common habit of worrying over the trivial things of life. Certainly the nervous energy spent in this way cannot be used in doing useful work, but must be counted as so much loss to the body. One who would use his nervous system to the best advantage must find some way of preventing waste of this kind.[108]

Undue excitement, as well as pleasurable dissipations, also tend toward nervous exhaustion. And while the fact is recognized that pleasurable activities supply a necessary mental exercise, the limit of healthful endurance must be watched and *excesses of all kinds avoided*. Intense emotional states are found to be exhausting in the extreme; and the suppression of such undesirable feelings as anger, fear, jealousy, and resentment are of immense value in the hygiene of the nervous system.

The Habit of Self-control.—Much of the needless waste of nervous energy, including that of worrying over trivial matters, may be prevented through the exercise of self-control. From the standpoint of the nervous system, the present age differs from the
[326] past mainly in supplying a greater number and variety of nerve stimuli. Self-control means the ability to suppress activities that would result from undesirable stimuli and to direct the bodily activities into channels that are profitable. Self-control, therefore, is not only to be exercised on occasions of great emergency, but in the everyday affairs of life as well. It is even more important that the daily toiler at his task be able to keep the petty annoyances

[108] Where a deep-seated cause for worry exists, there may be occasion for grave concern. Many people have become insane through continued worry about some *one* thing. In cases of this kind the sufferer needs the aid of sympathetic friends, and sometimes of the physician, in getting the mind away from the exciting cause. A change of scene, a visit, or some new employment is frequently recommended, where the actual cause for the worry cannot be removed.

of life from acting as irritants to his nervous system than that he keep cool during some great calamity. The habit of self-control is acquired mainly through the persistent effort to prevent any and all kinds of petty annoyances from affecting the nerves or the temper.

Nervousness.—Self-control is much more easily practiced by some than by others. This is due partly to habit, but is also due to an actual difference in the degree of sensitiveness, or irritability, of the nervous systems of different people. One whose nervous system tends to respond too readily to any and all kinds of stimuli is said to be "nervous." This condition is in some instances inherited, but is in most cases due to the wasteful expenditure of nervous energy or to the action of some drug upon the body. Excess of mental work, too much reading, long-continued anxiety, eye strain, and the use of tea, coffee, alcohol, tobacco, or other drugs, including many of those taken as medicines, are known to cause nervousness. Nervousness is not only a source of great annoyance, both to one's self and to others, but is a menace to the general health.

The first step toward securing relief from such a condition is the removal of the cause. The habits should be inquired into and excesses of all kinds discontinued. In some instances it may be necessary to *have the eyes examined* and glasses fitted by a [327]
competent oculist.[109] The nervous energy should be carefully economized and the habit of self-control diligently cultivated. Special exercises that have for their purpose the equalizing of

[109] Any part of the body which is overworked or which works at a disadvantage tends to disturb, more or less, the entire nervous system and to produce nervousness. Especially is this true of such delicate and highly sensitive structures as the eyes. If the eyes do not focus properly or if the muscles that move the eyeballs are out of their natural adjustment, extra work is thrown upon these delicate parts. One of the first and sometimes the only indication of eye strain is that of some disturbance of the nervous system. For this reason it is important to carefully test the eyes in determining the cause of nervousness (page 385).

the circulation and the strengthening of the blood vessels of the neck and the brain also have beneficial effects.

Nervous Overstrain.—Both mental and physical overwork tends to weaken the nervous system and to produce nervousness. Where hard mental work is long continued, or where it is carried on under excitement, a tense nervous condition is developed which is decidedly weakening in its effects. The causes which lead to such a condition, and in fact overwork of all kinds, should if possible be avoided. Where this is not possible, and in many cases it is not, the period of overwork should be followed by one of rest, recreation, and plenty of sleep. To the overworked in body or in mind, nothing is more important from a hygienic, as well as moral, standpoint, than the right use of the *one rest day in seven*. The best interests of our modern civilization *require* that the Sabbath be kept as a quiet, rest-giving day.

Disturbed Circulation of the Brain.—Nervousness not infrequently is accompanied by an increase in the circulation of the brain and disappears when this condition is relieved. Though mental work and excitement tend naturally to increase the circulation in the brain, this should subside with rest and relief
[328] from excitement. When there is a tendency for this condition to become permanent, effort should be made looking for relief. Increasing the circulation in the lower extremities by hot or cold foot baths, or by much walking, is found to be most beneficial. Special exercises of the muscles of the neck are also recommended as a means of relieving this condition.[110]

Hygienic Value of Work.—Within reasonable limits, both mental and physical work are conducive to the vigor of the

[110] One form of neck exercise recommended for this purpose is easily taken on retiring at night. Lying flat on the back, without a pillow, lift the head slowly from the bed and let it as slowly settle back to the level of the body. Repeat several times, lying on the back, and then again on the face and again on each side. Practice these exercises every night during an interval of a month or until relief is secured.

nervous system. Through work the energies of the body find their natural outlet, and this prevents dissipation and the formation of bad habits. Even hard work does not injure the nervous system, and severe mental exertion may be undergone, provided the proper hygienic conditions are observed. The nervous disorders suffered by brain workers are not, as a rule, due to the work which the brain does, but to violation of the laws of health, especially the law of exercise. Such persons should observe the general laws of hygiene and especially should they practice daily those forms of physical exercise that tend to counteract the effects of mental work.

Physical Exercise properly taken is beneficial to the nervous system through both direct and indirect effects. A large proportion of the nerve cells have for their function the production of motion, and these are called into play only through muscular activity. Then, as already suggested, physical exercise counteracts the unpleasant effects of mental work. Hard study causes an excess of blood to be sent to the brain and a diminished amount to the [329]
arms and to the legs. Physical exercise redistributes the blood and equalizes the circulation. Light exercise should, therefore, follow hard study. The student before retiring at night is greatly aided in getting to sleep and is put in a better condition for the next day's work by ten to fifteen minutes of light gymnastics. A daily walk of two or three miles is also an excellent means of counteracting the effects of mental work. The brain worker should, however, avoid violent exercise or the carrying of any kind of exercise to exhaustion.

Sleep, and plenty of it, is one of the first requirements of the nervous system. It is during sleep that the exhausted brain cells are replenished. To shorten the time for sleep is to weaken the brain and to lessen its working force. No one should attempt to get along with less than eight hours of sleep each day and most people require more. Children require more sleep than adults. Those under six years should have from eleven to twelve hours of sleep per day. Children between six and ten years should have at least ten hours.

Insomnia, or sleeplessness, on account of its effects upon the nervous system, is to be regarded as a serious condition, and hygienic means for relieving it should be diligently sought. Having its cause in nervousness, a disturbed circulation of the brain, or some form of nervous exhaustion, it is benefited through relieving these conditions and in the manner already described. Of course the external conditions for aiding sleep should not be overlooked. The bed should be comfortable, and the room should be cool, well ventilated, dark, and quiet. The inducing of sleep by means of drugs is a dangerous practice and should never be resorted to except under the direction of the physician.

[330] **Effects of Heat and Cold.**—Heat and cold both have their effects upon the nervous system. Heat increases the nervous irritability, while cold acts as a natural sedative to the nerves. A nervous person is made more nervous by an overheated atmosphere, but derives beneficial effects from exposing the body freely to cold air and water. The tonic cold bath (page 273), if taken with the usual precautions, can be used to good advantage in diminishing nervousness. The taking of outdoor exercise in cold weather is, for the same reason, an excellent practice.

Effect of Emotional States.—We have already noted the effect of certain emotional states upon the digestion of the food (page 162). Emotional states are also known to interfere with breathing and with the action of the heart. Such effects are explained through the close relation of the mind to the work of the nervous system in general. While certain emotional states, such as fear, anger, melancholia, and the impulse to worry, interfere seriously with the normal action of the nervous system, others, such as contentment, cheerfulness, and joy, are decidedly beneficial in their effects. How important, then, is the habit of suppressing the states that are harmful and of cultivating those that are beneficial. From a hygienic, as well as social, standpoint a cheerful, happy disposition is worth all the effort necessary for its attainment.

The Nervous Condition of Children should be a matter of deep concern on the part of both parents and teachers. In the home, as well as in the school, the child may be "pushed" until the nervous system receives permanent injury. Exhaustion of nerve cells is produced through too many and too vivid impressions being made upon the immature brain. The child should be protected from undue excitement. He should have the benefit of [331] outdoor exercise and should be early inured to cold. He should be shielded from the poisoning effects of tea, coffee, tobacco, alcohol, and other drugs. He should have impressed upon him the habit of self-control. He should not be indulged in foolish caprices or whims, but should be taught to be content with plain, wholesome food and with the simple forms of enjoyment.

Influences at School.—School life is necessarily a great strain upon the child. Night study added to the work of the day makes a heavy burden for elementary pupils to bear. Though the legal school age is usually fixed at six years, delicate children should be kept out of school until they are seven or eight years old, provided they have good homes. In addition to the excitation incident to studying and reciting lessons, conditions frequently arise both in the schoolroom and upon the playground that create a feeling of fear or dread in the minds of children. Quarrels and feuds among the children and the bullying of big boys on the playground may work untold harm. All conditions tending to develop fear, uneasiness, or undue excitement on the part of children should receive the attention of those in authority.

Excessive Reading is a frequent cause of injury to the nervous systems of children. This has a bad effect, both on account of too many impressions being made upon the mind and also on account of the strain to the eyes. Then if the reading consists mostly of light fiction, the mind is directed away from the really

important things of life. The reading of children should be thoughtfully controlled, both as to quality and quantity. Exciting stories should, as a rule, be excluded, but a taste for biography,
[332] historical and scientific writings, and for the great works of literature should be cultivated. Simple fairy tales which have a recognized value in developing the imagination of the child need not be omitted, but it is of vital importance that the "story-reading habit" be not formed.

Effects of Drugs.—Because of its delicacy of structure a number of chemical compounds, or drugs, are able to produce injurious effects upon the nervous system. Some of these are violent poisons, while others, in small quantities, are mild in their action. Certain drugs, in addition to their immediate effects, bring about changes in the nervous system which cause an unnatural appetite, or craving, that leads to their continued use. This is the case with alcohol, the intoxicating substance in the usual saloon drinks, and with nicotine, the stimulating drug in tobacco. The same is also true of morphine, chloral, and several other drugs used as medicines. The *danger of becoming a slave* to some useless and pernicious habit should dissuade one from the use of drugs except in cases of positive emergency.

Alcohol and the Nervous System.—Alcohol, as already shown, injures practically all portions of the body; but it has its worst effects upon the nervous system. Through its action on this system, it interferes with the circulation of the blood, produces a condition of "temporary insanity" called intoxication, weakens the will, and eventually dethrones the reason. Worst of all, it produces a condition of "chronic poisoning" which manifests itself in an unnatural craving, and this causes it to be used by the victim even when he knows he is "drinking to his own destruction." Though its use in small quantities does not, as a rule, produce such marked effects upon the nervous system, it develops the "craving," and this is apt in time to lead to its use in larger quantities. But even if this does not occur, the practice

is objectionable for its unhygienic effects in general.[111] Tippling [333]
with such mild solutions of alcohol as light wine, beer, and hard cider is, for these reasons, a dangerous pastime.

Alcohol and Crime.—It is sometimes stated that no one who leaves alcohol alone will be injured by it. This is true only of its direct effects; not of its indirect effects. Whenever a crime is committed somebody is injured, and alcohol is known to be a chief cause of crime. Alcohol causes crime through the loss of self-control, seen especially in intoxication, and also because of the moroseness and quarrelsomeness which it developes in certain individuals. Indirectly it causes crime through the poverty which it engenders and through its influence in bringing about social conditions out of which crime develops. Everything considered, the free use of alcohol is incompatible with the nervous health and moral tone of a community.

Nicotine and the Nervous System.—Nicotine is an oily substance which is extracted from the tobacco plant. Its action on the nervous system is in general that of a poison. Taken in small quantities, it is a mild stimulant and, if the doses are repeated, a habit is formed which is difficult to break. Tobacco is used mainly for the stimulating effect of this drug. While not so serious in its results as the alcohol and other drug habits, the use of tobacco is of no benefit, is a continual and useless expense, and, in many instances, causes a derangement of the
healthy action of the body.[112] With the bad effects of the nicotine [334]
must be included those of questionable substances added to the tobacco by the manufacturer, either for their agreeable flavor or

[111] Insurance statistics show that habitual *moderate drinkers* do not live so long as abstainers.

[112] Organs very frequently affected by tobacco are the heart and the eyes. It induces, as already stated (page 56), a dangerous nervous derangement called "tobacco heart," and it causes a serious disorder of the retina (retinitis) which leads in some instances to loss of vision. Tobacco smoke also acts as an irritant to the delicate lining of the eyes, especially when the tobacco is smoked indoors.

for adulteration.

Relation of Age to the Effects of Nicotine.—The use of tobacco by the young is especially to be deplored. In addition to the harmful effects observed in those of mature years, nicotine interferes with the normal development of the body and lays, in many instances, the foundation for physical and mental weakness in later life. The cigarette is decidedly harmful, especially when inhalation is practiced, its deadening effects being in part due to the wrappers, some of which have been shown to contain arsenic and other poisonous drugs. While dulling the intellect and weakening the body, cigarette smoking also tends to make criminals of boys.[113] Parents, teachers, school officers, and all who have the good of mankind at heart should take every precaution, including that of setting a good example, to prevent the formation of the tobacco habit by those of immature years.

Habit versus Self-control.—The power of self-control, already emphasized for its importance in the economical expenditure of the nervous energy, is of vital importance in its relation to the habits of the body. Self-control is the chief safeguard against the formation of bad habits and is the only means of redemption from such habits after they have once been formed. The persistent cultivation of the power to control the appetites and the passions, as well as all forms of activity which tend to injure the body or
[335] debase the character, gives a tone to the nervous system which increases the self-respect and raises the individual to a *higher plane of life*. The worst habits *can* be broken and good ones formed in their stead, if only there is sufficient determination to accomplish these results. Failure comes from not having the mind thoroughly "made up" and from not having, back of the desire to do better, "the strong will of a righteous determination."

[113] Of 4117 boys in the Illinois State Reformatory, 4000 used tobacco, and over 3000 were cigarette smokers. Dr. Hutchison, of the Kansas State Reformatory, says: "Using cigarettes is the cause of the downfall of more of the inmates of this institution than all other vicious habits combined."

Effects of External Conditions.—While the inner life and habits have most to do with the hygiene of the nervous system, a certain amount of attention may properly be given to those conditions outside of the body which affect directly or indirectly the state of this system. Noise, disorder, and confusion act as nervous irritants, but quiet, order, and system have the opposite effect. There is, therefore, much in the management of the office, factory, schoolroom, or home that has to do with the real hygiene of the nerves as well as with the efficiency of the work that is being done. The suppression of distracting influences not only enables the mind to be given fully to the work in hand, but actually prevents waste of nervous energy. Although the responsibility for securing the best conditions for work rests primarily with those in charge, it is also true that each individual in every organization may contribute to the order or disorder that prevails.

Social Relations.—In considering the external conditions that affect the nervous system, the fact must not be overlooked that man is a social being and has to adjust himself to an established social order. His relations to his fellow-men, therefore, affect strongly his nervous condition and theirs also. For this reason the best hygiene of the nervous system is based upon *moral* as well as physical right living. Along with the power of self-control and the maintenance of a correct nervous poise, there should be a proper regard for the welfare of others. On account of [336]
the ease with which one individual may disturb the nervous state of another, those social forms and customs which tend to establish harmonious relations among men are truly hygienic in their effects, and may well be carried out in spirit as well as "in letter."

It is also a fact that a given mental state in one person tends to excite a like state in those with whom he associates. How important, then, that each and all cultivate, as habits, the qualities of cheerfulness, kindness, and good-will, instead of the opposite states of mind. Especially in the family, and other groups of closely associated individuals, should the nervous effect of one member upon the others be considered and every effort made to secure and maintain harmonious relations.

The High Ideal.—Everything considered, the conditions most favorable to the healthfulness of the nervous system are in harmony with what our greatest teachers have pointed to as the higher plane of living. On this account a true conception of the value and meaning of life is of the greatest importance. *An ever present, strong desire to live a vigorous, but simple and noble, life* will suggest the proper course to pursue when in doubt and will stimulate the power of self-control. It will lead to the stopping of "nerve leaks" and to the maintenance of harmonious relations with one's fellows. It will cause one to recoil from the use of alcohol and other nerve poisons, as from a deadly serpent, seeing the end in the beginning, and will be the means eventually of leading the body into its greatest accomplishments.

Summary.—The nervous system, on account of its delicate structure, is liable to injury through wrong methods of using it and also through the introduction of drugs, or poisons, into
[337] the body. There are also found in our methods of living and systems of education conditions that tend to waste the nervous energy. To protect the nervous system from all these threatened dangers requires, among other things, the power of self-control. This enables the individual to direct his life according to his highest ideals and to free himself from habits known to be injurious. Children must have their nervous systems safeguarded by parents and teachers. Especially must they be kept from becoming enslaved to some drug, such as alcohol or the nicotine of tobacco.

Exercises.—1. In what respect is the hygiene of the nervous system the hygiene of the entire body?

2. Of what value in the hygiene of the nervous system is the power of self-control? How is the habit of self-control formed?

3. Name several forms of activity that waste the nervous energy.

4. Name several influences that react unfavorably on the nervous systems of children.

5. How may too much reading prove injurious to the nervous system?

6. What forms of physical exercise are beneficial to the brain worker?

7. Why is the use of alcohol even in small quantities to be regarded as a dangerous practice?

8. Name several causes of nervousness.

9. What are the unanswerable arguments for preventing the use of tobacco by the young?

10. Why do cigarettes have a more harmful effect upon the body than other forms of tobacco?

11. Enumerate conditions in the schoolroom that dissipate the nervous energy of pupils; that economize it.

[338]

CHAPTER XX - PRODUCTION OF SENSATIONS

Our study of the nervous system has shown that impulses arising at the surface of the body are able, through connecting neurons, to bring about various activities. Moving along definite pathways, they induce motion in the muscles, and in the glands the secretion of liquids. It is now our purpose to consider the effect produced by afferent impulses upon the brain and, through the brain, upon the mind.[114] This effect is manifested in a variety of similar forms, known as

The Sensations.—Sensations constitute the lowest forms of mental activity. Roughly speaking, they are the states of mind experienced as the *direct* result of impulses reaching the brain. In a sense, just as impulses passing to the muscles cause motion, impulses passing to the brain cause sensations. The feeling which results from the hand's touching a table is a sensation and so also is the pain which is caused by an injury to the body. The mental action in each case is due to impulses passing to the brain. Care must be exercised by the beginner, however, not to confuse sensations with the nervous impulses, on the one hand, or with *secondary* mental effects, such as emotion or imagination, on the other. Sensations are properly regarded as the first conscious effects of the afferent impulses and as the *beginning stage* in the series of mental processes that may take place on account of them.

[339] In some way, not understood, the mind associates the sensation with the part of the body from which the impulses come. Pain, for

[114] The term "mind" is used in this and preceding chapters in its popular, not technical, sense.

example, is not felt at the brain where the sensation is produced, but at the place where the injury occurs. This association, by the mind, of the sensations with different parts of the body, is known as "localizing the sensation."

Sensation Stimuli.—While the sensations are dependent upon the afferent impulses, the afferent impulses are in turn dependent upon causes outside of the nervous system. If these are removed, the sensations cease and they do not start up again unless the exciting influences are again applied. Any agency, such as heat or pressure, which, by acting on the neurons of the body, is able to produce a sensation, may be called a *sensation stimulus*. It has perhaps already been observed that the stimuli that lead to voluntary action, as well as those that produce reflex action of the muscles, cause sensations at the same time. From this we may conclude that sensation stimuli are the same in character as those that excite motion. On the other hand, it should be noted that sensations are constantly resulting from stimuli that are of too mild a nature to cause motion.

Classes of Sensations.—Perhaps as many as twenty distinct sensations, such as pain, hunger, touch, etc., are recognized. If these are studied with reference to their origin, it will be seen that some of them result from the action of definite forms of stimuli upon the neurons terminating in sense organs; while the others, as a rule, arise from the action of indefinite stimuli upon neurons in parts of the body that do not possess sense organs. The members of the first class—and these include the sensations of touch, temperature, taste, smell, hearing, and sight—are known [340]
as the *special* sensations. The others, including the sensations of pain, hunger, thirst, nausea, fatigue, comfort, discomfort, and those of disease, are known as *organic*, or general, sensations. These two classes of sensations differ in their purpose in the body as well as in the manner of their origin.

