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# PHYSIOLOGY

THORNTON

# ELEMENTARY PRACTICAL PHYSIOLOGY

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BY

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# PREFACE

THIS book has been prepared with a view of presenting to young students the important facts and principles of human physiology in a concise and intelligible form. In it I have attempted, not only to supply the information which such students need, but also to lead them to think as they acquire their knowledge of the subject.

The work meets all the requirements of Stage I. (the Elementary Stage), as set forth in the syllabus issued by the Board of Education, and in similar syllabuses of other examining bodies. As it is intended as a first work on the subject, the anatomy or structure of the body and its organs is described so far as this is necessary to the understanding of their functions. This includes some account of the cell, for an elementary knowledge of cells and the minute structure of tissues is now essential in order to have any intelligent comprehension of the working of the body and its parts.

A large number of illustrations, many of them new in an elementary work like this, have been supplied. A few of these are coloured to further increase their usefulness. Much can be learnt by an attentive study of these figures, and the reader is advised to examine them, with their accompanying descriptions, repeatedly, care being taken to distinguish between a diagram (see Glossary) and an actual drawing of a part.

Many simple, practical directions will be found, partly in the course of the text and partly under separate headings. These are of such a nature that neither the teacher nor the student should have any difficulty in making the observations and performing the experiments described. The importance of examining such organs as the heart, lungs, and kidneys, as well as of experimenting with such substances as blood, food-stuffs, and the digestive juices, cannot be overrated, if clear ideas and sound knowledge are to be acquired. As supplementary aids, models, such as those supplied by Emile Deyrolle of Paris, can be strongly recommended.

To aid the reader in acquiring the meaning and proper use of the technical language of physiology, a Glossary, giving the pronunciation and explanation of the difficult terms, has been supplied. Frequent reference to it will, it is believed, be of much service.

At the end of the book will be found a set of Questions and Exercises on each chapter, together with recent Examination Papers.

J. THORNTON.

BOLTON,
*July*, 1904.

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# ELEMENTARY PRACTICAL PHYSIOLOGY

## CHAPTER I.

### *INTRODUCTION.*

**1. What is Physiology?**—The word **physiology** (Greek, *phusis*, nature, and *logos*, a discourse) is used to denote the study of the changes and activities that go on in living beings. **Vegetable physiology** deals with the processes that occur in living plants. **Animal physiology** treats of the working of the bodies of living animals. **Human physiology** is that part of animal physiology that gives an account of the activities of the healthy human body, and it is with the body of man that we are chiefly concerned in this book.

To understand the action and working of a body that consists of distinct but connected parts, like the body of a man, it is first necessary to learn something regarding its **structure**, so that we may know, not only the forms and relations of the various parts, but the modes in which they are built up. The study of the structure of an animal is termed **anatomy** (Gk. *ana*, up; *temnein*, to cut), and it is carried out for the most part by the cutting up or dissecting of a lifeless body or its parts. As the structures of such higher animals as a rabbit or a sheep closely resemble that of the human body, any dissection required of an elementary student may be made on one of these animals. Closely connected with physiology there is another department of study called **hygiene. Hygiene** (Gk. *hygieia*, health) is that branch of science which treats of the means that promote and preserve health so that the various parts of the body may be kept in good working order. It will now be clear why a book on physiology often includes some anatomy and hygiene.

A student of physiology soon finds that, in order to understand the subject, it is also necessary to know something of such subjects as Chemistry, Physics, and Mechanics. This necessary preliminary knowledge will be introduced as the occasion arises, but the importance in physiology of some chemical knowledge is so great, and the need of such knowledge is felt so soon, that we shall supply some of it towards the end of this chapter.

**2. Organs and Tissues.**—The body of a man, or that of any of the higher animals, when examined carefully, especially in its interior, is seen to consist of distinct parts that carry on special kinds of work. Such, for example, are the eye, the tongue, the heart, the lungs, the kidneys, etc. Such a distinct part of the body is called an **organ** (Gk. *organon*, a tool or instrument), and the special work of an organ is called its **function.** Hence an **organ** has been defined as "a part of the body of a living being that is definitely fitted to perform some special function for the general benefit of the whole."