Purposes of Sensations.—Any given sensation is related to the stimulus which excites it as an *effect* to a *cause*. It starts up or stops, increases in intensity or diminishes, according to the action of the exciting stimulus. As the stimuli are outside of the nervous system, and in the majority of cases outside of the body, the sensations indicate to the mind what is taking place either in the body itself or in its surroundings. They supply, in other words, the means through which the mind acquires information. By means of the special sensations, a knowledge of the physical surroundings of the body is gained, and through the organic sensations the needs of the body and the state of the various organs are indicated. In general, sensations are made to serve two great purposes in the body, as follows:

1. They provide the necessary conditions for intelligent and purposeful action on the part of the body.

2. They supply the basis for the higher mental activities, as perception, memory, thought, imagination, and emotion.

Intelligent action is impossible without a knowledge both of the bodily organs and of the body's surroundings. Protection and the regulation of the work of an organ necessitate a knowledge of its condition, while the adapting and adjusting of the body to its surroundings require a knowledge of what those surroundings are. The dependence of all the higher forms of mental activity
[341] upon sensations is recognized by psychologists and is easily demonstrated by a study of the manner in which we acquire knowledge. "Without sensation there can be no thought."

Steps in the Production of Sensations.—The steps in the production of sensations are not essentially different from those in the production of reflex action. First of all, external stimuli act upon the fiber terminations in the sense organs, or elsewhere, starting impulses in the neurons. These pass into the central nervous system and there excite neurons which in turn discharge impulses into the cerebrum. The result is to arouse an activity of the mind—a sensation. The steps in the production of any *special* sensation naturally involve the following parts:

1. A sense organ where the terminations of the neurons are

acted upon by the stimulus.

2. A chain of neurons which connect the sense organ with the brain.

3. The part of the cerebrum which produces the sensation.

Sense Organs.—The sense organs are not parts of the afferent neurons, but are structures of various kinds, in which the neurons terminate. Their function is to enable the sensation stimuli to start the impulses. By directing, concentrating, or controlling the stimuli, the sense organs enable them to act to the best advantage upon the neurons. When it is recognized that such widely different forces as light waves, sound waves, heat, pressure, and odors are enabled by them to stimulate neurons, the importance of these organs becomes apparent. As would naturally be inferred, the construction of any sense organ has particular reference to the nature of the stimulus which it is to receive. This is most apparent in the sense organs of sight and hearing.

Simple Forms of Sense Organs.—The simplest form of a sense organ (if such it may be called) is one found among the various tissues. It consists of the terminal branches of nerve fibers which spread over a small area of cells, as a network or plexus. Such endings are numerous in the skin and muscles. [342]

Next in order of complexity are the so-called *end-bulbs*. These consist of rounded, or elongated, connective tissue capsules, within which the nerve fibers terminate. On the inside the fibers lose their sheaths and divide into branches, which wind through the capsule. End-bulbs are abundant in the lining membrane of the eye, and are found also in the skin of the lips and in the tissues around the joints.

Slightly more complex than the end-bulbs are the *touch corpuscles*. These are elongated bulb-like bodies, having a length of about one three-hundredth of an inch, and occupying the papillæ of the skin (Fig. 144). They are composed mainly of connective tissue. Each corpuscle receives the termination of one or more nerve fibers. These, on entering, lose the medullary sheath and separate into a number of branches that penetrate the corpuscle in different directions.

The largest of the simple forms of sense organs are bodies visible to the naked eye and called, from their discoverer Pacini, the *Pacinian corpuscles*. They lie along the course of nerves in many parts of the body, and have the general form of grains of wheat. (See Practical Work.) The Pacinian corpuscles are
[343] composed of connective tissue arranged in separate layers around a narrow central cavity called the core (Fig. 145). Within the core is the termination of a large nerve fiber. These corpuscles are found in the connective tissue beneath the skin, along tendons, around joints, and among the organs of the abdominal cavity.

The simple forms of sense organs have a more or less general distribution over the body, and are concerned in the production of at least three special sensations. These are *touch, temperature*, and the *muscular sensation*.

Touch, or feeling, is perhaps the simplest of the sensations. The sense organs employed are the touch corpuscles, and the external stimulus is some form of pressure or impact. Pressure applied to the skin, by acting on the fiber terminations in the corpuscles, starts the impulses that give rise to the sensation. The touch corpuscles render the fiber terminations so sensitive that the slightest pressure is able to arouse sensations of touch. It is found that *a change of pressure*, rather than pressure that is constant, is the active stimulus. That all parts of the skin are not equally sensitive to pressure, and that the mind does not interpret equally well the sensations from different parts, are facts easily demonstrated by experiment. (See Practical Work.)

[344] **The Temperature Sensation.**—Temperature sensations, like those of touch, are limited almost entirely to the skin. They

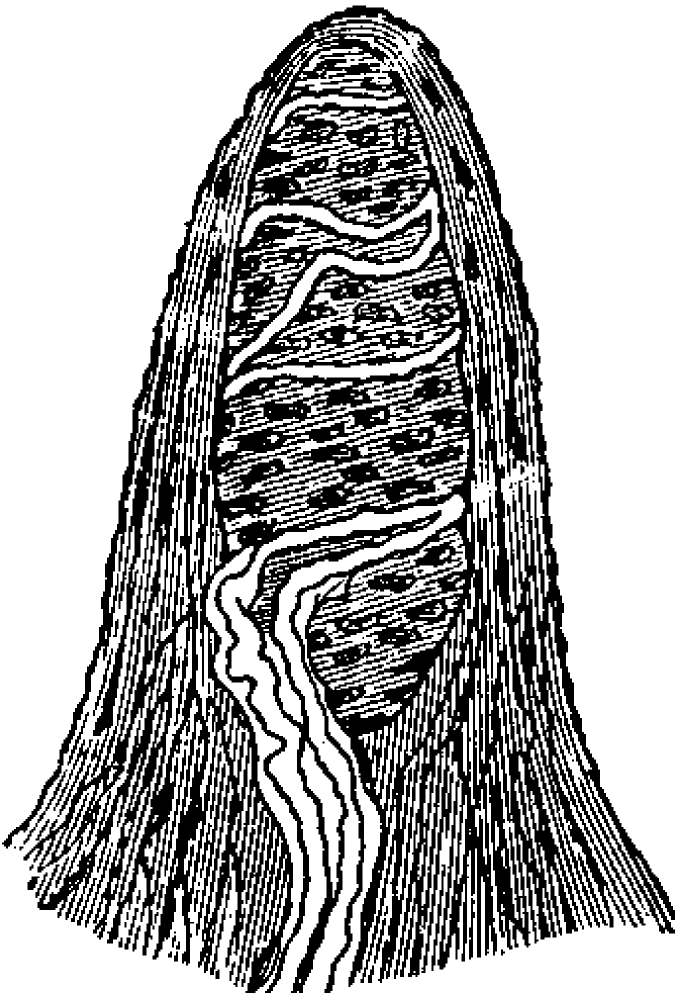

Fig. 144—**A touch corpuscle** highly magnified. (See text.)

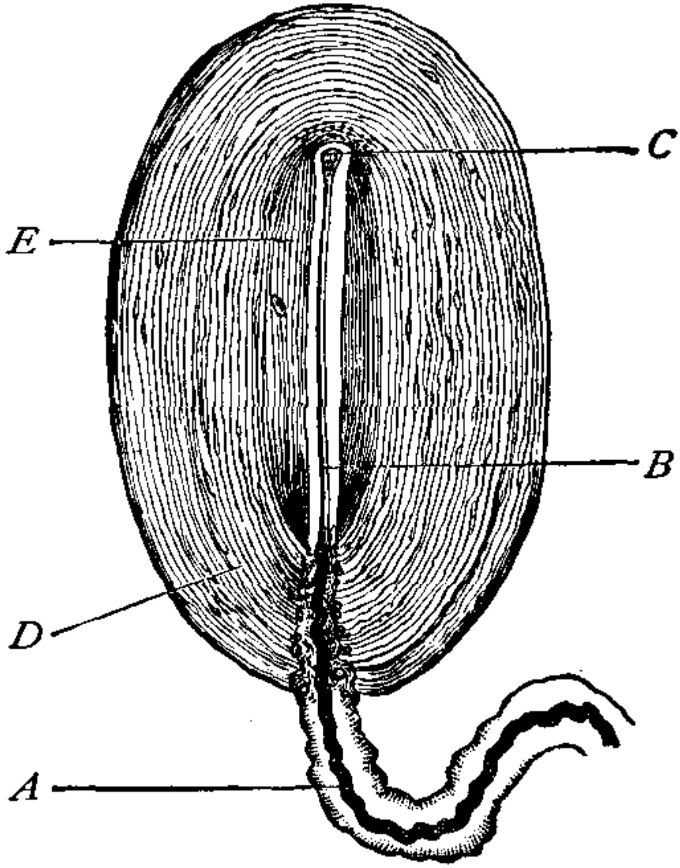

Fig. 145—**Pacinian corpuscle**, magnified. *A.* Medullated nerve fiber. *B.* Axis cylinder terminating in small bulb at *C*. *D.* Concentric layers of connective tissue. *E.* Inner bulb.

are of two kinds, and are designated as *heat* sensations and as *cold* sensations. Whether the sense organs for temperature are different from those of touch is not known. It is known, however, that the same corpuscles do not respond alike to heat, cold, and pressure.

A Change of Temperature, rather than any specific degree of heat or cold, is the active temperature stimulus. The sensation of warmth is obtained when the temperature of the skin is being raised, and of cold when it is being lowered. This explains why in going into a hallway from a heated room one receives a sensation of cold, while in coming into the same hallway from the outside air he receives a sensation of warmth. It is for the same reason that we are able to distinguish only the relative, not the actual, temperature of bodies.

Muscular Sensations.—These are sensations produced by impulses arising at the muscles. Such impulses originate at the fiber terminations which are found in both the muscles and their tendons. By muscular sensations one is conscious of the location of a contracting muscle and of the degree of its tension. They also make it possible to judge of the weight of objects.

The Sensation of Taste.—The sense organs of taste are found chiefly in the mucous membrane covering the upper surface of the tongue. Scattered over this surface are a number of rounded elevations, or large papillæ (A, Fig. 146). Toward the back of the tongue two rows of these, larger than the others, converge to meet at an angle, where is located a papilla of exceptional size. Surrounding each papilla is a narrow depression, within which are found the sense organs of taste (B, Fig. 146). These are called, from their shape, *taste buds*, and each bud
contains a central cavity which communicates with the surface [345]
by a small opening—*the gustatory pore*. Within this cavity are many slender, spindle-shaped cells which terminate in hair-like

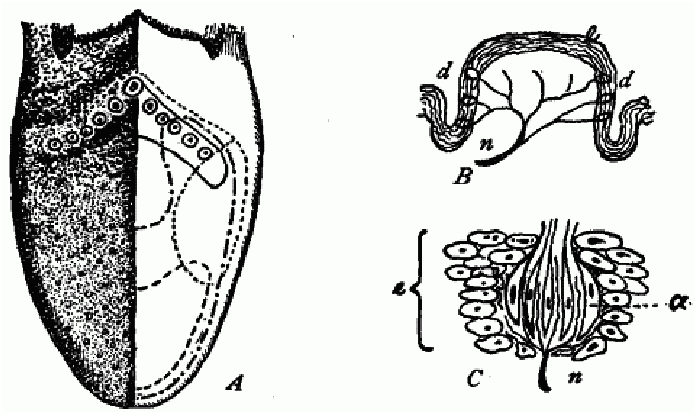

Fig. 146—**Sense organs of taste.** *A.* Map of upper surface of tongue, showing on the left the different kinds of papillæ, and on the right the areas of taste (after Hall). Area sensitive to bitter (——); to acid (....); to salt (—.—.—.—); to sweet (————). *B.* Section through a papilla. *n.* Small nerve connecting with taste buds at *d. e.* Epithelium. *C.* Single taste bud magnified. *n.* Nerve, the fibers of which terminate between the spindle-shaped cells *a. e.* Epithelial cells.

projections at the end nearest the pore, but in short fibers at the other end. Nerve fibers enter at the inner ends of the buds and spread out between the cells (*C*, Fig. 146). These fibers pass to the brain as parts of two pairs of nerves—those from the front of the tongue joining the trigeminal nerve, and those from the back of the tongue, the glossopharyngeal nerve.

The gustatary, or *taste stimulus*, is some chemical or physical condition of substances which is manifested only when they are in a liquid state. For this reason *only liquid substances can be tasted*. Solids to be tasted must first be dissolved.

The different taste sensations are described as bitter, sweet, [346]
sour, and saline, and in the order named are recognized as the tastes of quinine, sugar, vinegar, and salt. As to how these different tastes are produced, little is known. Flavors such as vanilla and lemon, and the flavors of meats and fruits, are really smelled and not tasted. Taste serves two main purposes: it is an aid in the selection of food and it is a means of stimulating the digestive glands (page 161).

The Sensation of Smell.—The sense organs of smell are found in the mucous membrane lining the upper divisions of the nasal cavities. Here are found two kinds of cells in great abundance—column-shaped epithelial cells and the cells which are recognized as the sense organs of smell. These olfactory cells are spindle-shaped, having at one end a slender, thread-like projection which reaches the surface, and at the other end a fiber which joins an olfactory nerve (B, Fig. 147). In fact, the olfactory cells resemble closely the cell-bodies of neurons, and are thought [347]
to be such. The divisions of the olfactory nerve pass through many small openings in the ethmoid bone to connect with the olfactory bulbs, which in turn connect with the cerebrum (A, Fig. 147).

The Olfactory Stimulus.—Only substances in the gaseous state can be smelled. From this it is inferred that the stimulus is supplied by gas particles. Solids and liquids are smelled because of the gas particles which separate from them. The substance which is smelled must be kept moving through the nostrils and made to come in direct contact with the olfactory cells. There is practically no limit to the number of distinct odors that may be recognized.

Value of Smell.—Although the sense of smell is not so acute in man as in some of the lower animals, it is, nevertheless, a most important and useful gift. It is the only sense that responds to matter in the gaseous state, and is, for this reason, the only natural means of detecting harmful constituents of the atmosphere. In this connection it has been likened to a sentinel standing guard over the air passages. Many gases are, however, without odor, and for this reason cannot be detected by the nostrils. It is of especial importance that gases which are likely to become mixed with the air supply to the body have odor, even though the odor be disagreeable. The bad odors of illuminating gas and of various compounds of the chemical laboratory, since they serve as danger signals to put one exposed to them on his guard, are of great protective value.

Sight and Hearing.—The sense organs of sight and hearing are highly complicated structures, and will be considered in the chapters following.

Summary.—Sensations are certain activities of the mind that
[348] result from excitations within the body or at its surface. These cause the neurons to discharge impulses which on reaching the cerebrum cause the sensations. Sensations are necessary for intelligent and purposeful action and for acquiring all kinds of knowledge. To enable the stimuli to act to the best advantage in starting the impulses, special devices, called sense organs, are employed. These receive the terminations of the neurons, and by their special structure enable the most delicate stimuli to start impulses. The simpler forms of sense organs are those of touch,

temperature, taste, and smell.

Exercises.—1. Compare sensations and reflex actions with reference to their nature and cause. Give steps in the production of each.

2. Give examples of sensation stimuli. State the purpose of sense organs.

3. How do general sensations differ from special sensations?

4. Of what value is pain in the protection of the body?

5. Show that sensations lead to the higher forms of mental activity, such as emotion and imagination.

6. Of what value to the body is the "localizing of the sensation"?

7. What kinds of sense organs are found in the skin? State the purpose of each.

8. Through what sense avenues is one made aware of solids, of liquids, and of gases?

9. Of what special protective value is the sense of smell?

PRACTICAL WORK

To demonstrate the Pacinian Corpuscles.—Spread out the mesentery from the intestine of a cat and hold it between the eye and the light: Pacinian corpuscles will appear as small translucent bodies having the general form of grains of wheat. Secure a portion of the mesentery over a circular opening in a thin piece of cork and examine it with a microscope of low power. Follow the course of the nerve fiber to the nerve from which it branches.

To show Relative Sensitiveness of Different Parts of the Skin.—Holding a bristle between the fingers, bring the end in contact with the skin, noting the amount of pressure necessary to cause a sensation of touch. Test the lips, tongue, tips of fingers, [349]
and palm and back of hand, trying different sizes of bristles. Has

the degree of sensitiveness any relation to the thickness of the cuticle?

To show Perceptive Differences of Different Portions of the Skin.—Place the points of a pair of dividers on the back of the hand of one who looks in the opposite direction. Is one point felt or two? Repeat several times, changing the distance between the points until it is fully determined how near the two points must be placed in order to be felt as one. In like manner test other parts of the body, as the tips of the fingers and the back of the neck. Compare results obtained at different places.

To locate Warm and Cold Sensation Spots.—Slowly and evenly draw a blunt-pointed piece of metal over the back of the neck. If it be of the same temperature as the skin, only touch sensations will be experienced. If it be a little colder (the temperature of the room) sensations of cold will be felt at certain spots. If slightly warmer than the body, heat sensation spots will be found on other parts of the skin. If the heat and cold sensation spots be marked and tested from day to day they will be found to remain constant as to position. Inference.

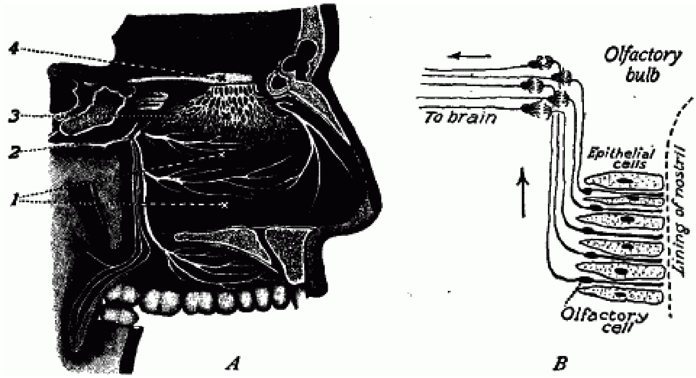

Fig. 147—**Sense organ of smell.** *A.* Distribution of nerves in outer wall of nasal cavity. 1. Turbinated bones. 2. Branch of fifth pair of nerves. 3. Branches of olfactory nerve. 4. Olfactory bulb. *B.* Diagram showing connection of neurons concerned in smell.

[350]

CHAPTER XXI - THE LARYNX AND THE EAR

Man is a social being. His inclinations are not to live alone, but to be a part of that great human organization known as society. For men to work together, to be mutually helpful one to another, requires the ability to exchange ideas and this in turn requires some means of communication.[115] One means of communication is found in certain movements of the atmosphere, known as *sound waves*. In the exchange of ideas by this means there are employed two of the most interesting divisions of the body—the larynx and the ear. The first is an instrument for the production of sound waves; the second is the sense organ which enables the sound waves to act as stimuli to the nervous system.

Nature of Sound Waves.—If some sonorous body, as a bell, be struck, it is given a quivering, or vibratory, motion. This is not confined to the bell, but is imparted to the air and other substances with which the bell comes in contact. These take up the movements and pass them to objects more remote, and they in turn give them to others, until a very considerable distance is reached. Such progressive vibrations are known as waves, and, since they act as stimuli to the organs of hearing, they are called *sound waves*. Sound waves *always originate in vibrating*
[351] *bodies*.[116] They are transmitted chiefly *by the air*, which, because

[115] The problem of social adjustment is but a phase of the general problem of establishing proper relations between the body and its surroundings.

[116] A vibrating body is one having a to-and-fro movement, like that of a clock pendulum or the string of a violin on sounding. Bodies to give out sound waves must vibrate rapidly, making not less than sixteen vibrations per second. The upper limit of hearing being about 40,000 vibrations per second, certain bodies may even vibrate too rapidly to be heard.

of its lightness, elasticity, and abundance, readily takes up the vibrations and spreads them in all directions (Fig. 148).

While these vibratory movements of the atmosphere are correctly classified as waves, they bear little resemblance to the waves on water. Instead of being made of crests and troughs, as are the water waves, the sound waves consist of alternating successions of slightly condensed and rarefied layers of air. Then, while the general movement of the water waves is that of ever widening circles *over a surface*, the sound waves spread as enlarging spherical shells *through* the air. In sound waves, as in all other waves, however, it is only the form of the wave that moves forward. The individual particles of air that make up the wave simply vibrate back and forth.

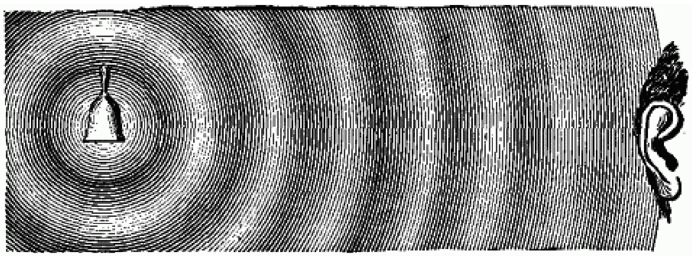

Fig. 148—Diagram illustrating the spreading of sound waves through air.

How Sound Waves act as Stimuli.—Any sound wave represents a small but definite amount of energy, this being a part of the original force that acted on the vibrating body to set it in motion. The hammer, for instance, in striking a bell imparts to it a measurable quantity of energy, which the bell in turn imparts to the air. This energy is in the sound waves and is communicated to the bodies against which they strike.[117] Though the force exerted [352] by most sound waves is, indeed, very slight, it is sufficient to enable them to act as stimuli to the nervous system.

How Sounds Differ.—Three distinct effects are produced by sound waves upon the nerves of hearing, and through them upon the mind. These are known as *pitch, intensity,* and *quality,* and they are dependent upon the vibrations of the sound-producing bodies.

Pitch, which has reference to the height, or degree of sharpness, of tones, is determined by the rapidity of the vibrations of the vibrating body. The more rapid the vibrations, the higher the pitch, the number of vibrations doubling for each musical interval known as the octave.

Intensity is the energy, or force, of the sound waves. This is recognized by the strength of the sensation and is expressed by the term *loudness*. Intensity is governed mainly by the width of the vibrations of the vibrating body, and the width depends upon the force applied to the body to make it vibrate.

Quality is that peculiarity of sound that enables tones from different instruments to sound differently, although they may have the same pitch and intensity. Quality depends upon the fact that most tones are complex in nature and result from the blending together of simple tones of different pitch.

Reënforcement of Sound Waves.—The sound vibrations from small bodies are not infrequently reënforced by surrounding conditions so that their outgoing waves reach farther and are more effective than waves from larger bodies. This is true of the sound waves produced by most musical instruments and also those produced by the human larynx. Such reënforcement is effected in two general ways—by sounding boards and by inclosed columns of air. Stringed instruments—violin, guitar, piano, etc.—employ sounding boards, while wind instruments,

[117] Somewhat as the waves on a body of water impart motion to the sticks and weeds along the shore, sound waves are able to cause bodies that are small or that are delicately poised to vibrate.

as the flute, pipe organ, and the various kinds of horns, employ air columns for reënforcing their vibrations. In the use of the sounding board, the vibrations are communicated to a larger surface, and in the use of the air column the vibrations are communicated to the inclosed air. (See Practical Work.)

Value of Sound Waves to the Body.—From a physiological standpoint, the value of sound waves is not easily overestimated. In addition to the use made of them in the communication of ideas, they serve the purpose of protecting the body, and in the sphere of music provide one of the most elevating forms of entertainment. Sounds from different animals, as well as from inanimate objects, may also be the means of supplying needed information. The existence of two kinds of sound instruments in the body—the one for the production, the other for the detection, of sound—is certainly suggestive of the ability of the body to adjust itself to, and to make use of, its physical environment. Both the larynx and the ear are constructed with special reference to the nature and properties of sound waves. [353]

THE LARYNX

The Sound-producing Mechanism of the Body consists of the following parts:

1. Delicately arranged bodies that are easily set in vibration.
2. An arrangement for supplying the necessary force for making these bodies vibrate.
3. Contrivances for modifying the vibrating parts so as to produce changes in pitch and intensity.
4. Parts that reënforce the vibrations.
5. Organs by means of which the sounds are converted into the forms of speech.

The central organ in this complex mechanism is

The Larynx.—The larynx forms a part of the air passages, being a short tube at the upper end of the trachea. Mucous

[354] membrane lines the inside of it and muscles cover most of the outer surface. The framework is made of cartilage. At the top it is partly encircled by a small bone (the hyoid), and its opening into the pharynx is guarded by a flexible lid, called the *epiglottis*. The cartilage in its walls is in eight separate pieces, but the greater portion of the structure is formed of two pieces only. These are known as the *thyroid cartilage* and the *cricoid cartilage* (Fig. 149). Both can be felt in the throat—the thyroid as the projection known as "Adam's apple," and the cricoid as a broad ring just below.

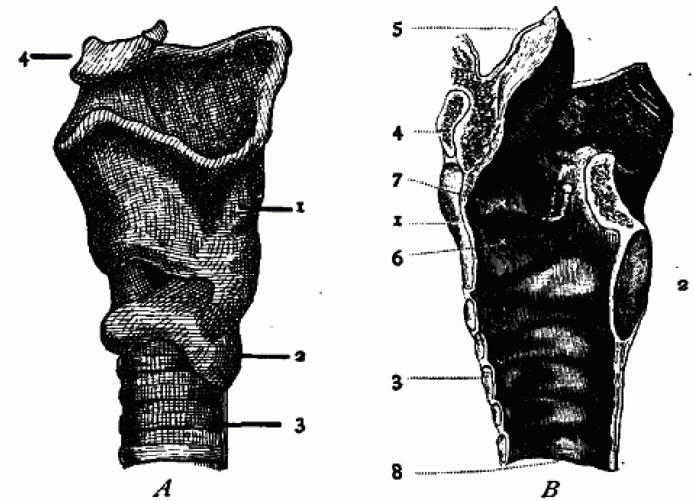

Fig. 149—The larynx.—*A.* Outside view. *B.* Vertical section through larynx, showing inside. 1. Thyroid cartilage. 2. Cricoid cartilage. 3. Trachea. 4. Hyoid bone. 5. Epiglottis. 6. Vocal cord. 7. False vocal cord. 8. Lining of mucous membrane.

The *thyroid cartilage* consists of two V-shaped pieces, one on either side of the larynx, meeting at their points in front, and each terminating at the back in an upward and a downward projection. Between the back portions of the thyroid is a space equal to about one third of the circumference of the larynx. This is occupied by the greater portion of the *cricoid cartilage*. This cartilage has the general shape of a signet ring and is so placed [355] that the part corresponding to the signet fits into the thyroid space, while the ring portion encircles the larynx just below the thyroid. Muscles and connective tissue pass from the thyroid to the cricoid cartilage at all places, save one on each side, where the downward projections of the thyroid form hinge joints with the cricoid. These joints permit of motion of either cartilage upon the other.

At the summit of the cricoid cartilage, on each side, is a small piece of triangular shape, called the *arytenoid cartilage*. Each arytenoid is movable on the cricoid and is connected with one end of a vocal cord.

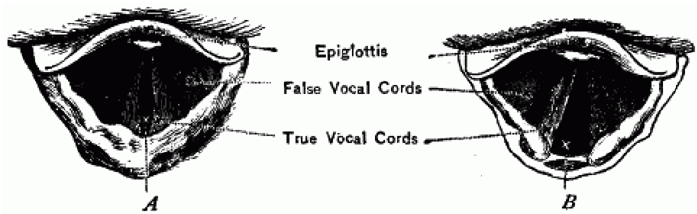

Fig. 150—**Vocal cords** as seen from above. *A.* In producing sound, *B.* During quiet breathing.

The Vocal Cords are formed by two narrow strips of tissue which, connecting with the thyroid cartilage in front and the arytenoid cartilages behind, lie in folds of the mucous membrane. They have the general appearance of ridge-like projections from the sides of the larynx, but at their edges they are sharp and

smooth. The open space between the cords is called the *glottis*. When sound is not being produced, the glottis is open and has a triangular form, due to the spreading apart of the arytenoid cartilages and the attached cords. But when sound is being produced, the glottis is almost completely closed by the cords.
[356] Above the vocal cords, and resembling them in appearance, are two other folds of membrane, called the *false vocal cords* (B, Fig. 149). The false cords do not produce sound, but they aid in the closing of the glottis.

How the Voice is Produced.—The voice is produced through the vibrations of the vocal cords. A special set of muscles draws the arytenoid cartilages toward each other, thereby bringing their edges very near and parallel to each other in the passage. At the same time other muscles act on the thyroid and cricoid cartilages to separate them at the top and give the cords the necessary tension. With the glottis now almost closed, blasts of air from the lungs strike the sharp edges of the cords and set them in vibration (Fig. 150). The vocal cords do not vibrate as strings, like the strings of a violin, but somewhat as reeds, similar to the reeds of a French harp or reed organ.

The location of the vocal cords in the air passages enables the lungs and the muscles of respiration to aid in the production of the voice. It is their function to supply the necessary force for setting the cords in vibration. The upper air passages (mouth, nostrils, and pharynx) supply resonance chambers for reënforcing the vibrations from the vocal cords, thereby greatly increasing their intensity. In ordinary breathing the vocal cords are in a relaxed condition against the sides of the larynx and are not acted upon by the air as it enters or leaves the lungs.

Pitch and Intensity of the Voice.—Changes in the pitch of the voice are caused mainly by variations in the tension of the cords, due to the movements of the thyroid and cricoid cartilages upon each other.[118] In the production of tones of very high pitch,

[118] Some idea of how the movements of the cartilages change the tension of

the vibrating portions of the cords are thought to be actually shortened by their margins being drawn into contact at the back. This raises the pitch in the same manner as does the shortening of the vibrating portion of a violin string. [357]

The *intensity*, or loudness, of the voice is governed by the force with which the air is expelled from the lungs. The vibrations of the cords, however, are greatly reënforced by the peculiar structure of the upper air passages, as stated above.

Production of Speech.—The sounds that form our speech or language are produced by modifying the vibrations from the vocal cords. This is accomplished by "mouthing" the sounds from the larynx. The distinct sounds, or words, are usually complex in nature, being made up of two or more elementary sounds. These are classed either as *vowels* or *consonants* and are represented by the different letters of the alphabet. The vowel sounds are made with the mouth open and are more nearly the pure vibrations of the vocal cords. The consonants are modifications of the vocal cord vibrations produced by the tongue, teeth, lips, and throat.

Words and their Significance.—In the development of language certain ideas have become associated with certain sounds so that the hearing of these sounds suggests the ideas. Our words, therefore, consist of so many sound signals, each capable of arousing a definite idea in the mind. To talk is to express ideas through these signals, and to listen is to assume an attitude of mind such that the signals may be interpreted. In learning a language, both the sounds of the words and their associated ideas are mastered, this being necessary to their practical use in [358]
exchanging ideas. From spoken language man has advanced to written language, so that the sight of the written or printed word

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the cords may be obtained by holding the fingers on the larynx, between the thyroid and cricoid cartilages, and making tones first of low and then of high pitch. For the high tones the cartilages are pulled together in front, and for the low tones they separate. As they pull together in front, they of course separate behind and above, where the cords are attached.

also arouses in the mind the associated idea.

THE EAR

The Ear is the sense organ which enables sound waves to so act upon afferent neurons as to excite impulses in them. The effect upon the mind which these impulses produce is known as the *sensation of hearing*. In the performance of its function the ear receives and transmits sound waves and also concentrates them upon a suitable exposure of nerve cells. It includes three parts—the *external ear*, the *middle ear*, and the *internal ear*.

External Ear.—The external ear consists of the part on the outside of the head called the *pinna*, or auricle, and the tube leading into the middle ear, called the *auditory canal* (Fig. 151). The pinna by its peculiar shape aids to some extent the entrance of sound waves into the auditory canal.[119] It consists chiefly of cartilage. The auditory canal is a little more than an inch in length and one fourth of an inch in diameter, and is closed at its inner end by a thin, but important membrane, called

The Membrana Tympani.—This membrane consists of three thin layers. The outer layer is continuous with the lining of the auditory canal; the inner is a part of the lining of the middle ear; and the middle is a fine layer of connective tissue. Being thin and delicately poised, the membrana tympani is easily made to
[359] vibrate by the sound waves that enter the auditory canal. In this way it serves as a receiver of sound waves from the air. It also protects

[119] It is only the central portion of the pinna that aids the entrance of sound into the auditory canal. If by accident the outer portion of the pinna is removed, there is no impairment of the hearing.

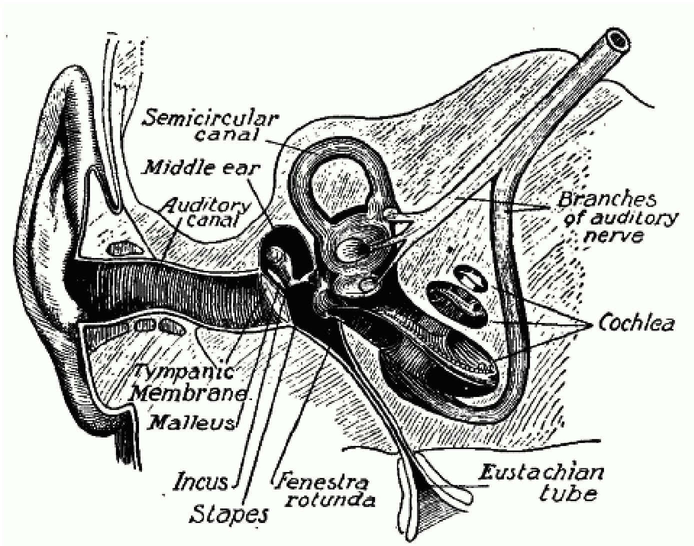

Fig. 151—**Diagram of section through the ear**, showing relations of its various parts. (See text.)

The Middle Ear.—The middle ear, or tympanum,[120] consists of an irregular cavity in the temporal bone which is lined with mucous membrane and filled with air. It is connected with the pharynx by a slender canal called the *Eustachian tube*. Extending across the middle ear and connecting with the membrana tympani on one side, and with a membrane closing a small passage to the internal ear on the other, is a tiny bridge formed of three small bones. These bones, named in their order from the membrana tympani, are the *malleus*, the *incus*, and the *stapes* (Fig. 151). Where the malleus joins the membrane is a small muscle whose
[360] contraction has the effect of tightening the membrane. The Eustachian tube admits air freely to the middle ear, providing in this way for an equality of atmospheric pressure on the two sides of the drum membrane. The bridge of bones and the air in the middle ear receive vibrations from the membrana tympani and communicate them to the membrane of the internal ear.

Purposes of the Middle Ear. —The middle ear serves two important purposes. In the first place, it makes it possible for sound waves to set the membrana tympani in vibration. This membrane could not be made to vibrate by the more delicate of the sound waves if it were stretched over a bone, or over some of the softer tissues, or over a liquid. Its vibration is made possible by the presence of air on *both* sides, and this condition is supplied, on the inner side, by the middle ear. The Eustachian tube, by providing for an *equality* of pressure on the two sides of the membrane, also aids in this purpose.

In the second place, the middle ear provides a means for *concentrating the force of the sound waves* as they pass from the membrana tympani to the internal ear. This concentration is effected in the following manner:

1. The bridge of bones, being pivoted at one point to the walls of the middle ear, forms a lever in which the malleus is

[120] The middle ear is also called the *ear drum*, and, by the same system of naming, the membrana tympani is referred to as the *drum membrane*.

the long arm, and the incus and stapes the short arm, their ratio being about that of three to two. This causes the incus to move through a shorter distance, but with greater force than the end of the malleus.

2. The area of the membrana tympani is about twenty times as great as the membrane of the internal ear which is acted upon by the stapes. The force from the larger surface is, therefore, concentrated by the bridge of bones upon the smaller surface. By the combination of these two devices, the waves striking upon the membrane of the internal ear are rendered some thirty times more effective than are the same waves entering the auditory canal.

The Internal Ear, or labyrinth, occupies a series of irregular channels in the petrous process of the temporal bone.[121] It is very complicated in structure, and at the same time is very small. Its greatest length is not more than three fourths of an [361]
inch and its greatest diameter not more than one half of an inch. It is filled with a liquid which at one place is called the *perilymph*, and at another place the *endolymph*. It is a double organ, being made up of an outer portion which lies next to the bone, and which surrounds an inner portion of the same general form. The outer portion is surrounded by a membrane which serves as periosteum to the bone and, at the same time, holds the liquid belonging to this part, called the perilymph. The inner portion, called the *membranous labyrinth*, consists essentially of a closed membranous sac, which is filled with the endolymph. The auditory nerve terminates in this portion of the internal ear. Three distinct divisions of the labyrinth have been made out, known as the *vestibule*, the *semicircular canals*, and the *cochlea* (Fig. 152).

[121] The inner projection of the temporal bone is known as the petrous process.

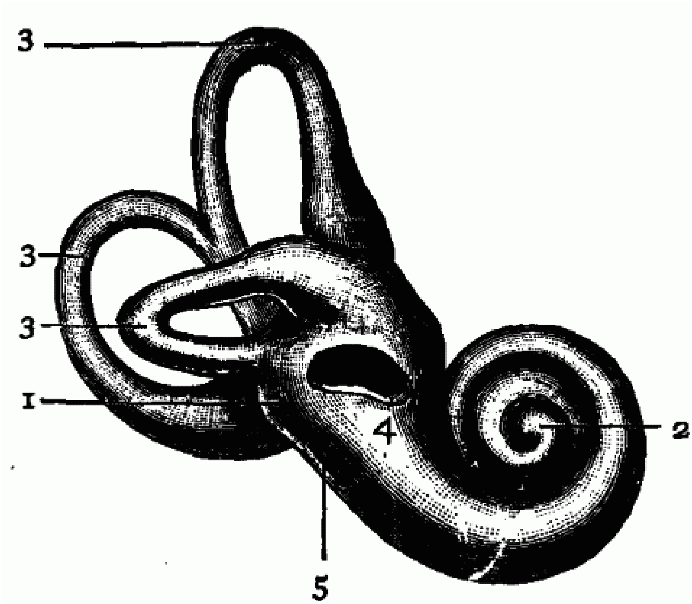

Fig. 152—**General form, of internal ear.** The illustration represents the structures of the internal ear surrounded by a thin layer of bone. 1. Vestibule. 2. Cochlea. 3. Semicircular canals. 4. Fenestra ovalis. 5. Fenestra rotunda.

The Vestibule forms the central portion of the internal ear and is somewhat oval in shape. It is in communication with the middle ear through a small opening in the bone, called the *fenestra ovalis*, at which place it is separated from the middle ear only by a thin membrane. Sound waves enter the liquids of the internal ear at this point, the foot of the stapes being attached to the membrane. Six other openings lead off from the vestibule at [362] different places. One of these enters the cochlea. The other five open into

The Semicircular Canals.—These canals, three in number, pass through the bone in three different planes. One extends in a horizontal direction and the other two vertically, but each plane is at right angles to the other two. Both ends of each canal connect with the vestibule, though two of them join by a common opening. The inner membranous labyrinth is continuous through each canal, and is held in position by small strips of connective tissue.

The purpose of the semicircular canals is not understood. It is known, however, that they are not used in hearing. On the other hand, there is evidence to the effect that they act as equilibrium sense organs, exciting sensations necessary for balancing the body. Their removal or injury, while having no effect upon the hearing, does interfere with the ability to keep the body in an upright position.

The Cochlea is the part of the internal ear directly concerned in hearing. It consists of a coiled tube which makes two and one half turns around a central axis and bears a close resemblance to a snail shell (Figs. 151 and 152). It differs in plan from a snail shell, however, in that its interior space is divided into three distinct channels, or canals. These lie side by side and are named, from their relations to other parts, the *scala vestibula*, the *scala tympani*, and the *scala media*. Any vertical section of the cochlea shows all three of these channels (Fig. 153).

[363] **The Scala Vestibula and the Scala Tympani** appear in cross section as the larger of the canals. The former, so named from its connection with the vestibule, occupies the upper position in all parts of the coil. The latter lies below at all places, and is separated from the channels above partly by a margin of bone and partly by a membrane. It receives its name from its termination at the tympanum, or middle ear, from which it is separated only by a thin membrane.[122] Both the scala vestibula and the scala tympani belong to the outer portion of the internal ear and are, for this reason, filled with the perilymph. At their upper ends they communicate with each other by a small opening, making by this means one continuous canal through the cochlea. This canal passes from the vestibule to the tympanum and, in so doing, goes entirely around

The Scala Media.—This division of the cochlea lies parallel to and between the other two divisions. It is above the scala tympani and below the scala vestibula, and is separated from each by a membrane. The scala media belongs to the membranous portion of the internal ear and is, therefore, filled with the endolymph. It receives the terminations of fibers from the auditory nerve and may be regarded as the true sense organ of hearing. The nerve fibers terminate upon the membrane known as the *basilar membrane*, which separates it from the scala tympani. This membrane extends the length of the cochlear canals, and is stretched between a projecting shelf of bone on one side and the outer wall of the cochlea on the other. It is covered with a layer of epithelial cells, some of which have small, hair-like projections and are known as the *hair cells*. Above the membrane, and
[364] resting partly upon it, are two rows of rod-like bodies, called the *rods of Corti*. These, by leaning toward each other, form a kind of tunnel beneath. They are exceedingly numerous, numbering

[122] A small opening in the bone at this place is called the *fenestra rotunda*.

more than 6000, and form a continuous series along the margin of the membrane.