In man and the higher animals the great life functions of respiration, digestion, excretion, etc., are carried on by a set of organs or closely related parts that form a **system.** Thus the digestive system includes the mouth, the gullet, the stomach, the liver, the pancreas, and intestines. In later chapters these various systems, and the organs forming them, will be explained in some detail.

An examination of a limb, or of any of the organs just mentioned, shows that the parts of the body are formed of different kinds of materials, called textures or **tissues,** just as a house is made up of stone, wood, iron, mortar, and other substances. As examples of such different kinds of building materials in the body, we may note the red flesh that forms **muscular tissue,** the soft greyish-white matter that forms the brain and nerves called **nervous tissue,** and the harder compact substance forming bone, and termed **osseous tissue.** The soft stringy substance that binds the skin to the body, and passes thence between the muscles to ensheath the bones as well as to hold together the materials of every organ, is known as **connective tissue. Epithelium**, or epithelial tissue, is the name given to the tissue that covers the exterior of the body and lines all the passages and cavities leading from the exterior to the interior.

An organ is usually made up of several tissues; the heart, for example, contains muscular tissue, fatty tissue, and connective tissue. Most tissues also enter into the formation of very different organs. Muscular tissue, for example, is found, not only in the large skeletal muscles, but in the heart, in the walls of the stomach and intestines, and in the walls of blood-vessels, while adipose or fatty tissue, is present, more or less, in almost every organ of the body.

**3. Tissues are composed of cells.**—When the different building materials or tissues of the body are examined with the aid of a microscope, each tissue is found to consist of a number of minute masses of a soft substance connected together by material originally derived from such masses. These microscopic units of the tissues are called **cells**, and one tissue differs from another in the form and nature of its cells, as well as in the way the cells are united together by intercellular substance. To get some idea of the nature of a cell, let us leave the human body for a short time and examine one of the simplest living creatures, an animal called the **amœba.**

On taking a drop of water from the surface of the mud at the bottom of a stagnant pool, and placing it under a high power of the microscope, we may often notice, among other things, one or more specks of a jelly-like substance undergoing a slow change of shape. Each speck, in fact, is of irregular shape, and moves with a kind of flowing motion, the locomotion being caused by the streaming forward of the substance into projections or processes at some points, and the withdrawal of processes at other points. The tiny object we see is a living creature called an **amœba.** Careful scrutiny under a higher power of the microscope will show that the jelly-like mass forming the amœba exhibits a clear outside and a rather granular interior. There is also seen a denser central body called the **nucleus**, and usually a clear space called, from its action, the pulsatory **vacuole**.

The jelly-like mass of which the amœba consists is present in all living matter, and is called living substance, or **protoplasm**. Such a minute mass of nucleated protoplasm is the unit mass of living matter, and is known as a cell. An amœba is, therefore, a living creature consisting of a single cell. Chemically considered, protoplasm is a mixture of water and various solids, the chief of which are chemical compounds called proteids and carbohydrates (par. 7). The amœba manifests life not only by its motion, but in several other ways. It undergoes waste, giving off carbon dioxide and other waste products, and to repair this waste it takes in food. It feeds by putting forth a process round a particle of food and gradually engulfing it, the food-particle undergoing digestion in the interior, and being changed into the ingredients of protoplasm by assimilation. Any particle that is indigestible is excreted.

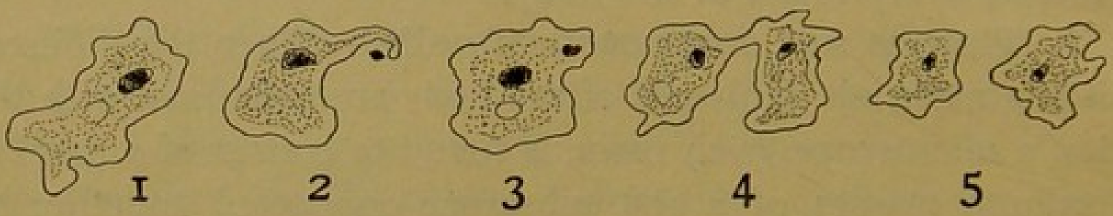



FIG. 1.—An amœba, showing granular protoplasm, nucleus, and small vacuole. At 2 it is throwing out a process to take in a particle of food ; at 4 it is in process of dividing into two, the nucleus having undergone division ; at 5 the division into two is complete, each part containing its own nucleus. (Highly magnified.)