How We Hear.—The sound waves which originate in vibrating bodies are transmitted by the air to the external ear. Passing through the auditory canal, the waves strike against the membrana tympani, setting it into vibration. By the bridge of bones and the air within the middle ear the vibrations are carried to and concentrated upon the liquid in the internal ear (Fig. 154). From here the vibrations pass through the channels of the cochlea and set into vibration the contents of the scala media and different portions of the basilar membrane. This serves as a stimulus to the fibers of the auditory nerve, causing them to transmit impulses which, on passing to the brain, produce the sensation of hearing.

Much of the peculiar structure of the cochlea is not understood. Its minute size and its location in the temporal bone make its study extremely difficult. The connection of the scala vestibula with the scala tympani, and this with the middle ear, is necessary for the passage of vibrations through the internal ear. Its liquids, being practically incompressible and surrounded on all sides by bones, could not otherwise yield to the movements of the stapes. (See Practical Work.) The rods of Corti are thought to act as dampers on the basilar membrane, to prevent the continuance of vibrations when once they are started.

Detection of Pitch.—The method of detecting tones of different pitch is not understood. Several theories have been advanced [365] with reference to its explanation, one of the most interesting being that proposed by Helmholtz. This theory is based on our knowledge of sympathetic vibrations. The basilar membrane, while continuous throughout, may be regarded as made up of many separate cords of different lengths stretched side by side. A tone of a given pitch will set into vibration only certain of these cords, while tones of different pitch will set others into vibration.

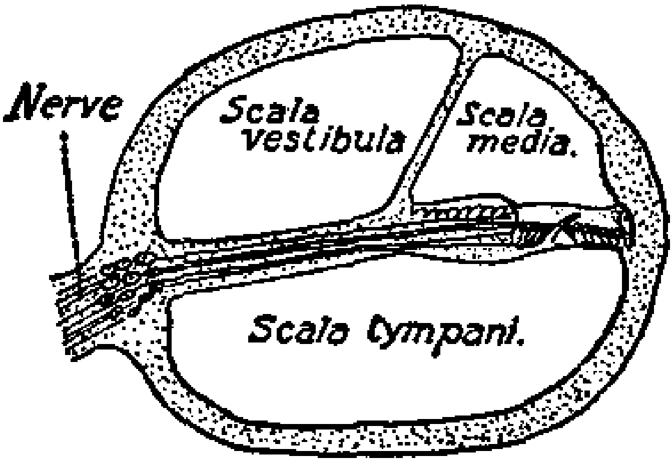

Fig. 153—Diagram showing the divisions of cochlear canal.

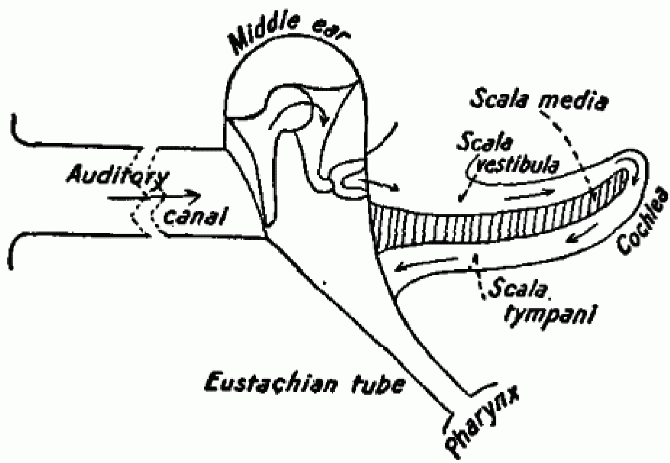

Fig. 154—**Diagram** illustrating passage of sound waves through the ear.

Another theory is that the basilar membrane responds to all kinds of vibrations and the analysis of sound takes place in the brain.

A third view is that the filaments from the hair cells, rather than the basilar membrane, respond to the vibrations and in turn stimulate the terminations of the nerve fibers.

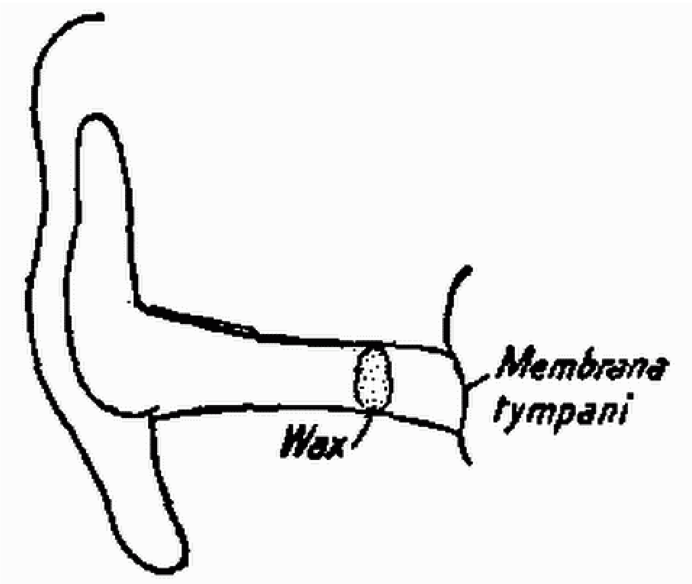

Fig. 155—**Diagram** showing how wax may plug the auditory canal and cause deafness.

Hygiene of the Ear.—The ear, being a delicate organ, is frequently injured by careless or rough treatment. The removal of the ear wax by the insertion of pointed instruments has been found to interfere with the natural method of discharge and to irritate the membrane. It should never be practiced. It is unnecessary in the healthy ear thus to cleanse the auditory canal, as the wax is passed by a natural process to where it is easily removed by a damp cloth. If the natural process is obstructed, clean warm water and a soft linen cloth may be employed in cleansing the canal, without likelihood of injury. Clean warm water may also be introduced into the auditory canal as a harmless remedy in relieving inflammation of the auditory canal and of the middle ear. Children's ears are easily injured, and it goes without saying that they should never be pulled nor boxed.

It frequently happens that a mass of wax collects in the auditory
[366] canal and closes the passage so completely as to cause deafness (Fig. 155). This may come about without pain and so gradually that one does not think of seeking medical aid. Such masses are easily removed by the physician, the hearing being then restored. Both for painful disturbances of the ear and for the gradual loss of hearing, the physician should be consulted.

The Hearing of School Children.—School children not infrequently have defective hearing and for this reason are slow to learn. The hearing is easily tested with a watch, the normal ear being able to hear the watch tick at a distance of at least two feet. Pupils with defective hearing should, of course, have medical attention, and in the classroom should be seated where they can hear to the best advantage.

Summary.—Sound waves constitute the external stimuli for the sensation of hearing. They consist of progressive vibratory movements of the air that originate in vibrating bodies. Through the larynx and the ear, sound waves are utilized by the body in different ways, but chiefly as a means of communication. The larynx produces sound waves which are reënforced and modified by the air passages. The ear supplies suitable conditions for the action of sound waves upon nerve cells. Both the ear and the larynx are constructed with special reference to the nature and properties of sound waves, and they illustrate the body's ability to adjust itself to, and to make use of, its physical environment.

Exercises.—1. For what different purposes are sound waves employed in the body?

2. How do sound waves originate? How are they transmitted? How do they differ from the waves on water?

3. How are sound waves able to act as nerve stimuli?

4. Describe two methods of reënforcing sound waves. Which method is employed in the body?

5. Name all the parts of the body that are directly or indirectly [367] concerned in the production of sound.

6. Describe the larynx.

7. Describe the condition of the vocal cords in speaking and in ordinary breathing.

8. How are sounds differing in pitch and intensity produced by the larynx?

9. How is the sound produced by the vocal cords changed into speech?

10. What parts of the ear are concerned in transmitting sound waves?

11. Give the purposes of the middle ear.

12. Trace a sound wave from a bell to the basilar membrane, and trace the impulse that it causes from there to the brain.

13. Give the purpose of the Eustachian tubes; of the rods of Corti; of the semicircular canals.

14. Give directions for the proper care of the ear.

PRACTICAL WORK

To illustrate the Origin of Sound.—1. Strike a bell an easy blow and hold some light substance, as a pith ball attached to a thread, against the side, noting the result. 2. Sound a tuning fork by striking it against the table. Test it for vibrations as above, or by letting the vibrating prongs touch the surface of water. 3. Pluck a string of a guitar or violin, and find proof that it is vibrating while giving out sound.

To show the Transmission of Sound.—1. Vibrate a tuning fork and press the stem against a table or desk. The vibrations which are reënforced in this way will be heard in all parts of the room. Now press one end of a wooden rod, as a broom handle, against the table, and bring the stem of the vibrating fork against the other end. The vibrations now move down the stick to the table, from whence they are communicated to the air. Observe that the sound waves, to reach the ear, must pass through the rod, the table, and the air. 2. Fasten the tuning fork to a flat piece of cork by pressing the stem into a small hole in the center. Vibrate the fork and let the cork rest on the surface of water in a half-filled tumbler on the table. The sound will, as before, pass to the table and then to the air. Observe that in this case
[368] the vibrations are transmitted by a liquid, a solid, and by the air. Compare this action with the transmission of sound waves by different portions of the ear.

To show Effects of Sound Waves.—1. Place two large tuning forks of the same pitch, and mounted on thin boxes for reënforcing their vibrations, near each other on a table. Vibrate one of the forks for a moment and then stop it by means of the hand. Observe that the other fork has been set in vibration. (This experiment does not work with forks of different pitch.) 2. While holding a thin piece of paper against a comb with the open lips, produce musical tones with the vocal cords. These will set the paper in vibration, producing the so-called "comb music." 3. Examine the disk in a telephone which is set in vibration by the voice. Observe that it is a thin disk and, like the membrane of the ear, has air on both sides of it.

To show the Reënforcement of Sound.—1. Vibrate a tuning fork in the air, noting the feebleness of the tone produced. Then hold the stem against a door or the top of a table, noting the difference. 2. Hold a vibrating tuning fork over a tall jar, or bottle, and gradually add water. If the vessel is sufficiently tall, a depth will be reached where the air in the vessel reënforces the sound from the fork. 3. Hold a vibrating fork over the mouth of a small fruit jar, partly covered with a piece of cardboard. By varying the size of the opening, a position will be found where the sound is reënforced. If not successful at first, try bottles and jars of different sizes.

To illustrate the Manner of Vibration of the Liquid in the Internal Ear.—Tie a piece of dental rubber over the end of a glass or wooden tube about half an inch in diameter and six inches in length. Fill the tube entirely full of water and, without spilling, tie a piece of thin rubber tightly over the other end. Holding the tube horizontally, press the rubber in at one end and note that it is pushed out at the other end. Make an imitation of a vibration with the finger against the rubber at one end of the tube and note the effect at the other end. To what do the tube and the rubber on the ends of the tube correspond in the internal ear?

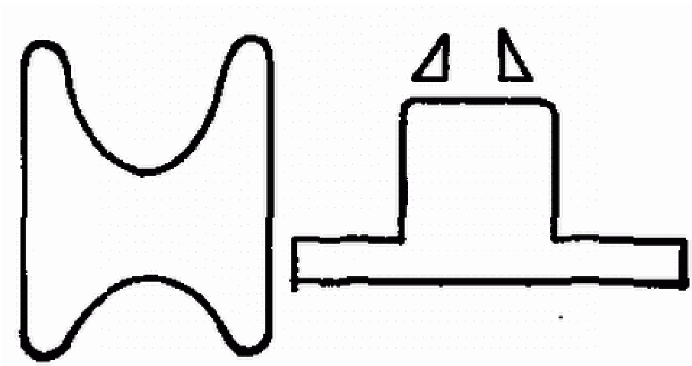

Fig. 156—**Simple apparatus** for demonstrating the larynx.

To show the Plan of the Larynx.—Cut from stiff paper four pieces of different shapes as indicated in Fig. 156. (The piece to the left should have a length of about six inches, the others

proportionally large.) The largest represents the thyroid cartilage, [369]
the next in size the cricoid, and the two smallest the arytenoid cartilages. By means of pins, or threads, connect these with each other according to the description of the larynx on page 253. With this simple model the movements of the different cartilages and their effect upon the vocal cords may be illustrated.

To show the Relation of the Movements of the Vocal Organs to the Production of Different Sounds.—1. Lightly grasp the larynx with the fingers while talking. Observe the changes, both in the position and shape of the larynx, in the production of sounds of different pitch. 2. Observe the difference in the action of the muscles of respiration in the production of loud and faint sounds. 3. Pronounce slowly the vowels, A, E, I, O, U, and the consonants C, F, K, M, R, S, T, and V, noting the shape of the mouth, the position of the tongue, and the action of the lips in each case.

To demonstrate the Ear.—Examine a dissectible model of the ear, locating and naming the different parts. Trace as far as possible the path of the sound waves and find the termination of the auditory nerve. Note also the relative size of the parts, and calculate the number of times the model is larger than the natural ear. *Suggestion*: The greatest diameter of the internal ear is about three fourths of an inch.

In an extended course it is a profitable exercise to dissect the ear of a sheep or calf, observing the auditory canal, middle ear, bridge of bones, and the tympanic membrane with attached malleus and tensor tympanic muscle. Pass a probe from the nasal pharynx through the Eustachian tube into the middle ear. With bone forceps or a fine saw, split open the petrous portion of the temporal bone and observe the cochlea and the semicircular canals. By a careful dissection other parts of interest may also be shown.

[370]

CHAPTER XXII - THE EYE

Sight is considered the most important of the sensations. It is the chief means of bringing the body into proper relations with its surroundings and, even more than the sensation of hearing, is an avenue for the reception of ideas. The sense organs for the production of sight are the eyes; the external stimulus is

Light.—Light, like sound, consists of certain vibrating movements, or waves. They differ from sound waves, however, in form, velocity, and in method of origin and transmission. Light waves are able to pass through a vacuum, thus showing that they are not dependent upon air for their transmission. They are supposed to be transmitted by what the physicist calls ether—a highly elastic and exceedingly thin substance which fills all space and penetrates all matter. As a rule, light waves originate in bodies that are highly heated, being started by the vibrations of the minute particles of matter.

Light is influenced in its movements by various conditions. In a substance of uniform density it moves with an unchanging velocity and in a straight line. If it enters a less dense, or rarer, substance, its velocity increases; if one more dense, its velocity diminishes; and if it enters either the rarer or denser substance in any direction other than perpendicularly, it is bent out of its course, or *refracted*. If it strikes against a body lying in its course, it may be thrown off (*reflected*), or it may enter the body and either be passed on through (*transmitted*) or *absorbed* (Fig. 157). Light which is absorbed is transformed into heat.

Kinds of Reflection.—Waves of light striking against the [371] smooth surface of a mirror are thrown off in definite directions, depending on the angle at which they strike. (Illustrate by holding a mirror in the direct rays of the sun.) But light waves that strike rough surfaces are reflected in practically all directions and apparently without reference to the angle at which they strike. (Illustrate by placing a piece of white paper in the direct rays of the sun. It matters not from what direction it is viewed, waves of light strike the eye.) This kind of reflection is called *diffusion*, and it serves the important purpose of making objects visible. The light waves passing out in all directions from objects which have received light from the sun, or some other luminous body, enable them to be seen.

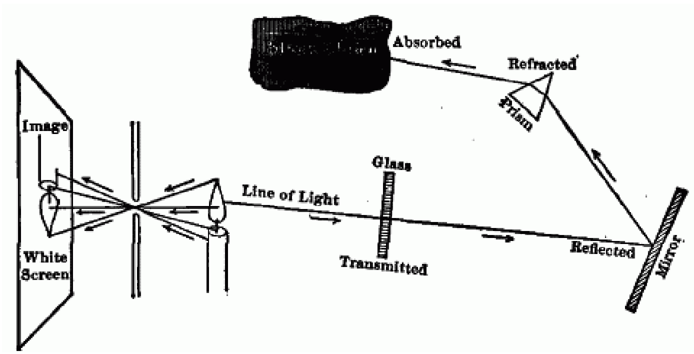

Fig. 157—**Diagram illustrating passage of light waves.** On the right the light is transmitted by the glass, reflected by the mirror, refracted by the prism, and absorbed by the black cloth. On the left the light from the candle forms an image by passing through a small hole in a cardboard and falling upon a screen.

Formation of Images.—Another principle necessary to seeing is that of refraction. *Refraction* means the bending, or turning, of light from a straight course. One of the most interesting effects of refraction is the formation of images of objects, such as may be accomplished by light from them passing in a certain manner through convex lenses. If, for example, a convex lens be moved back and forth between a candle and a screen in a dimly lighted room, a position will be found where a picture of the candle falls upon the screen. This picture, called the *image*, results from the refraction of the candle light in passing through the lens. [372]

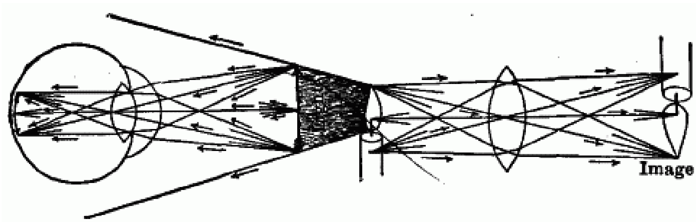

Fig. 158—**Diagram illustrating formation of images.** On the right the image is formed by a double convex lens; on the left by the lenses of the eye. The candle flame represents a luminous, or light-giving, body; but light passes from the large arrow by reflection. (See text.)

In order to form an image, the light waves spreading out from the object must be brought together, or focused. Focusing means literally the bringing of light to a point, but it is evident in the formation of an image that all the waves are not brought to a single point. If they were, there would be no image. In the example of the candle given above, the explanation is as follows:

The light from the candle comes from a great number of separate and distinct points in the candle flame. The lens, by its peculiar shape, bends the waves coming from any single point so that they are brought to a corresponding point on the screen. Furthermore, the points of focused light are made to occupy the same relative positions on the screen as the points from which they emanate in the candle flame (Fig. 158). This is why the area of light on the screen has the same form as the candle, or makes an image of it. The same explanation applies if, instead of the luminous candle, a body that simply reflects light, as a book, is used.

The Problem of Seeing.—What we call *seeing* is vastly more than the stimulation of the brain through the action of light upon afferent neurons. It is the *perceiving* of all the different things
[373] that make up our surroundings. If one looks toward the clear sky, he receives a *sensation of light*, but sees no object. He may also get a sensation of light with the eyelids closed, if he turn the eyes toward the window or some bright light. But how different when the light from various objects enters the eyes. There is apparently no consciousness of light, but instead a consciousness of the size, form, color, and position of the objects. *Seeing is perceiving objects.* Stimulation by the light waves is only the means toward this end. The chief problem in the study of sight is that of determining *how light waves enable us to become conscious of objects.*

Sense Organs of Sight.—The sense organs of sight consist mainly of the two eyeballs. Each of these is located in a cavity of the skull bones, called the *orbit*, where it is held in position by suitable tissues and turned in different directions by a special set of muscles. A cup-shaped receptacle is provided within the orbit, by layers of fat, and a smooth surface is supplied by a double membrane that lies between the fat and the eyeball. In front the eyeballs are provided with movable coverings, called the *eyelids*. These are composed of dense layers of connective tissue, covered on the outside by the skin and lined within by a sensitive membrane, called the *conjunctiva*. At the base of the lids the conjunctiva passes to the eyeball and forms a firmly attached covering over its front surface. This membrane prevents the passage of foreign materials back of the eyeball, and by its sensitiveness stimulates effort for the removal of irritating substances from beneath the lids. The eyelashes and the eyebrows are also a means of protecting the eyeballs.

The Eyeball, or globe of the eye, is a device for *focusing* light upon a sensitized nervous surface which it incloses and protects. In shape it is nearly spherical, being about an inch in diameter [374] from right to left and nine tenths of an inch both in its vertical diameter and from front to back. It has the appearance of having been formed by the union of two spherical segments of different size. The smaller segment, which forms about one sixth of the whole, is set upon the larger and forms the projecting transparent portion in front. The walls of the eyeballs are made up of three separate layers, or coats—an *outer coat*, a *middle coat*, and an *inner coat* (Fig. 159).

The Outer Coat surrounds the entire globe of the eye and consists of two parts—the sclerotic coat and the cornea. The *sclerotic coat* covers the greater portion of the larger spherical segment and is recognized in front as "the white of the eye." It is composed mainly of fibrous connective tissue and is dense, opaque, and tough. It preserves the form of the eyeball and protects the portions within. It is pierced at the back by a small opening which admits the optic nerve, and in front it becomes [375] changed into the peculiar tissue that makes up the cornea.

The *cornea* forms the transparent covering over the lesser spherical segment of the eyeball, shading into the sclerotic coat at its edges. It has a complex structure, consisting in the main of a transparent form of connective tissue. It serves the purpose of admitting light into the eyeball.

The Middle Coat consists of three connected portions—the *choroid coat*, the *ciliary processes*, and the *iris*. These surround the larger spherical segment. All three parts are rich in blood vessels, containing the blood supply to the greater portion of the eyeball.

The *choroid coat* lies immediately beneath the sclerotic coat at all places except a small margin toward the front of the eyeball.

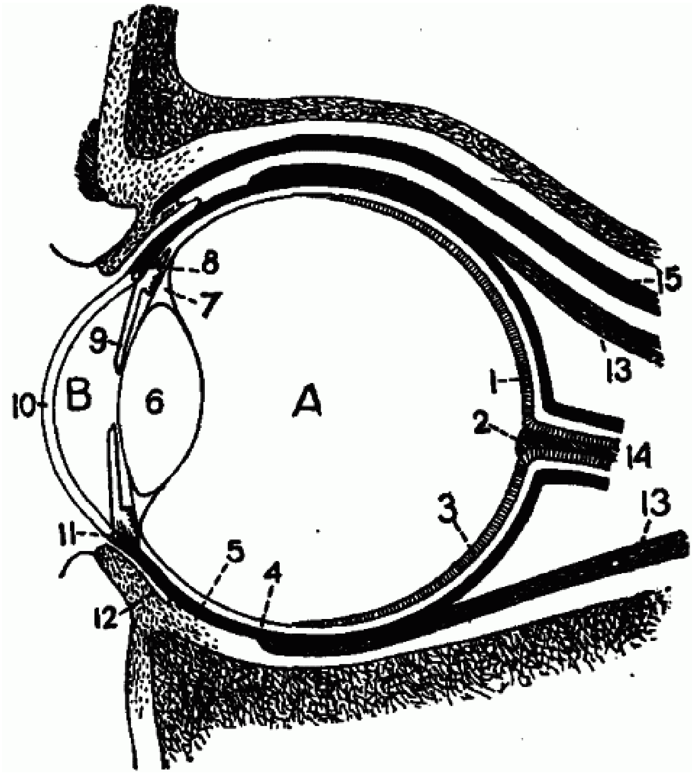

Fig. 159—**Diagram of the eyeball in position.** 1. Yellow spot. 2. Blind spot. 3. Retina. 4. Choroid coat. 5. Sclerotic coat. 6. Crystalline lens. 7. Suspensory ligament. 8. Ciliary processes and ciliary muscle. 9. Iris containing the pupil. 10. Cornea. 11. Lymph duct. 12. Conjunctiva. 13. Inferior and superior recti muscles. 14. Optic nerve. 15. Elevator muscle of eyelid. 16. Bone. *A.* Posterior chamber containing the vitreous humor. *B.* Anterior chamber containing the aqueous humor.

It is composed chiefly of blood vessels and a delicate form of connective tissue that holds them in place. It contains numerous pigment cells which give it a dark appearance and serve to absorb surplus light. Near where the sclerotic coat joins the cornea, the choroid coat separates from the outer wall and, by folding, forms many slight projections into the interior space. These are known as the *ciliary processes*. The effect of these folds is to collect a large number of capillaries into a small space and to give this part of the eyeball an extra supply of blood. Between the ciliary processes and the sclerotic coat is a small muscle, containing both circular and longitudinal fibers, called the *ciliary muscle*.

The *iris* is a continuation of the choroid coat across the front of the eyeball. It forms a dividing curtain between the two spherical segments and gives the color to the eye. At its center is a circular opening, called the *pupil*, which admits light to the back of the eyeball. By varying the size of the pupil, the iris is [376]
able to regulate the amount of light which passes through and it employs for this purpose two sets of muscular fibers. One set of fibers forms a thin band which encircles the pupil and serves as a sphincter to diminish the opening. Opposing this are radiating fibers which are attached between the inner and outer margins of the iris. By their contraction the size of the opening is increased. Both sets of fibers act reflexively and are stimulated by variations in the light falling upon the retina.

The Inner Coat, or Retina.—This is a delicate membrane containing the expanded termination of the optic nerve. It rests upon the choroid coat and spreads over about two thirds of the back surface of the eyeball. Although not more than one fiftieth of an inch in thickness, it presents a very complex structure, essentially nervous, and is made up of several distinct layers. Of [377]
chief importance in the outer layer are the cells which are acted upon directly by the light and are named, from their shape, the

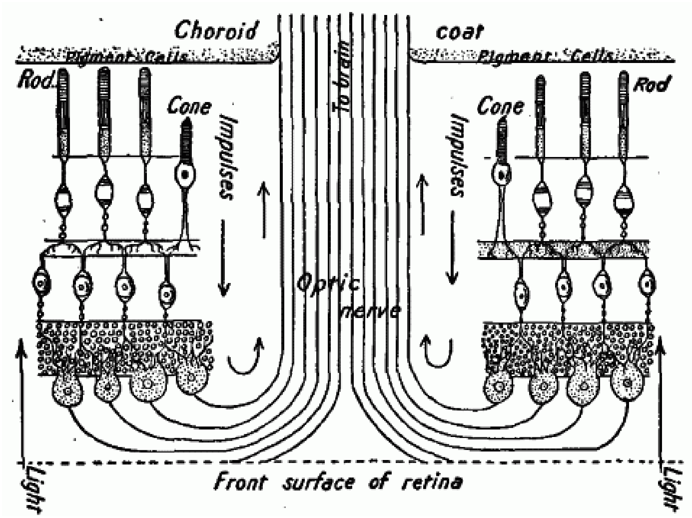

Fig. 160—**Diagram showing main nervous elements in the retina.** Light waves stimulate the rods and cones at back surface of the retina, starting impulses which excite the ganglion cells at the front surface. Fibers from the ganglion cells pass into the optic nerve.

rods and *cones*. In contact with these, but occupying a separate layer, are the ends of small afferent nerve cells. These in turn communicate with nerve cells in a third layer, known as the ganglion cells, that send their fibers into the optic nerve (Fig. 160).

In the center of the retina is a slight oval depression having a faint yellowish color, and called, on that account, the *yellow spot*. This is the part of the retina which is most sensitive to light. Directly over the place of entrance of the optic nerve is a small area from which the rods and cones are absent and which, therefore, is not sensitive to light. This is called the *blind spot*. (See Practical Work.)

The Crystalline Lens.—Immediately back of the iris and touching it is a transparent, rounded body, called the crystalline lens. This is about one fourth of an inch thick and one third of an inch through its long diameter, and is more curved on the back than on the front surface. It is inclosed in a thin sheath, called the *membranous capsule*, which connects with a divided sheath from the sides of the eyeball, called the *suspensory ligament* (Fig. 159). Both the lens and the capsule are highly elastic.

Chambers and "Humors" of the Eyeball.—The crystalline lens together with the suspensory ligament and the ciliary processes form a partition across the eyeball. This divides the eye space into two separate compartments, which are filled with the so-called "humors" of the eye. The front cavity of the eyeball, which is again divided in part by the iris, is filled with the *aqueous* humor. This is a clear, lymph-like liquid which contains an occasional white corpuscle. It has a feeble motion and is slowly [378]
added to and withdrawn from the eye. It is supplied mainly by the blood vessels in the ciliary processes and finds a place of exit through a small lymph duct at the edge of the cornea (Fig. 159).

The back portion of the eyeball is filled with a soft, transparent, jelly-like substance, called the *vitreous* humor. It is in contact with the surface of the retina at the back and with the attachments of the lens in front, being surrounded by a thin covering of its own, called the *hyaloid membrane*. The aqueous and vitreous humors aid in keeping the eyeball in shape and also in focusing.

How we see Objects.—To see an object at least four things must happen:

1. Light must pass from the object into the eye. Objects cannot be seen where there is no light or where, for some reason, it is kept from entering the eye.

2. The light from the object must be focused (made to form an image) on the retina. In forming the image, an area of the retina is stimulated which corresponds to *the form of the object*.

3. Impulses must pass from the retina to the brain, stimulating it to produce the sensations.

4. The sensations must be so interpreted by the mind as to give an impression of the object.

Focusing Power of the Eyeball.—The eyeball is essentially a device for focusing light. All of its transparent portions are directly concerned in this work, and the portions that are not transparent serve to protect and operate these parts and hold them in place. Of chief importance are the crystalline lens and the cornea. Both of these are lenses. The cornea with its inclosed
[379] liquid is a plano-convex lens, while the crystalline lens is double convex.[123] Because of the great difference in density between the air on the outside and the aqueous humor within, the cornea is the more powerful of the two. The crystalline lens, however, performs a special work in focusing which is of great importance. The iris also aids in focusing since it, through the pupil, regulates the amount of light entering the back chamber of the eyeball and causes it to fall in the center of the crystalline lens, the part which focuses most accurately.

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[123] Consult some work on physics on the different kinds of lenses and their uses.

Accommodation.—A difficulty in focusing arises from the fact that the degree of divergence of the light waves entering the eye from different objects, varies according to their distance. Since the waves from any given point on an object pass out in straight lines in all directions, the waves that enter the eye from distant objects are at a different angle from those that enter from near objects. In reality waves from distant objects are practically parallel, while those from very near objects diverge to a considerable degree. To adjust the eye to different distances requires some change in the focusing parts that corresponds to the differences in the divergence of the light. This change, called [380] *accommodation*, occurs in the crystalline lens.[124] In the process of accommodation, changes occur in the shape of the crystalline lens, as follows:

1. In looking from a distant to a near object, the lens becomes more convex, *i.e.*, rounder and thicker (Fig. 161). This change is necessary because the greater divergence of the light from the near objects requires a greater converging power on the part of the lens.[125]

2. In looking from near to distant objects, the lens becomes flatter and thinner (Fig. 161). This change is necessary because the less divergent waves from the distant objects require less converging power on the part of the lens.

The method employed in changing the shape of the lens is difficult to determine and different theories have been advanced to account for it. The following, proposed by Helmholtz, is the

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[124] With respect to its adjustments the eye does not differ in principle from various other optical instruments, such as the microscope, telescope, photographer's camera, etc., which, in their use, form images of objects. These all require some adjustment of their parts, called focusing, which adapts them to the distance. The eye's method of focusing, however, differs from that of most optical instruments, in that the adjustment is brought about through changes in the curvature of a lens.

[125] The converging power of convex lenses varies as the curvature—the greater the curvature, the greater the converging power.

theory most generally accepted:

The lens is held in place back of the pupil by the suspensory ligament. This is attached at its inner margin to the membranous capsule, and at its outer margin to the sides of the eyeball, and entirely surrounds the lens. It is drawn perfectly tight so that the sides of the eyeball exert a continuous tension, or pull, on the membranous capsule, which, in its turn, exerts pressure on the sides of the lens, tending to flatten it. This arrangement brings the elastic force of the eyeball into opposition to the elastic force of the lens. The ciliary muscle plays between these opposing forces in the following manner:

To thicken the lens, the ciliary muscle contracts, pulling forward the suspensory ligament and releasing its tension on the
[381] membranous capsule. This enables the lens to thicken on account of its own elastic force. *To flatten the lens*, the ciliary muscle relaxes, the elastic force of the eyeball resumes its tension on the suspensory ligament, and the membranous capsule resumes its pressure on the sides of the lens. This pressure, overcoming the elastic force of the lens, flattens it.

Movements of the Eyeballs.—In order that the light may enter the eyeballs to the best advantage, they must be moved in various directions. These movements are brought about through the action of six small muscles attached to each eyeball. Four of these, named, from their positions, the superior, inferior, internal, and external recti muscles, are attached at one end to the sides of the eyeball and at the other end to the back of the orbit (Fig. 162). These, in the order named, turn the eyes upward, downward, inward, and outward. The other two, the superior and inferior oblique muscles, aid in certain movements of the recti muscles and, in addition, serve to rotate the eyes slightly. The movements of the eyeballs are similar to those of ball and socket joints.

Binocular Vision.—In addition to directing the eyeballs so

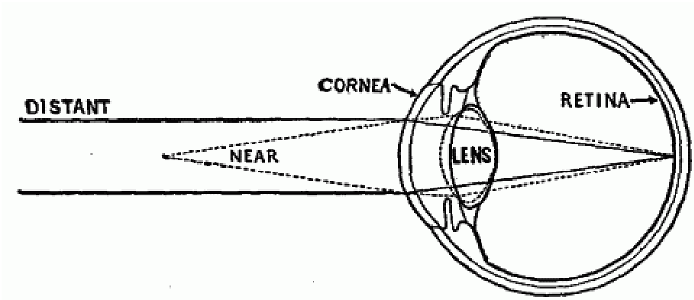

Fig. 161—**Diagram showing changes in shape of crystalline lens** to adapt it to near and distant vision.

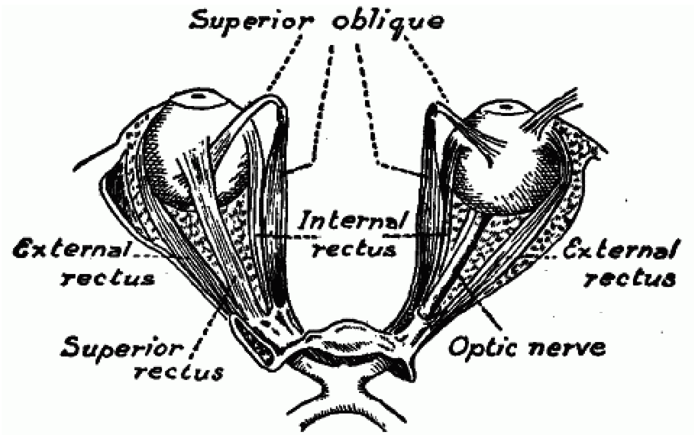

Fig. 162—**Exterior muscles of eyeball.**

that light may enter them to the best advantage from different [382] objects, the muscles also enable two eyes to be used as one. Whenever the eyes are directed toward the same object, an image of this object is formed on the retina of each. Double vision is prevented only by having the images fall on corresponding places in the two eyes. This is accomplished by the muscles. In each act of seeing, it becomes the task of the superior and inferior recti muscles to keep the eyes in the same plane, and of the external and internal recti muscles to give just the right amount of convergence. If slight pressure is exerted against one of the eyes, the action of the muscles is interfered with and, as a consequence, one sees double. The advantages of two eyes over one in seeing lie in the greater distinctness and broader range of vision and in the greater correctness of judgments of distance.

Visual Sensations.—The visual sensations include those of *color* and those of a *general sensibility to light*. Proof of the existence of these types of sensation is found in color blindness, a defect which renders the individual unable to distinguish certain colors when he is still able to see objects. Color sensations are the results of light waves of different lengths acting on the retina. While the method by which waves of one length produce one kind of sensation and those of another length a different sensation is not understood, the cones appear to be the portions of the retina acted on to produce the color. On the other hand, the rods are sensitive to all wave lengths and give general sensibility to light.

Visual Perceptions.—"Seeing" is very largely the mental interpretation of the primary sensations and the conditions under which they occur. For example, our ability to see objects in their natural positions when their images are inverted on the retina is explained by the fact that we are not conscious of the retinal image, but of the mind's interpretation of it through experience. Experience has also taught us to locate objects in the direction toward which it is necessary to turn the eyes in order to see them. In other words, we see objects in the direction from which the light enters the eyes. That the object is not always in that direction is shown by the image in the mirror. The apparent size and form of objects are inferences, and they are based in part upon the size and form of the area of the retina stimulated. We judge of distance by the effort required to converge the eyes upon the objects, by the amount of divergence of the waves entering the pupil, and also by the apparent size of the object.

The Lachrymal Apparatus.—Seeing requires that the light [383]
penetrate to the retina. For this reason all the structures in front of the retina are transparent. One of these structures, the cornea, on account of its exposure to the air, is liable to become dry, like the skin, and to lose its transparency. To preserve the transparency of the cornea, and also to lubricate the eyelids and aid in the removal of foreign bodies, a secretion, called *tears*, is constantly supplied.

The lachrymal, or tear, glands are situated at the upper and outer margins of the orbits. They have the general structure of the salivary glands and discharge their liquid by small ducts beneath the upper lids. From here the tears spread over the surfaces of the eyeballs and find their way in each eye to two small canals whose openings may be seen on the edges of the lids near the inner corner (Fig. 163). These canals unite to form the *nasal duct*, which conveys the tears to the nasal cavity on the same side of the nose. When by evaporation the eyeball becomes too dry, the lids close reflexively and spread a fresh layer of tears over the surface. Any excess is passed into the nostrils, where it aids in moistening the air entering the lungs.

HYGIENE OF THE EYE

Defects in Focusing.—The delicacy and complexity of the sense organs of sight render them liable to a number of imperfections, or

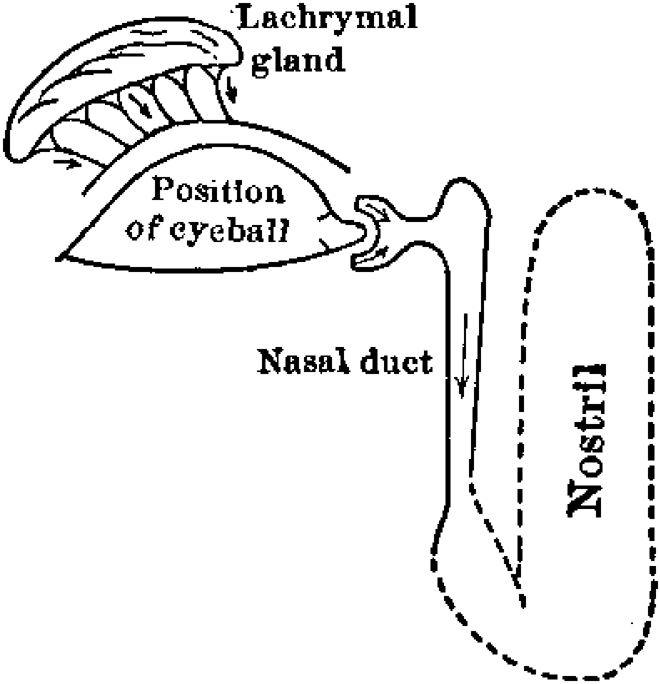

Fig. 163—**Diagram of irrigating system of the eye.** After wetting the eyeball the tears may also moisten the air entering the lungs.

defects, the most frequent and important being those of focusing. Such defects not only result in the imperfect vision of objects, [384] but they throw an extra strain upon the nervous system and may render the process of seeing exceedingly painful.

A normal eye is able, when relaxed, to focus light accurately from objects which are twenty feet or more away and to accommodate itself to objects as near as five inches. An eye is said to be *myopic*, or *short-sighted*, when it is unable to focus light waves from distant objects, but can only distinguish the objects which are near at hand. In such an eye the ball is too long for the converging power of the lenses, and the image is formed in front of the retina (*C*, Fig. 164).

A *long-sighted*, or *hypermetropic*, eye is one which can focus light from distant objects, but not from near objects. In such an eye the ball is too short for the converging power of the lenses and the image tends to form back of the retina (*B*, Fig. 164). These defects in focusing are remedied by wearing glasses with lenses so shaped as to counteract them. Short-sightedness is corrected by concave lenses and long-sightedness by convex lenses, as shown in diagrams above.

Astigmatism is another defect in the focusing power of the eye. In astigmatism the parts of the eye fail to form the image in the same plane, so that all portions of the object do not appear equally distinct. Certain parts of it are indistinct, or blurred. The cause is found in some difference in curvature of the surfaces of [385] the cornea or crystalline lens. It is corrected by lenses so ground as to correct the particular defects present in a given eye.