The taking in and digestion of food not only repair waste, but lead to an increase of the quantity of protoplasm, so than an amœba **grows**. An amœba responds to certain excitations or *stimuli*, such as warmth and shock. Gentle warmth increases its movement, a sharp shock checks its movement. An amœba is, therefore, said to be **irritable**. It can be shown that an amœba breathes by taking in at every part of its surface oxygen dissolved in the water, and giving out carbon dioxide at any part. In pure distilled water that contains no oxygen the amœba cannot live. It also possesses the power of reproducing itself, for on carefully watching an amœba for some time we may often notice that the creature becomes constricted and divides into two parts, each containing a portion of the nucleus, and each detached portion performing all the actions just described (Fig. 1). The amœba, therefore, although possessing no separate parts or organs, such as mouth, stomach, heart, and lungs, to perform its separate vital actions, is yet a distinct living creature as much as a frog or a man, and is quite different from a particle of clay or a grain of sand. The amœba is a simple creature of one cell, but man and the higher animals are composed of countless millions of such cells grouped into tissues and organs adapted for special functions. For, as already stated, when we examine under the microscope nerve tissue, muscular tissue, fat, or any other tissue from the human body, or from any of the higher animals, we find each to be composed of cells with more or less connecting material, the cells of each tissue having a special structure suitable for carrying out the special function of that tissue.

In the early stages of an animal, every tissue is a mass of closely packed similar cells, but later many of the cells undergo