Whenever defects in focusing are present, particularly in astigmatism, extra work is thrown on the ciliary muscle as well as the muscles that move the eyeballs. The result is frequently to induce a condition, known as *muscle weakness*, which renders it difficult to use the eyes. Even after the defect in focusing has

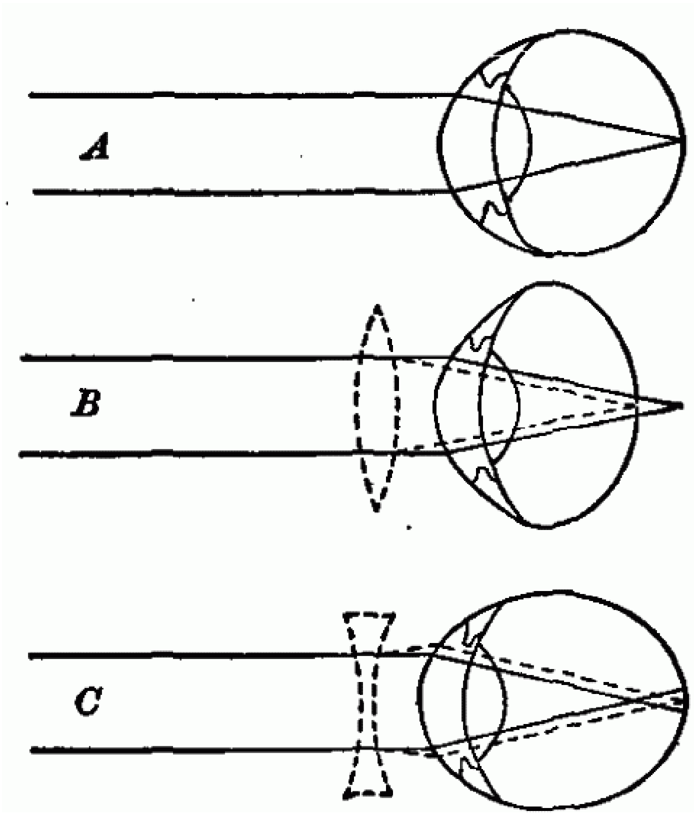

Fig. 164—**Diagrams illustrating long-sightedness and short-sightedness**, and method of remedying these defects by lenses. *A.* Normal eye. *B.* Long-sighted eye. *C.* Short-sighted eye.

been remedied, the muscles recover slowly and must be used with care. For this reason glasses should be fitted by a competent oculist[126] as soon as a defect is known to exist. When one is unduly nervous, or suffers from headache, the eyes should be examined for defects in focusing (page 326).

Eye Strain and Disease.—The extra work thrown upon the nervous system through seeing with defective eyes, especially in reading and other close work, is now recognized as an important cause of disease. Through the tax made upon the nervous system by the eyes, there may be left an insufficient amount of nervous energy for the proper running of the vital processes. As a result there is a decline of the health. Ample proof that eye strain interferes with the vital processes and causes ill health, is found in the improvements that result when, by means of glasses, this is relieved.

The Eyes of School Children.—School children often suffer from defects of vision which render close work burdensome, and cause headache, general nervousness, and disease. Furthermore, the visual defects may be unknown both to themselves and to their parents. Pupils showing indications of eye-strain should be examined by an oculist, and fitted with glasses should defects [386]
be discovered.[127] The precaution, adopted by many schools, of having the eyes of all children examined by a competent physician employed for the purpose, is most excellent and worthy of imitation.

Reading Glasses.—Many people whose eyes are weak, because slightly defective, find great relief in the use of special glasses for reading and other close work. By using such glasses they may postpone the time when they are compelled to wear glasses constantly. It is in the close work that the extra strain

[126] An oculist is a physician who specializes in diseases of the eye.

[127] Some of the more common symptoms of eye strain are nervousness, headache, insomnia, irritations of the eyelids, sensitiveness to bright light, and pain in the use of the eyes.

comes upon the eyes, and if this is relieved, one can much better withstand the work of distant vision. The reading glasses should be fitted by a competent oculist, and used only for the purpose for which they are intended.

General Precautions in the Use of the Eyes.—If proper care is exercised in the use of the eyes, many of their common ailments and defects may be avoided. Any one, whether his eyes are weak or strong, will do well to observe the following precautions:

1. Never read in light that is very intense or very dim. 2. When the eyes hurt from reading, stop using them. 3. Never hold a book so that the smooth page reflects light into the eyes. The best way is to sit or stand so that the light passes over the shoulder to the book. 4. Never study by a lamp that is not shaded. 5. Practice cleanliness in the care of the eyes. Avoid rubbing the eyes with the fingers unless sure the fingers are clean.

If the eyes are weak, use them less and avoid, if possible,
[387] reading by artificial light. Weak eyes are sometimes benefited by bathing them in warm water, or with water containing enough salt to make them smart slightly. Boracic acid dissolved in water (40 grains to 4 ounces of distilled water) is also highly recommended as a wash for weak eyes.

Removal of Foreign Bodies from the Eyes.—Foreign bodies embedded in the eyeball should be removed by the oculist or physician. Small particles of dust or cinder may be removed without the aid of the physician, by exercising proper care. First let the tears, if possible, wash the offending substance to the corner of the eye, or edge of the lid, where it can be removed with a soft cloth. If it sticks to the ball or the under surface of the lid, it will be necessary to find where it is located, and then dislodge it from its position. Begin by examining the lower lid. Pull it down sufficiently to expose the inner surface, and,

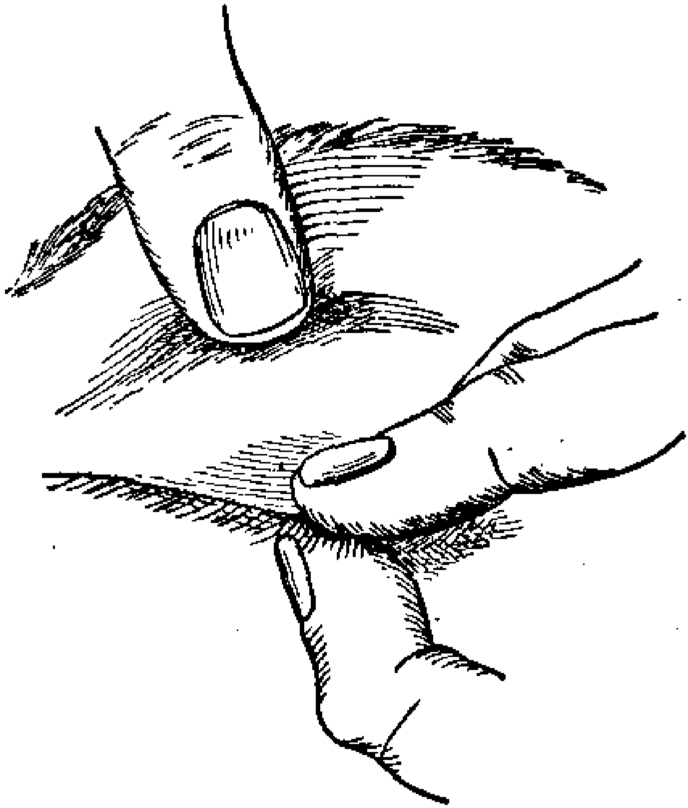

Fig. 165—**Method of procedure in lifting the eyelid** (Pyle).

if the foreign substance be there, wipe it off with the hem of a clean handkerchief. If it is not under the lower lid, it will be necessary to fold back the upper lid. "The patient is told to look down, the edge of the lid and the lashes are seized with the forefinger and thumb of the right hand (Fig. 165), and the lid is drawn at first downward and forward away from the globe; then upward and backward over the point of the thumb or forefinger of the left hand, which is held stationary on the lid, and acts as
[388] a fulcrum."[128] The foreign body is now removed in the same manner as from the lower lid. A large lens may be used to good advantage in finding the irritating substance.

Strong Chemicals in the Eyes.—Students in the laboratory frequently, through accident, get strong chemicals, as acids and bases, in the eyes. The first thing to do in such cases is quickly and thoroughly to *flood the eyes with water*. Any of the chemical which remains may then be counteracted by the proper reagent, care being taken to use a very dilute solution. To counteract an acid, use sodium bicarbonate (cooking soda), and for bases use a very dilute solution of acetic acid (vinegar). To guard against getting the counteractive agent too strong for the inflamed eye, it should first be tried on an eye that has not been injured.

Summary.—The nervous impulses that cause the sensation of sight are started by light waves falling upon a sensitized nervous surface, called the retina. By means of refractive agents, forming a part of the eyeball in front of the retina, light from different objects is focused and made to form images of the objects upon the surface. In this way the light is made to stimulate a portion of the retina corresponding to the form of the object. This, *the image method of stimulation*, enables the mind to recognize objects and to locate them in their various positions. While the greater portion of the eyeball is concerned in the focusing of light, the crystalline lens, operated by the ciliary muscle, serves

[128] Pyle, *Personal Hygiene*.

as the special instrument of accommodation. Muscles attached to the eyeballs turn them in different directions, and so adjust them with reference to each other that double vision is avoided.

Exercises.—1. Under what conditions are light waves reflected, refracted, and absorbed?

2. Why does the body not need a light-producing apparatus, corresponding to the larynx in the production of sound? [389]

3. How is the light from a candle made to form an image?

4. What different things must happen in order that one may see an object?

5. Make a sectional drawing of the eyeball, locating and naming all the parts.

6. Of what parts are the outer, middle, and inner coats of the eyeball made up?

7. What portions of the eyeball reflect light? What absorb light? What transmit light? What refract light?

8. Show how the iris, the crystalline lens, the retina, the ciliary muscle, and the cornea aid in seeing.

9. Trace a wave of light from a visible object to the retina.

10. Why does not the inverted image on the retina cause us to see objects upside down?

11. What change occurs in the shape of the crystalline lens when we look from distant to near objects? From near to distant objects? Why are these changes necessary? How are they brought about?

12. How does the method of adjustment, or accommodation, of the eyeball differ from that of a telescope or a photographer's camera?

13. With two eyes how are we kept from seeing double?

14. What different purposes are served by the tears. Trace them from the lachrymal glands to the nostrils.

15. Show how the proper lenses remedy short- and long-sightedness.

16. Describe the conjunctiva and give its functions. Why should it be so sensitive?

17. How may eye strain cause disease in parts of the body remote from the eyes?

18. How does "image stimulation" differ from light stimulation in general?

PRACTICAL WORK

To illustrate Simple Properties of Light.—1. Heat an iron or platinum wire in a clear gas flame. Observe that when a high temperature is reached it gives out light or becomes luminous.

2. Cover one hand with a white and the other with a black piece of cloth, and hold both for a short time in the direct rays of the sun. Note and account for the difference in temperature which is felt.

[390] 3. Stand a book or a block of wood by the side of an empty pan in the sunlight, so that the end of the shadow falls on the bottom of the pan. Mark the place where the shadow terminates and fill the pan with water. Account for the shadow's becoming shorter.

4. Place a coin in the center of an empty pan and let the members of the class stand where the coin is barely out of sight over the edges of the pan. Fill the pan with water and account for the coin's coming into view. Show by a drawing how light, in passing from the water into the air, is so bent as to enter the eye.

5. With a convex lens, in a darkened room, focus the light from a candle flame so that it falls on a white screen and forms an image of the candle. Observe that the image is inverted. In a well-lighted room focus the light from a window upon a white screen. Show that, as the distance from the window to the screen is changed, the position of the lens must also be changed. (Accommodation.)

6. Hold a piece of cardboard, about eight inches square and having a smooth, round hole an eighth of an inch in diameter in the center, in front of a lighted candle in a darkened room. Back of the opening place a muslin or paper screen (Fig. 157). Observe that a dim image is formed. Account for the fact that it is inverted. Hold a lens between the cardboard and the screen so that the light passes through it also. The image should now appear smaller and more distinct.

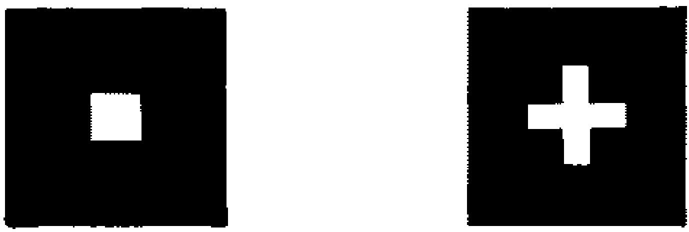

Fig. 166—**Diagram** for proving presence of the blind spot.

To prove the Presence of the Blind Spot.—Close the left eye and with the right gaze steadily at the spot on the left side of this page (Fig. 166). Then starting with the book a foot or more from the face, move it slowly toward the eye. A place will be found where the spot on the right entirely disappears. On bringing it nearer, however, it is again seen. As the book is moved forward or backward, the position of the image of this spot changes on [391] the retina. When the spot cannot be seen, it is because the image falls on the blind spot.

Dissection of the Eyeball.—Procure from the butcher two or three eyeballs obtained from cattle. After separating the fat, connective tissue, and muscle, place them in a shallow vessel and cover with water. Insert the blade of a pair of sharp scissors at the junction of the sclerotic rotic coat with the cornea and cut from this point nearly around the entire circumference of the eyeball, passing near the optic nerve. Spread open in the water and identify the different parts from the description in the text. Open the second eyeball in water by cutting away the cornea. Examine the parts in front of the lens.

Fig. 167—**Model** for demonstrating the eyeball.

To illustrate Accommodation.—Paste together the ends of a strip of stiff writing paper (two by five inches) making a ring a little less than three inches in diameter. This is to represent the crystalline lens. Now paste a piece of thin paper (two by seven inches) upon a second strip of the same size, leaving an open place in the middle for the insertion of the paper lens. A flexible piece of cardboard (three by twelve inches) is now bent into the form of a half circle and to its ends are fastened the strips of paper containing the ring. Make a small hole in each of the four corners of the bent cardboard. Through these holes pass two loops of thread, or fine string, in opposite directions, letting the ends hang loose from the cardboard.

When everything is in position, the tension from the cardboard flattens the paper lens, while pulling the strings releases this tension and permits the lens to become more rounded. With this simple device the changes in the curvature of the lens for near and distant vision are easily shown.

[392]

CHAPTER XXIII - THE GENERAL PROBLEM OF KEEPING WELL

> "To cure was the voice of the Past: to prevent is the divine whispering of To-day."

As stated in the introduction to our study, the fundamental law of hygiene is the law of harmony: *Habits of living must harmonize with the plan of the body.* Having acquainted ourselves with the plan of the body, we may now review briefly those conditions that help or hinder its various activities. The hygiene already presented in connection with the study of the various organs may be condensed into general rules, or laws, as follows:

1. Of exercise: Exercise daily the important groups of muscles.

2. Of form: Preserve the natural form of the body.

3. Of energy: Observe regular periods of rest and exercise and avoid exhaustion.

4. Of nutriment: Eat moderately of a well-cooked and well-balanced diet and drink freely of pure water.

5. Of respiration: Breathe freely and deeply of pure air and spend a part of each day out of doors.

6. Of nervous poise: Suppress wasteful and useless forms of nervous activity, avoid nervous strain, and practice cheerfulness.

7. Of cleanliness: Keep the body and its immediate surroundings clean.

[393] 8. Of restraint: Abstain from the unnecessary use of drugs as well as from the practice of any form of activity known to be harmful to the body.

9. Of elimination: Observe all the conditions that favor the regular discharge of waste materials from the body.

Obedience to these laws is of vast importance in the proper management of the body. They should, indeed, be so thoroughly impressed upon the mind as to become fixed habits. There are, however, other conditions that relate to this problem, and it is to these that we now turn. These conditions have reference more specifically to

The Prevention of Disease.—While the average length of life is not far from thirty-five years, the length of time which the average individual is capable of living is, according to some of the lowest estimates, not less than seventy years. This difference is due to disease. People do not, as a rule, die on account of the wearing out of the body as seen in extreme old age, but on account of the various ills to which flesh is heir. It is true that many people meet death by accident and not a few are killed in wars, but these numbers are small in comparison with those that die of bodily disorders. The prevention of disease is the greatest of all human problems. Though the fighting of disease is left largely to the physician, much is to be gained through a more general knowledge of its causes and the methods of its prevention.

Causes of Disease.—Disease, which is some *derangement of the vital functions*, may be due to a variety of causes. Some of these causes, such as hereditary defects, are remote and beyond the control of the individual. Others are the result of negligence in the observance of well-recognized hygienic laws. Others still are of the nature of influences, such as climate, the house in which one lives, or one's method of gaining a livelihood, that [394]
produce changes in the body, imperceptible at the time, but, in the long run, laying the foundations of disease. And last, and most potent, are the minute living organisms, called microbes or germs, that find their way into the body. Although there are two general kinds of germs, known as *bacteria* (one-celled plants) and *protozoa* (one-celled animals), most of our germ diseases are caused by bacteria.

Effects of Germs.—While there are many kinds of germs that have no ill effect upon the body and others that are thought to aid it in its work, there are many well-known varieties that produce effects decidedly harmful. They gain an entrance through the lungs, food canal, or skin, and, living upon the fluids and tissues, multiply with great rapidity until they permeate the entire body. Not only do they destroy the protoplasm, but they form waste products, called *toxins*, which act as poisons. Diseases caused by germs are known as infectious, or contagious, diseases.[129] The list is a long one and includes smallpox, measles, diphtheria, scarlet fever, typhoid fever, tuberculosis, la grippe, malaria, yellow fever, and others of common occurrence. In addition to the diseases that are well pronounced, it is probable that germs are responsible also for certain bodily ailments of a milder character.[130]

[395] **Avoidance of Germ Diseases.**—The problem of preventing diseases caused by germs is an exceedingly difficult one and no solution for all diseases has yet been found. One's chances of avoiding such diseases, however, may be greatly enhanced:

1. By strengthening the body through hygienic living so that it offers greater resistance to the invasions of germs.

2. By living as far as possible under conditions that are unfavorable to germ life.

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[129] "An infectious disease is one in which disease germs infect (that is, invade) the body from without. Among the infectious diseases are some that are quite directly and quickly conveyed from person to person and to these the term contagious is applied. Formerly a sharp line was drawn between infection and contagion, but to-day it is recognized that no such line exists."—HOUGH AND SEDGWICK, *The Elements of Hygiene and Sanitation.*

[130] The arctic explorer, Nansen, states that during all the time that his party was exposed to the low temperature of the arctic region, no one was attacked by a cold, but on returning to a warmer climate they were subject to colds as usual. The difference he attributes to the absence of germs in the severe arctic climate. There seems to be no doubt but that most of our common colds are due to attacks of germs.

3. By understanding the agencies through which disease germs are spread from person to person.

Conditions Favorable and Unfavorable for Germs.—Conditions favorable for germ life are supplied by animal and vegetable matter, moisture, and a moderate degree of warmth. Hence disease germs may be kept alive in damp cellars and places of filth. Even living rooms that are poorly lighted or ventilated may harbor them. Water may, if it contain a small per cent of organic matter, support such dangerous germs as those of typhoid fever. Fresh air, sunlight, dryness, cleanliness, and a high temperature, on the other hand, are destructive of germs. The germs in impure water, as already noted (page 165), are destroyed by boiling.

How Germs are Spread.—Some of the more common methods by which the germs of disease are spread, and by so doing find new victims, are as follows:

1. *By Means of Foods.*—Foods, on account of the locality in which they are produced or the method of gathering or of handling-them, may become contaminated with germs, which are then transported with the foods to the consumer.

2. *By Means of Dust.*—Material containing germs, *e.g.*, discharges from the throat and lungs, will on drying form dust. [396]
This is lifted with other fine particles by the air and may be carried quite a distance. The dust from public halls and other places where people congregate is the kind most likely to contain disease germs. Dust should be breathed as little as possible and only through the nostrils. Where one is compelled, as in sweeping, to breathe dust-laden air for some time, he should inhale through a moistened sponge, or cloth, tied in front of the nostrils.

3. *By Means of Domestic Pets and Different Kinds of Household Vermin.*—Germs sticking to the bodies of small animals are carried about and may be easily communicated to people. By this means, rats, mice, bedbugs, etc., where such exist, are frequently

the means of spreading disease; and particularly dangerous, on this account, is the common house fly. Feeding as it does on filth of all kinds, it is easy for it to transfer the bacteria that may stick to its body to the food which is supplied to the table. The proper screening of houses and the destruction of material in which flies may develop, such as the refuse from stables, are necessary precautions.

Germs are spread also by the clothing of people, by railroad and steamship lines, by the mails, and by the natural elements. In fact, any kind of carrier, in or upon which germs can live, may serve as a means of spreading those of certain kinds.