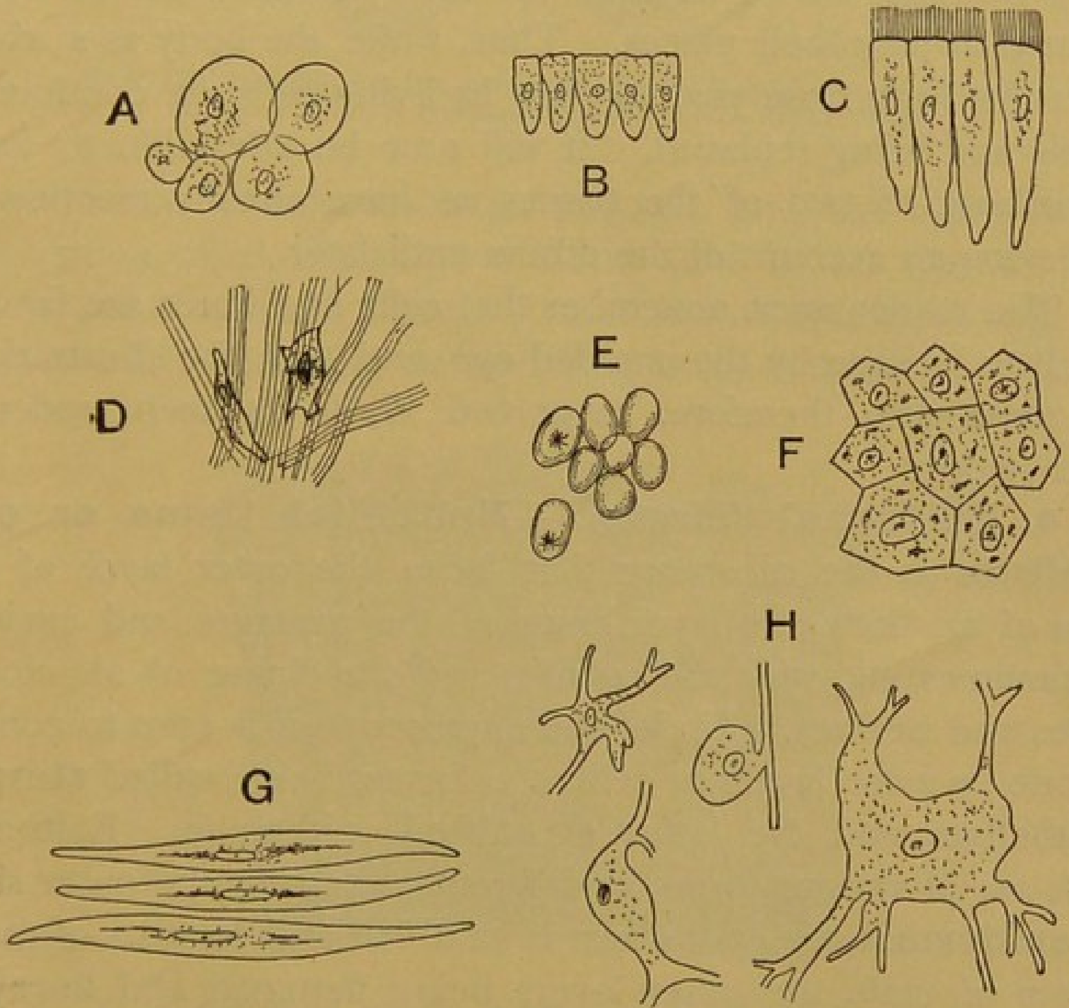



FIG. 2.—Various animal cells highly magnified. A, squamous epithelial cells; B, simple columnar cells; C, ciliated epithelial cells; D, white fibrous tissue with connective tissue cells; E, fat cells; F, polygonal liver cells; G, smooth muscle cells; H, various nerve cells.

changes or give off products, so that fine threads or **fibres** with or without other structures often unite with cells to form a tissue. A tissue, in fact, may be defined as **a building** material of the body composed of cells of the same kind bound together with more or less intercellular substance, while a cell may be defined as a minute mass of protoplasm with a firmer substance at the centre called its nucleus. Thus cells are bound together to form tissues; tissues are bound together to form organs; and the body of a man or of any other higher animal consists of a number of organs or special parts, each with one or more special functions, but all working together for the general good. It may now be remarked that each of the cells forming a tissue of the body is a living thing that feeds and undergoes changes, but the life of a cell is not of long duration, for in most tissues they become worn out and die after a time, others being formed to take their places. Thus, while the body as a whole keeps its form from year to year, its living cells are continually dying and being replaced. It will now be advisable to learn something of two of the tissues we have already mentioned, reserving an account of the others until later.

The reader must remember that cells and fibres are far too small to be seen by the unaided eye, and that the illustrations of them are, therefore, magnified views as seen under a microscope.

**4. Epithelial Tissue.**—**Epithelial tissue or epithelium** is the substance that forms the outer layer of the skin of the body, the layer lining all the passages and cavities communicating with the outside and the lining of all closed tubes and cavities. Under the microscope it is seen to consist of one or more layers of cells, the former being called **simple** epithelium, and the latter **stratified** epithelium. Epithelial cells are of various forms in different parts. In the outer skin, or **epidermis**, the epithelium is stratified and consists of many layers of cells, the outer layers being flattened and horny in structure, and the deeper layers rounded or formed of columnar, nucleated cells (Fig. 3). The soft skin called mucous membrane lining the air passages, the nose, windpipe, and bronchial tubes is formed on its outside of epithelial cells, the outer ones of which are columnar and provided with fine hair-like processes called **cilia**, which, in the living tissue, are constantly in rapid vibration with a whip-like movement that work outwards (Fig. 4). Ciliary movement can be easily seen by snipping a small piece from the gill of a common mussel and examining it under a microscope.

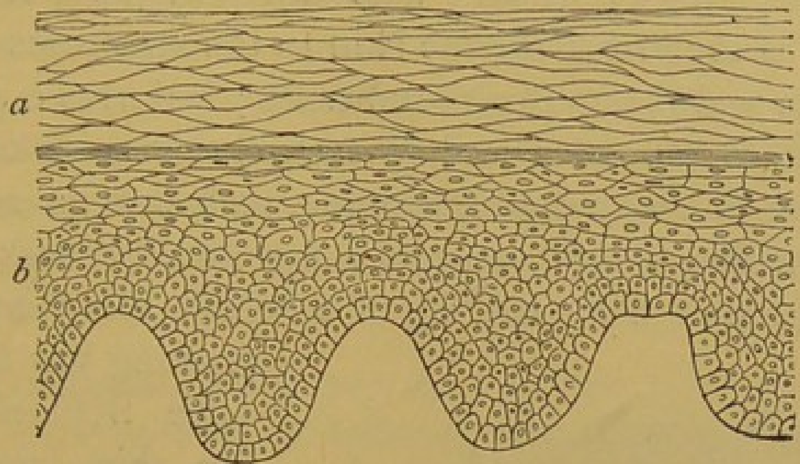



FIG. 3.—Epithelial cells forming the epidermis or outer layer of the skin. *a*, The horny flattened cells; *b*, the nucleated cells of the deeper layer.

Some of the cells in the air passages and the tubes of the alimentary canal discharge a slimy fluid called **mucus** that keeps these passages moist. Other active epithelial cells are engaged in separating or secreting some substance from the

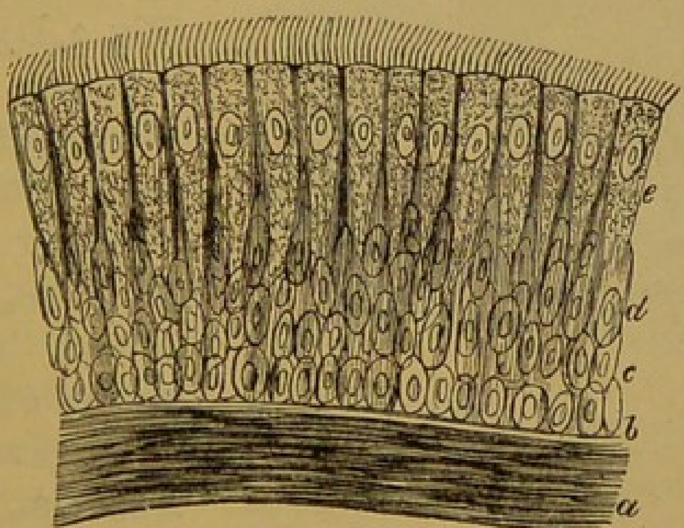



FIG. 4.—Ciliated epithelium from the human trachea. Magnified 350 times. *a*, Innermost layers of the elastic longitudinal fibres; *b*, homogeneous innermost layer of the mucous membrane; *c*, deepest round cells; *d*, middle elongated cells; *e*, superficial cells, bearing cilia. (*From Gray's "Anatomy."*)

blood and pouring it out into the tube or cavity which they line. Such active secreting epithelial cells are found lining the stomach, the intestines, the tubes, and recesses of the salivary and other glands. These epithelial cells will be further described when treating of the organs in which they occur.

**5. Connective Tissue.**—Connective tissue is a fibrous tissue found in all parts of the body, lying between and uniting different organs and also different parts of the same organ. It is found uniting the skin to the structures beneath; it surrounds and penetrates the muscles; it forms a sheath for nerves and blood-vessels, and, in fact, enters more or less into the structure of every organ, forming, as it were, a soft framework to enclose and connect all the other tissues. On removing the skin from the leg of a rabbit the filmy material forming this tissue is at once noticed beneath the skin and around the muscles. Examined under the microscope it is seen to consist of fibres of two kinds, among which lie a number of cells, called connective tissue corpuscles (Fig. 2, D). One kind of fibre runs a wavy course in bundles, which often cross each other, and the other kind consists of single, fine, straight fibres. The first kind of tissue is called from its appearance **white fibrous connective tissue**, and the second kind **yellow elastic tissue.** White fibrous tissue, therefore, consists of fine, wavy, parallel fibres running in bundles that form a meshwork, which encloses spaces or **areolæ.** When the spaces are large, as in the tissue under the skin, the tissue is called **areolar tissue.** Scattered among the bundles of white