Public Sanitation.—The general conditions under which germs may thrive and some of the means by which they are scattered, emphasize the practical value of measures which have for their purpose the making of one's surroundings more wholesome and hygienic. Such measures may be directed both toward one's immediate surroundings—the home—and toward
[397] the neighborhood, town, or city in which one lives. The hygienic conditions of primary importance in every city or town are as follows:

1. An adequate public supply of pure water.

2. An efficient system of underground pipes for the removal of sewage.

3. An efficient system for removing from the streets and alleys everything of the nature of waste.

4. Prevention, by enforcement of ordinances, of spitting upon sidewalks and the floors of public halls and conveyances.

5. A hospital or sanitarium in which people can be cared for when sick with infectious diseases.

In the larger cities other hygienic measures demand attention, such as provisions for parks and playgrounds, the proper housing of the poor of the city, and the suppression of the smoke and dust nuisances. Crowded together as people are in the cities, the welfare of each individual depends in a large measure upon the welfare of all. Hence the problems of public sanitation are matters in which all are vitally concerned.

Sanitary Conditions of the Home.—The home, being the feeding and resting place for the entire family, is the most important factor in one's physical, as well as moral, environment. For this reason there is no place where careful attention to hygienic requirements will yield better results. Much of the danger from germs may be prevented by instituting and maintaining proper sanitary conditions in and about the home.

One of the first requisites of the home is a suitable location for the house. The house should be built upon ground that is well drained, and if natural drainage be lacking, artificial drainage must be supplied. It should not be situated nearer than a quarter of a mile to any marsh or swamp and, if so near as that, it ought [398] to be on the side from which the wind usually blows. A stone foundation should be provided, and at least eighteen inches of ventilated air space should be left between the ground and the floor. Ample provisions must be made for pure air and sunlight in all the rooms. The cellar, if one is desired, needs to be constructed with special care. It should be perfectly dry and provided with windows for light and ventilation. Adequate means must also be provided, by sewage pipes and other methods, for the disposal of all waste. Where drainage pipes are provided, care must be taken to prevent the entrance of sewer gas into the house and also the passage of material from these pipes into the water supply. The placing and connecting of sewer pipes should, of course, be under the direction of a plumber.

The Water Supply.—Since water readily takes up and holds the impurities with which it comes in contact, it should be exposed as little as possible in the process of collecting. Where cistern water is used, care must be taken to prevent filth from the roof (Fig. 168), water pipes, or soil from getting into the reservoir. Water should be collected from the roof only after it has rained long enough for the roof and pipes to have been thoroughly cleaned. The cistern should have no leaks (Fig. 169), and the top should be tightly closed to prevent the entrance of small animals and rubbish.

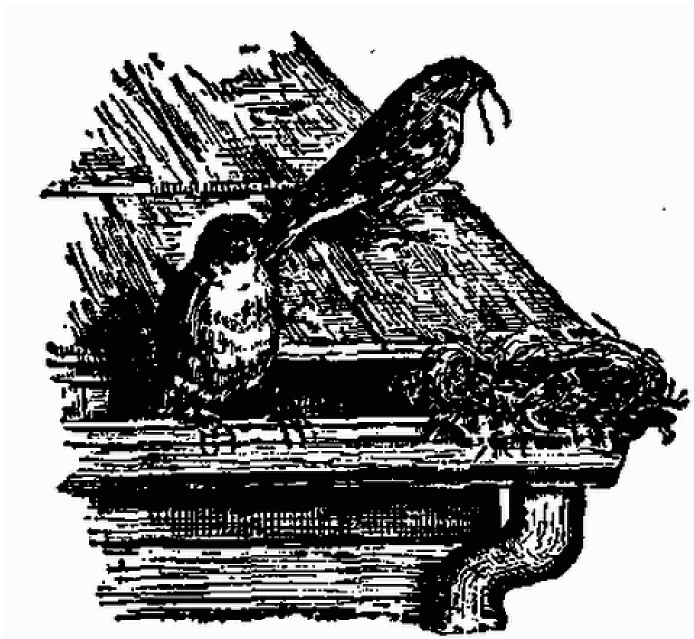

Fig. 168—**Contamination of cistern water** by birds nesting in the gutter trough.

[399] Shallow wells are to be condemned, as a rule, because of the likelihood of surface drainage (Fig. 169), and water from springs should, for the same reason, be used with caution. Deep wells that are kept clean usually may be relied on to furnish water free from organic impurities, but such water often holds in solution so much of mineral impurities as to render it unfit for drinking. The

presence in water of any considerable quantity of the compounds of iron or calcium makes it objectionable for regular use.

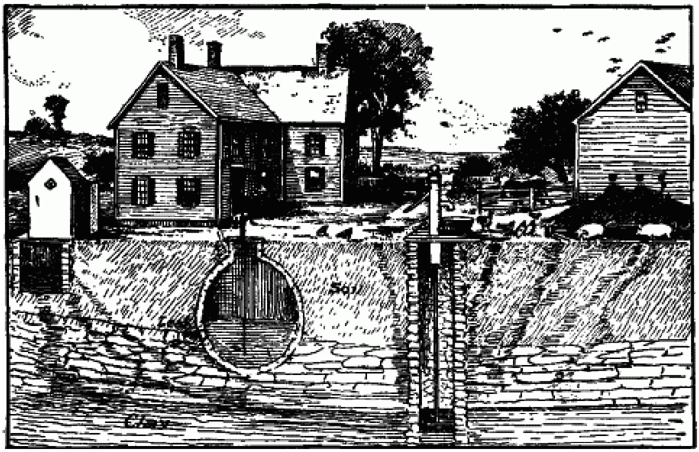

Fig. 169—**Sources of contamination of cistern and well water.** Illustration shows liability of contamination from surface drainage and from entrance of filth at top.

Hygienic Housekeeping.—However carefully a house has been constructed from a sanitary standpoint, the constant care of an intelligent housekeeper is required to keep it a healthful place in which to live. Daily cleaning and airing of all living rooms are necessary, while such places as the kitchen, the cellar, and the closets need extra thoughtfulness and, at times, hard work. Moreover, the problem is not all indoors. The immediate premises must be kept clean and sightly, and all decaying vegetable and animal matter should be removed. Home sanitation consists, not [400]
of one, but of many, problems, all more or less complex. None of these can be slighted or turned over to a novice.

Destruction of Infectious Material.—At times the housekeeping has to be directed especially toward hygienic requirements, such an occasion being the sickness of one of the inmates with some contagious disease. Unless special precautions are taken, the disease will spread to other members of the household and may reach people in the neighborhood. Not only must great care be exercised that nothing used in connection with the sick shall serve as a carrier of disease, but germs passing from the patient should, as far as possible, be actually destroyed. All discharges from the body likely to contain bacteria, should be burned or treated with disinfectants and buried deeply at a remote distance from the water supply to the house.

After recovery all clothing, bedding, and furniture used in connection with the sick should be disinfected or burned. The room also in which the sick was cared for should be thoroughly disinfected and cleaned; in some instances the woodwork ought to be repainted and the walls repapered or calcimined. The purpose is, of course, to destroy all germs and prevent, by this means, a recurrence of the disease.

Fumigation.—To destroy germs in the air or adhering to the walls of rooms, furniture, clothing, etc., fumigation is employed. This is accomplished by saturating the air of rooms with some vapor or gas which will destroy the germs. Fumigation is quite generally employed in the general cleaning after the patient leaves his room. This, to be effective, must be thorough. Formaldehyde is considered the best disinfectant for this purpose, and it should be evaporated with heat in the proportion of one half pint of the 40 per cent solution to 1000 cu. ft. of space. Since formaldehyde
[401] is inflammable and easily boils over, it has to be evaporated with care. It should be boiled in a tall vessel (a tin or copper vessel which holds about four times the quantity to be evaporated) over a quick fire, the room being tightly closed (openings around windows and doors plugged with cotton or cloth). After three or four hours the room may be opened and thoroughly aired. Since

formaldehyde is most disagreeable to breathe, one should not attempt to occupy the room until it is free from the gas. This will require a day or more of thorough ventilation.

Facts Relating to the Spread of Certain Diseases.—The problem of preventing disease in general often resolves itself into the problem of preventing the spread of some particular disease. It is then of vital importance to know the special method by which the germs of this disease leave the body of the patient and are conveyed to the bodies of others. Some of these methods are novel in the extreme, and are not at all in accord with prevailing notions. Particularly is this true of that disease known as

Malaria, or Malarial Fever.—This disease, so common in warm climates and also prevalent to a large extent in the temperate zones, is due to animal germs (protozoa), which attack and destroy the red corpuscles of the blood. These germs, it is found, pass from malarial patients to others through the agency of a variety of mosquitoes known as *Anopheles*. In sucking the blood of a malarial patient, the mosquito first infects her own body.[131] In the body of the mosquito the germs undergo an essential stage of their development, after which they are injected beneath the skin of whomsoever the mosquito feeds upon. For the spreading of malaria, then, two conditions are necessary: first, there must be people who have the disease; and second, there must be in the neighborhood the special variety of mosquito that spreads the disease. If either condition be lacking, [402]
the disease is not spread. The malarial mosquito (*Anopheles*) may be distinguished from the harmless variety (*Culex*) by the position which it assumes in resting, as shown in Fig. 170.

[131] An interesting biological fact is that the female *Anopheles*, and not the male, sucks the blood of animals and is the cause of the spreading of malaria.

Remedies against Mosquitoes.—The natural method of preventing the spread of malaria is, of course, the destruction of mosquitoes. This is accomplished by draining pools of water where they are likely to breed, and by covering pools of water that cannot be drained with crude petroleum or kerosene. The kerosene, by destroying the larvae, prevents the development of the young. In communities where such measures have been diligently carried out, the mosquito pest has been practically eliminated. Other methods are also under investigation, such as the stocking of shallow bodies of water with varieties of fish that feed upon the mosquito larvae.

[403] **Yellow Fever.**—This scourge of the tropics is, like malaria, caused by animal germs. It is also propagated in the same manner as malaria, but by a different variety of mosquito (*Stegomyia*, Fig. 171). The stamping out of yellow fever in Havana, the Panama Canal Zone, and other places, through the destruction of this variety of mosquito, affords ample proof of the correctness of the "mosquito theory."

Consumption, or tuberculosis of the lungs, spoken of as the "white plague," was among the first diseases shown to be due to bacteria. Consumption is now recognized as an infectious disease, though not so readily communicated as some other diseases. Several methods are recognized by which the germs are passed from the sick to the well, the most important being as follows:

1. By personal contact of the sick with the well, especially in kissing.

2. By the sputum, or spit, which, if allowed to dry, is blown about as dust and breathed into the lungs[132] (Fig. 172).

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[132] The habit of spitting upon the floors of public buildings and street cars, and

3. By means of objects (drinking cups, tableware, etc.) that have been handled by consumptives.

4. By infectious material associated with houses or rooms in which consumptives have lived. [404]

These methods of spreading consumption suggest the necessity for the greatest care, on the part of both the patient and those having him in charge.[133] The material coughed up from the lungs and throat should be collected on cloths or paper handkerchiefs and afterwards burned. The house where a consumptive has lived should be disinfected, repapered or calcimined, and thoroughly cleaned before it is again occupied. The inside woodwork should also be repainted. The approaches to the house where the patient may have expectorated should be disinfected and cleaned. Since the germs are able to live in the soil, fresh lime or wood ashes should be spread around the doorsteps and along the walks.

Typhoid Fever, one of our most dangerous diseases, is caused by germs (bacteria) that enter the body through the food canal. They attack certain glands in the walls of the small intestine, where they produce toxins that pass with the germs to all parts of the body. Typhoid fever germs spread from those having the disease to others, chiefly through the discharges from the bowels and the kidneys. The germs contained in these, if not destroyed by disinfectants, find their way into the soil, or into sewage, where they may be picked up by water and widely distributed. Finding suitable places, such as those containing decaying material, the germs may rapidly increase in number, and from these sources find their way into the bodies of new victims. They are likely, on account of manures, to get on vegetables; on account of uncleanly methods of milking, to get into the milk supply; and

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also upon sidewalks, is now recognized as a most dangerous practice. Not only consumptives, but people with throat affections, may do no end of harm in the spreading of disease by carelessness in this respect.

[133] For further information on the care of consumptives, consult Huber's *Consumption and Civilization*.

[405] from sewerage outlets, to get into the oysters that grow in bays and harbors near seaboard cities; but they are most frequently introduced into the body through the drinking of impure water.

Diphtheria, also known as "membranous croup," is caused by germs that attack the membranes of the throat. This most dangerous of children's diseases is spread chiefly by discharges from the mouth and throat. These should be collected on cloths and burned, or rendered harmless with disinfectants. The disease may be spread also by objects brought into contact with the mouth, such as cups, toys, pencils, etc. Children are known to have diphtheria germs in the mouth for some time after recovering from the disease, and should, for this reason, be kept away from other children until pronounced safe by the physician.

The *antitoxin method* of treating diphtheria has robbed this disease of much of its terror, yet it not infrequently happens that the physician is called too late to administer this remedy to the best advantage. Since certain cases of diphtheria are likely to be mistaken for croup, the parent frequently does not realize the serious condition of the child. A croupy cough *that lasts through the day*, or a sore throat which shows small white patches, are indications of diphtheria.

Scarlet Fever, Measles, Chicken Pox, and Smallpox, on account of the eruptions of the skin which attend them, are classed as eruptive diseases. As the eruptions heal, scales separate from the skin, and these are supposed to be the chief means of spreading the germs. Attention must be given to the destruction of these scales by burning or thoroughly disinfecting all objects, such as clothing, bedding, etc., that may serve as carriers of them. Those having eruptive diseases should be confined to their rooms as long as the scales continue to separate from the body.

[406] **Vaccination.**—The method of preventing smallpox known as vaccination, which has been practiced since its discovery in 1796 by Jenner, has always proved effective. In some instances the sore

arm causes considerable inconvenience, but this generally results from neglect to cleanse the arm thoroughly before applying the virus, or from contact of the sore with the clothing later. The virus should be applied by a physician and the wound should be protected after the operation. If discomfort is felt when it "takes," medical advice should be sought.

Isolation, or quarantining, is a most important method of combating contagious diseases. By removing the sick from the well many outbreaks of disease are quickly checked. Isolation of individual patients, and sometimes of infected neighborhoods, is absolutely necessary; and while this works a hardship to the few, it is frequently the only safeguard of the many. The community, on the other hand, should make ample provision for the care of the afflicted in the way of hospitals, or sanitaria, and if it is deemed necessary to remove people from their homes, they should not be subjected to unnecessary hardship.

Where one is sick from some contagious disease in the home and there is liability of communicating it to the other members of the family, *room isolation* should be practiced. Infection cannot spread through solid walls, and where the doors, and the cracks around the doors, are kept completely closed and the usual precautions are observed by those attending the patient, the other inmates of the house can be protected from the disease.

The Physician and His Work.—In combating disease the services of the physician are a prime necessity. The special knowledge which he has at his command enables the conflict to be carried on according to scientific requirements and vastly [407]
increases the chances for recovery. He should be called early and his directions should be carefully followed. Everything, however, must not be left to the physician, for recovery depends as much upon proper nursing and feeding as upon the drugs that are administered. Of great importance is *the saving of the energy of the patient*, and to accomplish this visitors should, as a rule, be excluded from the sick room.

Precautions in Recovery from Disease.—Many diseases, if severe, not only leave the body in a weakened condition, but may, through the toxins which the germs deposit, cause untold harm if the patient leaves his bed or resumes his usual activities too soon. Especially is this true of typhoid fever,[134] diphtheria, scarlet fever, and measles. Rheumatism and affections of the heart, lungs, kidneys, and other bodily organs frequently follow these diseases, as the result of slight exposure or exertion before the body has sufficiently recovered from the effects of the toxins. To guard against such results, certain physicians require their patients to keep their beds for a week, or longer, after apparent recovery from diseases like typhoid fever, diphtheria, and scarlet fever.

Relation of Vocation to Disease.—With a few exceptions, the pursuit of one's vocation, or calling in life, does not supply either the quantity or the kind of activity that is most in harmony with the plan of the body. Especially is this true of work that requires most of the time to be spent indoors, or which exercises but a small portion of the body. The effect of such vocations, if
[408] not counteracted, is to weaken certain organs, thereby disturbing the functional equilibrium of the body—a result that may be brought about either by the overwork of particular organs or by lack of exercise of others. Herein lies the explanation of the observed fact that people of the same calling in life have similar diseases.

A Special Problem for the Brain Worker.—Farthest removed from those forms of activity which harmonize with the plan of the body, and which therefore are most hygienic, is that class of workers known as the professional class, or the "brain workers." This class includes not only the members of

[134] As typhoid fever is a disease of the small intestine, great care must be exercised in taking food and in the bodily movements. Solids greatly irritate the diseased lining of the intestine, and the weakened walls may actually be broken through by pressure resulting from moving about.

the learned professions—law, medicine, and the ministry—but a vast army of business men, engineers, teachers, stenographers, office clerks, etc., a class that is ever increasing as our civilization advances. It is this class in particular that must give attention to those conditions that indirectly, but profoundly, influence the bodily well-being and must seek to obviate if possible such weaknesses as the occupation induces.

The Remedy lies in two directions—that of spending sufficient time away from one's work to allow the body to recover its normal condition, and that of counteracting the effect of the work by special exercise or other means. In many cases the first symptoms of weakness indicate a suitable remedy. Thus exhaustion from overwork suggests rest and recreation. The diverting of too much blood from other parts of the body to the brain suggests some form of exercise which will equalize the circulation. If feebleness of the digestive organs is being induced, some natural method of increasing the blood supply to these organs is to be looked for. And effects arising from lack of fresh air and sunlight are counteracted by spending more time out of doors.

Exercise as a Counteractive Agent.—In counteracting tendencies to disease and in the maintenance of the functional equilibrium of the body, no agent has yet been discovered of greater importance than physical exercise, when applied systematically and persistently. This may consist of exercises that call into play all the muscles of the body, or which are concentrated upon special parts. When general tonic effects are desired, the exercise should be well distributed; but when counteractive or remedial effects are wanted, it must be applied chiefly to the parts that are weak or that have not been called into action by the regular work. Unfortunately, health is sometimes confused with physical strength and exercise is directed toward the stronger parts of the body with the effect of making them still stronger. Not only is health not to be measured by the pounds that one can lift or by some gymnastic feat that one can perform, but the [409] possession of great muscular power may, if the heart and other vital organs be not proportionally strong, prove a menace to the health. This being true, one having his health primarily in view will use physical exercise, in part at least, as a means of building up organs that are weak. Since the body, like a chain, can be no stronger than its weakest part, this is clearly the logical method of fortifying it against disease.

Value of Work.—Although there may exist in one's vocation certain tendencies to disease, it must not be inferred that work in itself is detrimental to health. Health demands activity, and those forms of activity that provide a regular and systematic outlet for one's surplus energy and compel the formation of correct habits of eating, sleeping, and recreating best serve the purpose. Work
[410] furnishes activity of this kind and serves also as a safeguard against the unhealthful and immoral habits contracted so often from idleness. Even physical exercise which has for its purpose the reënforcement of the body against disease may frequently consist of useful work without diminishing its hygienic effects.

The Mental Attitude.—While a proper thoughtfulness and care for the body is both desirable and necessary, it is also true that over-anxiety about, or an unnatural attention to, the needs of the body reacts unfavorably upon the nervous system. Observance of the laws of health, therefore, should be natural and without special effort—a matter of habit. The attention should never be turned with anxiety upon any organ or process, but the mental attitude should at all times be that of *confidence in the power of the body organization to do its work.* Fear and morbidity, which are disturbing and paralyzing factors, should be supplanted by courage, cheerfulness, and hopefulness.

Let it be borne in mind that hygienic living requires nothing more than the application of the same intelligence and practical common sense to the care of the body that the skillful mechanic applies to an efficient, but delicate, machine. And, just as in the case of the machine, care of the body keeps its efficiency at the maximum and lengthens the period that it may be used. This end and aim of hygienic living is best attained by cultivating that attitude of mind toward the body that avoids interference in the vital processes and permits the natural appetites, sensations, and desires to indicate very largely the body's needs.

Attitude toward Habit-forming Drugs.—Among the different substances introduced into the body, either as foods or as medicines, are a number which have the effect of developing [411] an artificial appetite or craving which leads to their continued use. Since the effect of such substances is usually harmful and since they tend to engraft themselves upon communities as social customs, they present a twofold relation to the general problem of keeping well. The individual may be injured through the personal use which he makes of them, or he may be injured through the effect which they have upon relatives or friends or upon society at large. Since our social environment is a factor in health little less important than our physical environment, the conditions that make for their continuance should be more generally understood.