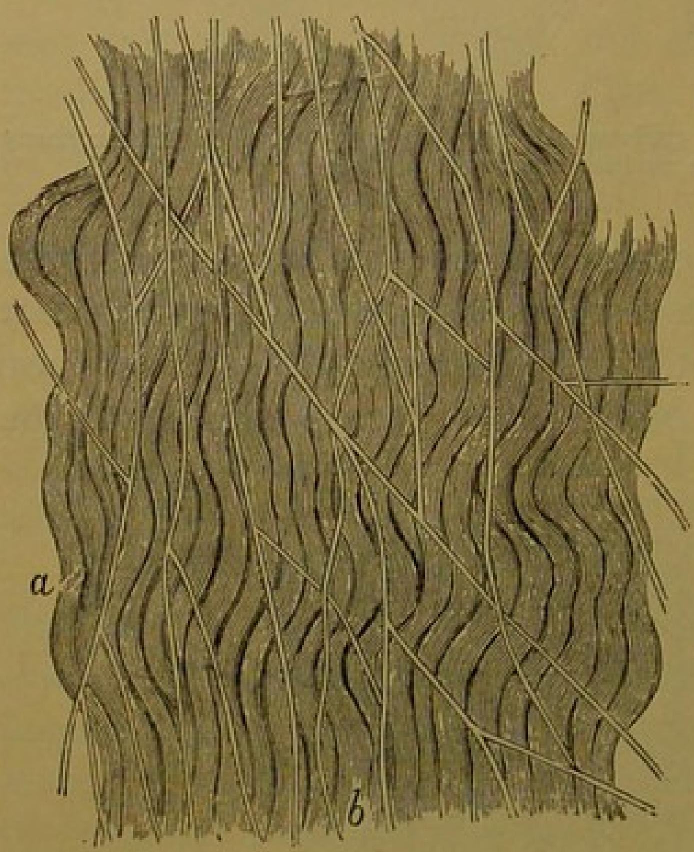



FIG. 5—Connective tissue. (Klein and Noble Smith.) *a*, The white fibrous element—a layer of more or less sharply outlined, parallel, wavy bundles of connective tissue fibrils. On the surface of this layer is *b*, a network of fine elastic fibres. (*From Gray's "Anatomy."*)

fibrous tissue are a few coarse fibres that are elastic and sometimes branch. It is these elastic fibres of connective tissue that confer elasticity on the skin and on the walls of the blood-vessels. The connective tissue corpuscles are nucleated cells lying on or among the bundles of fibres. Through the connective tissue pass nerves and blood-vessels, and the spaces are largely filled with a fluid termed lymph, that has passed out of the minute blood-vessels. In **tendons** and **ligaments** the fibrous tissue is closer and denser than in that under the skin, or than in that ensheathing muscles, and the bundles of fibres do not cross, but run parallel.

**Fat** or **adipose tissue** may be regarded as a kind of connective tissue, for it consists of fibres of white fibrous tissue in which oval fat cells (Fig. 2, E) are embedded. These cells are connective tissue cells, in which oil drops have gathered until nothing remains but a globule of fat covered by a thin layer of the original protoplasm of the cell. Adipose tissue forms a layer beneath the skin (subcutaneous fat), is collected round various organs, as the kidneys and heart, forms a packing for the eyeballs, and is present in small quantity in the tissues of most organs. It serves to give roundness to the limbs, it forms a packing material between organs, and, as it is a bad conductor, it checks the loss of heat from the body. It also acts as a store of nutriment for the body.

**6. Chemical Composition of the Body.**—Besides studying the body as composed of tissues and organs, it is necessary to consider it as composed of different chemical substances, and as the seat of chemical changes connected with the functions of the various organs. At present we can only make a few remarks about the more important substances found in the body, taking up in more suitable places the chemical changes that occur when treating of the functions of the different organs.

Chemists divide all substances into **elements** and **compounds.** An **element** is a simple or indecomposable substance; one that cannot be split up into substances different from itself. A **compound** is a substance formed by the chemical union of two or more elements. A compound is thus a substance that can be decomposed; that is, split up into two or more elements or simple substances. The properties of chemical compounds are quite different from those of the elements that enter into their composition.