How Social Agencies perpetuate the Use of Habit-forming Drugs.—When the use of some habit-forming drug has risen to the importance of a general custom, a number of conditions arise which tend to continue its use, even though the fact may be quite generally known that the substance does harm. In the first place, those who have formed the habit suffer inconvenience and distress when deprived of its use. In the second place, a number of people will have become interested in the production and sale of the substance, and these will lose financially if it is discontinued. In the third place, those of the rising generation will, from imitation or persuasion, be constantly acquiring the habit before they are sufficiently mature to decide what is best for them. Thus may the use of a substance most harmful, such as the opium of the Chinese, be indefinitely continued—a species of slavery from which the individual finds it hard to escape.

Such is human nature and such are the forces and influences

of human society, that the freeing of a people from the bondage of some habit-forming drug cannot be accomplished without
[412] strenuous and persistent effort. Education, persuasion, the good example of abstainers, and legal restrictions must be pitted against the forces that make for its continuance. Such a struggle is now in progress in all civilized countries relative to the use of alcoholic beverages.[135]

How the Use of Alcohol became a Social Custom.—The general use of alcohol as a beverage may be accounted for by three facts. Alcohol is a habit-forming drug; it has a stimulating effect which many have found agreeable; and being a product of the fermentation of fruit juices and other liquids containing sugar, it is easily obtained. Through the operation of these causes the human family became habituated very early to the use of alcohol. The "wine" of primitive man, however, did little harm as compared with the alcoholic liquors of modern times. It was a weak solution and on account of the crude methods of manufacture and storage could only be produced in limited quantities. Perhaps the worst effect of its early use was the establishment of a general belief in its power to benefit, since this laid the foundation for excess in its use when the developments of a later period made it possible.

During the eleventh century the method of making alcoholic drinks from starch-producing substances, such as wheat, barley,

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[135] Alcoholic beverages include all the various kinds of drinks that owe their stimulating properties to a substance, ethyl alcohol (C_2H_5OH), which is made from sugar by the process of fermentation. They include *malt liquors*, such as beer and ale, which contain from three to eight per cent of alcohol; *wines*, such as claret, hock, sherry, and champagne, which contain from five to twenty per cent of alcohol; and *distilled liquors*, such as brandy, whisky, rum, and gin, which contain from thirty to sixty-five per cent of alcohol. Alcoholic beverages all contain constituents other than alcohol, these varying with the materials from which they are made and with the processes of manufacture. The distilled liquors are so called from the fact that their alcohol has been separated from the fermenting substances by distillation.

and potatoes, became quite generally known, and also the method of concentrating them by distillation. This knowledge made [413] possible the manufacture of alcoholic drinks in large quantities and in considerable variety. Alcoholic indulgence was now no longer the pastime of the few, but the privilege of all. Its evil effects followed as a matter of course; and as these became more and more apparent, there began the struggle to restrict the consumption of alcohol which has continued with varying success to the present time.

Counts against Alcohol.—The statements found in different parts of this book relative to the effects of alcohol upon the body may here be summarized as follows:—

1. Alcohol has an injurious effect upon the white corpuscles of the blood and lessens the power of the body to resist attacks of disease (pages 35, 98).

2. Alcohol injures the heart and the blood vessels (page 56).

3. Alcohol causes diseases of the liver and kidneys and interferes with the discharge of waste through these organs (pages 210, 212).

4. Alcohol interferes seriously with the regulation of the body temperature (page 271).

5. Alcohol is one of the worst enemies to the nervous system (pages 326, 332-334. 336, 337).

6. Through its effect upon the nervous system and through its interference with the production of bodily energy (page 195), alcohol greatly diminishes the efficiency of the individual.

7. The taking of alcohol in amounts that apparently do not harm the tissues is, nevertheless, liable to produce a habit which leads to its use in amounts that are decidedly harmful.

Alcohol and the Social Environment.—Our social environment includes the people with whom we are directly or indirectly [414] associated. The presence in any community of those who are immoral, inefficient, or defective, places a burden upon those who are mentally and physically capable and renders them liable to results which are the outgrowth of weakness or viciousness. The fact that alcohol causes pauperism, crime, and general inefficiency, thereby rendering the social environment less conducive to what is best in life, is plainly evident. To realize how alcohol harms the individual through its effects upon society in general, one has only to take into account his dependence upon society for intellectual and moral stimuli, for industrial and economic opportunity, for protection, and for general conditions that make for health and happiness. As we strive to improve our physical environment, so should we also strive for the betterment of social conditions.

Industrial Use of Alcohol.—Interesting and instructive in this connection is the fact that alcohol is, after all, a substance capable of rendering great service to humanity. The injury which it causes is the result of its misuse. Though unfit for introduction into the human body, except in the most guarded manner, it is adapted to a great variety of uses outside of the body. A combustible substance which is readily convertible into a gas, it may be substituted for gasoline in the cooking of food, lighting of dwellings, and the running of machinery. As a solvent for gums, resins, essential oils, etc., it is used in the preparation of varnishes, extracts, perfumes, medicines, and numerous other substances of everyday use. Through its chemical interactions, it is used in the manufacture of ether, chloroform, explosives, collodion, celluloid, dyestuffs, and artificial silk. In fact, alcohol is stated by one authority to be, next to water, the most valuable liquid known.[136]

Opposed to an extensive use of alcohol for industrial purposes is the guard which the government must keep over its manufacture on account of its use in beverages. Though alcohol may be profitably manufactured and sold at thirty cents per gallon, the government revenue stamp of $2.08 per gallon practically

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[136] Duncan, *The Chemistry of Commerce*.

prohibits its use for many purposes. A step toward a wider application to industrial purposes has been taken by the law [415] permitting the sale of so-called "denatured"[137] alcohol without the tax for revenue. This law has proved beneficial to some extent, though the practical solution of the problem is still remote.

Nicotine and Social Custom.—The influences which brought about a general use of tobacco are similar to, though not identical with, those that engrafted alcohol upon society. The drug nicotine is a habit-forming substance and the plant producing it is easily cultivated.[138] Its immediate effect upon the user is generally agreeable, acting as a stimulant to some, but having a soothing effect upon the nerves of others. Moreover, a strong deterring factor in its use is lacking, since its harmful effects are not readily discernible and by many are avoided through moderation in its use.

As with alcohol, tobacco is conveniently used to promote sociability among men, a fact which has much to do with its very general use. If it could be limited to social purposes, it would likely do little harm, but the habit, once started, is continued without reference to sociability—a matter of selfish indulgence. In fact, one effect of tobacco is to cause the user to become less sensitive to the rights of others, this being evidenced by smokers who do not hesitate to make rooms and public halls almost unbearable to those unaccustomed to tobacco.

Counts against Nicotine.—The physiological objections to the use of tobacco, as already stated (pages 56, 92, 326, 333, 336), are the following:—

1. The use of tobacco before one reaches maturity stunts the [416]

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[137] Alcohol is "denatured" by adding substances to it such as wood alcohol, which render its use as a beverage impossible.

[138] The tobacco plant, *Nicotiana tobacum*, is a native of America, and the use of tobacco began with the American Indians. It was taken back to Europe by the early explorers, Sir Walter Raleigh being credited with introducing it to the nobility of England.

growth. The boy who uses it cannot develop into so strong and capable a man as he would by leaving it alone.

2. Tobacco injures the heart.

3. Tobacco injures the air passages, especially when inhalation is practiced.

4. Tobacco injures the nervous system and by this means interferes in a general way with the bodily processes. For the same reason it interferes with mental and moral development, the cigarette being a chief cause of criminal tendencies in boys.

5. In some cases tobacco injures the vision.

6. The tobacco habit is expensive and is productive of no good results.

Tobacco and the Rising Generation.—The problem of limiting the use of tobacco to the point where it would do slight harm, in comparison to what it now does, would be solved if those under twenty years of age could be kept from using it. But few would then acquire the habit, and those who did would not be so seriously injured. In our own country it lies within the province of the home and the school to bring about this result. The fact that parents use tobacco is no reason why the boys should also indulge. The decided difference in effects upon the young and upon the mature makes this point very clear. Laws protecting boys from the evil effects of tobacco, not only cigarettes, but other forms as well, are both just and necessary.

Social Custom and the Caffeine Habit.—By suitable processes a white, crystalline solid, easily soluble in water, can be separated from the leaves of tea, and from the berry of the coffee plant. This is the drug caffeine, the substance which gives to tea
[417] and coffee their stimulating properties, but not their agreeable flavors. Less injurious, on the whole, than either alcohol or tobacco, caffeine has come into general use in much the same way as these substances. In a sense, however, caffeine is more deceptive than either alcohol or nicotine, because the usual mode of preparing tea and coffee gives them the appearance of real

foods. The housewife who would feel condemned in purchasing caffeine put up as a drug somehow feels justified when she extracts it from plant products in the regular preparation of the meal.

Counts against Caffeine.—People of vigorous constitutions and of active outdoor habits are injured but slightly, if at all, by either tea or coffee when these are used in moderation. As already stated (pages 56, 167, 326, 329), they do harm when used to excess and, in special cases, in very small amounts, in one of the following ways:—

1. By stimulating the nervous system, thereby causing nervousness and insomnia and interfering with vital organs.

2. By introducing a waste which forms uric acid into the body, thereby throwing an extra burden upon the organs of elimination.

In this connection it may also be stated that there appears to be little, if any, real advantage to the healthy body from the use of either tea or coffee, beyond that of temporary stimulation and the gratification of an appetite artificially acquired. Hence the large sums of money expended for these substances in this country yield no adequate returns.

Caffeine Restrictions Necessary.—Though with many the cup of tea or coffee at breakfast does no harm, but gives an added pleasure to the meal, there is no question but that the use of caffeine beverages should be greatly curtailed. Children should not be permitted to drink either tea or coffee. Brain workers and [418]
indoor dwellers generally should use these substances very sparingly, and people having a tendency to indigestion, nervousness, constipation, rheumatism, or diseases of the heart, kidneys, or liver frequently find it best to omit them altogether.

Caffeine and "Soft" Drinks.—Recently the practice has sprung up of using caffeine as a constituent of certain drinks supplied at the soda-water fountains. Such drinks usually purport to be made from the kola nut, which contains caffeine, or to consist of extracts from the plants which yield cocoa and chocolate, when in reality they consist of artificial mixtures to which caffeine has been added. Those using these beverages are stimulated as they would be by tea or coffee and soon acquire the habit which makes them regular customers. Chief harm comes to the children who frequent the soda fountains and to those who, on account of constitutional tendencies, should avoid caffeine in all of its forms. It is generally understood that the so-called "soft" drinks are harmless. If this reputation is to be maintained, those containing caffeine must be excluded.

Danger from Certain Medicinal Agents.—Among the most valuable drugs used by the physician in the treatment of disease are several, such as morphine, chloral, and cocaine, which possess the habit-forming characteristic. Sad indeed are the cases in which some pernicious drug habit has been formed through the reckless administration of such medicines. Even the taking of such a drug as quinine as a "tonic" tends to develop a dependence upon stimulation which is equivalent to a habit. In the same list come also the drugs that are taken to relieve a frequently recurring indisposition, such as headache. The so-called headache powders
[419] are most harmful in their effects upon the nervous system and should be carefully avoided.[139]

Stimulants in Health Unnecessary.—Stimulants have been aptly styled "the whips of the nervous system." The healthy nervous system, however, like the well-disposed and well-fed horse, needs no whip, but is irritated and harmed through its use. Even in periods of weakness and depression, stimulants are usually not called for, but a more perfect provision for hygienic needs. Rest, relaxation, sleep, proper food, and avoidance of irritation, not stimulants, are the great restorers of the nervous system. A surplus of nervous energy gained through natural means is more conducive to health and effective work than any

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[139] Most headaches are the result either of eye strain or of digestive disturbances, such as indigestion and constipation, and are to be relieved through the work of the oculist or through attention to the hygiene of the digestive system.

result that can possibly be secured through drugs. Then withal comes the satisfaction of knowing that one has the expression of his real self in the way in which he feels and in what he accomplishes—not a "whipped-up" condition that must be paid for by weakness or suffering later on.

Summary.—To solve the problem of keeping well, one must live the life which is in closest harmony with the plan of the body. Such a life, because of differences in physical organization, as well as differences in environment and occupation, cannot be the same for all. All, however, may observe the conditions under which the body can be used without injuring it and the special hygienic laws relative to the care of different organs. Causes of disease, whether they be in one's environment, vocation, in his use of foods or drugs, or in his mode of recreation, must either be avoided or counteracted.

While the problem is beset with such difficulties as lack of sufficient knowledge, inherited weakness, and time and opportunity for doing what is known to be best for the body, yet study [420]
and work that have for their aim the preservation or improvement of the health are always worth while. *Health is its own reward.* The expression of the poet,

> "Each morn to feel a fresh delight to wake to life,
> To rise with bounding pulse to meet whate'er of work, of
> care, of strife,
> day brings to me,"

suggests the *joy* of being well. But the ultimate realization of one's aims and ambitions in life and the actual prolongation of one's period of usefulness are *higher and more enduring rewards*.

Exercises.—1. Summarize the different laws of hygiene. Upon what one fundamental law are these based?

2. State the important differences between a condition of health and one of disease.

3. In what general ways may disease originate in the body?

4. Describe a model sanitary home. With what special hygienic problems has the housekeeper to deal?

5. Describe a method of collecting a wholesome supply of cistern water. State possible objections to well and spring water.

6. What means may be employed in preventing the spread of contagious diseases?

7. By what means are malaria, typhoid fever, diphtheria, and tuberculosis spread from one individual to another?

8. Why are extra precautions necessary in the recovery from certain diseases, as typhoid fever, diphtheria, and scarlet fever?

9. How may one's vocation become a cause of disease? What conditions in the life of a student may, if uncounteracted, lead to poor health?

10. Of what special value are the parks and pleasure grounds in a city to the health of its inhabitants?

11. Discuss the hygienic value of work.

12. What conditions lead to the continuance of habit-forming substances after their use has become general?

13. How is it possible for one not using alcohol to be injured by this substance?

14. Discuss the effect of alcoholic abuse upon social environment.

15. Summarize the rewards of hygienic living.

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SUMMARY OF PART II

For the maintenance of life the needs of the cells must be supplied and *the body as a whole must be brought into proper relations with its surroundings*. The last-named condition requires that the body be moved from place to place; that its parts be controlled and coördinated; and that it be adjusted in its various activities to external physical conditions. To accomplish these results there are employed:

1. The skeleton, or bony framework, which preserves the form of the body and supplies a number of mechanical devices, or machines, for causing a variety of special movements.

2. The muscular system, which supplies the energy necessary for executing the movements of the body.

3. The nervous system, which (*a*) controls and coördinates the various activities and (*b*) provides for the *intelligent* adjustment of the body to its environment. (Review Summary of Part I, page 215, and consult Fig. 92, page 214.)

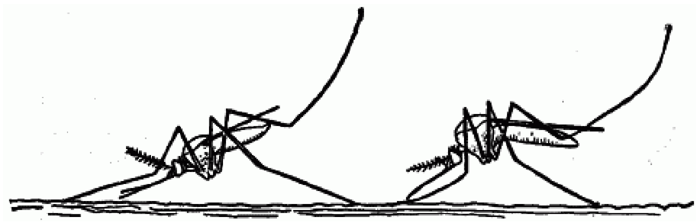

Fig. 170—**Mosquitoes** in resting position. (From Howard's *Mosquitoes*.) On left the malarial mosquito (*Anopheles*); on the right the harmless mosquito (*Culex*).

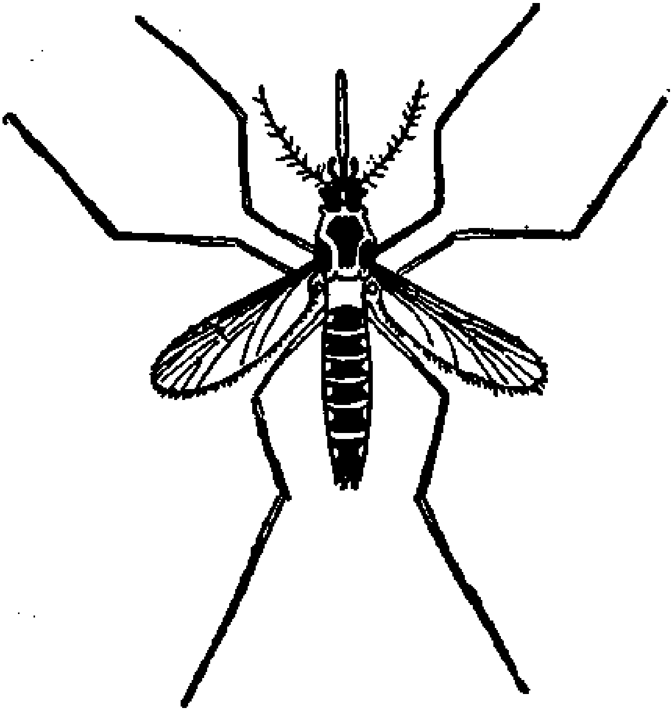

Fig. 171—**Stegomyia**, the yellow-fever mosquito (after Howard).

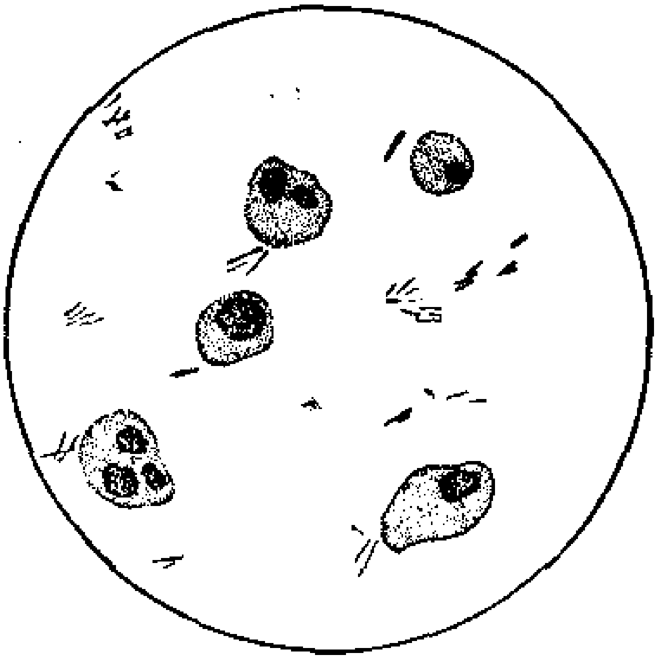

Fig. 172—**Consumption germs** from the spit of one having the disease. Highly magnified and stained. (Huber's *Consumption and Civilization*.)

APPENDIX

Equipment.—Nearly all of the apparatus and materials called for in this book may be found in the physical, chemical, and biological laboratories of the average high school. There should be ready, however, for frequent and convenient use, the following: One or more compound microscopes with two-thirds and one-fifth inch objectives; a set of prepared and mounted slides of the various tissues of the body; a set of dissecting instruments, including bone forceps; a mounted human skeleton and a manikin or a set of physiological charts; a set of simple chemical apparatus including bottles, flasks, test tubes, and evaporating dishes; and a Bunsen burner or some other means of supplying heat.

The few chemicals required may be obtained from a drug store or from the chemical laboratory. Access to a work bench having a set of carpenter's tools will enable one to prepare many simple pieces of apparatus as they are needed.

Physiological Charts are easily prepared by teachers or pupils by carefully enlarging the more important illustrations found in text-books or by working out original sketches and diagrams. These, if drawn on heavy Manila paper, may be hung on the wall as needed and preserved indefinitely. By the use of colors, necessary contrasts are drawn and emphasis placed on parts as desired. The author has for a number of years used such home-made charts in his teaching and has found them quite satisfactory. His plan has been to draw on heavy Manila paper, cut in sizes of two by three feet, the general outline in pencil and then to mark over this with the desired colors. There is of course an opportunity for producing results that are artistic as well as practical, and if one has time and artistic skill, better results can be obtained. Many of the cuts in this book are excellently suited to enlargement and, if properly executed, will provide a good set for general class purposes.

Models.—The use of prepared models of the different bodily organs is strongly urged. These may be so used in elementary courses as to obviate much of the dissections upon lower animals. Although the actual tissues cannot be so well portrayed, the general form and construction of organs are much better shown. Models well adapted to class or laboratory work are easily obtained through supply houses. Illustrations of several of these are shown in connection with the "Practical Work."

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