About seventy-five elements are known to chemists, but many of these are rare in nature, and do not occur either free or combined in the human body. The elements found in the body are:—Oxygen, nitrogen, hydrogen, carbon, sulphur, phosphorus, chlorine, sodium, potassium, calcium, magnesium, iron, silicon, fluorine, lithium, and manganese. The first three occur both free and in various combinations, while the remainder only occur in compounds.

**Oxygen** (O) is an invisible gas that forms about one-fifth of the atmosphere by volume. It supports combustion, and is absolutely necessary for animal life. It occurs free in the air passages of the lungs, and to some extent in blood, though there it is more abundant in a state of loose chemical combination with the minute bodies called the red corpuscles of the blood. It also occurs combined with other elements in many of the substances of the body.

**Nitrogen** (N) is an invisible, inert gas that forms about four-fifths of the atmosphere by volume. It occurs free in the air passages of the lungs, and to a small extent dissolved in the blood. In combination with other elements it forms a large number of the substances of the body, many of these nitrogenous compounds being of great importance.

**Hydrogen** (H) is a very light, invisible, and combustible gas. When it burns in the air, it unites with the oxygen of the air to form water. Conversely, water can be decomposed by the electric current into the two gases oxygen and hydrogen. A little free hydrogen is sometimes found in the intestines, owing to the fermentation of certain foods. In combination with other elements it occurs in many common compounds of the body.

**Carbon** (C) is a solid element existing in a variety of forms. Blacklead, or graphite, and diamond are natural conditions of the element. Charcoal and lampblack are artificial forms of the element. When carbon burns it unites with oxygen from the air to form a compound called carbon dioxide, or **carbonic acid gas** ($CO_2$). Carbon does not exist free in the body; but it exists in a combined form in most animal and vegetable substances, and the oxidation or burning of any of these substances results in the formation of carbon dioxide as one of the products.

**7. Chemical Compounds of the Body.**—Chemists divide compounds into **inorganic compounds** and **organic compounds**, and it is important that the student should know something of this distinction.

Every separate living being, whether plant or animal, is sometimes termed an "**organism.**" The various substances that are built up or produced by organisms came to be called **organic substances**, and organic chemistry was defined as "the chemistry of the compounds produced by plants and animals." On the other hand, substances obtained from the crust of the earth, that is, from the mineral kingdom, were called **inorganic** or **mineral substances.** Inorganic chemistry is therefore the chemistry of the substances that neither are nor have been parts of plants or animals, the chemistry of the metals and metallic compounds of the earth, including water and air.

It was at one time thought that organic compounds could only be produced by the agency of living beings. But though this is almost the only source of such substances, chemists have been able to produce many organic substances artificially. However obtained, organic compounds always contain carbon as the central or grouping element in the compound. Organic chemistry, therefore, is better defined as "the chemistry of the carbon compounds." With these ideas of the two great classes of chemical compounds, it is easy to understand that clay, common salt, limestone (calcium carbonate), and quartz or silica, are examples of inorganic substances; while fat, sugar, starch, and the white of egg are organic substances.

Plants, like animals, consist of living cells that are constantly building up living matter out of the food supplied to them. This food, in the case of plants, consists of the simple inorganic substances found in the soil, and of the carbon dioxide in the air from which they obtain the carbon they require. In other words, plants can live on simple inorganic materials dissolved out of the soil or derived from the air, and can convert these into the complex organic substances that form their tissues. On the other hand, man and other animals cannot convert inorganic materials, except water, into the living substances of the body; but animals must feed on the organic substances formed by plants or supplied by the tissues of other animals that have lived on plants.

The chief inorganic compounds found in the human body are water, carbon dioxide, hydrochloric acid, sodium chloride, calcium carbonate, and calcium phosphate.

**Water** (the chemical formula of which is $H_2O$) is a compound of the two elementary gases hydrogen and oxygen. It is present in all the tissues of the body, and forms, in fact, two-thirds of the weight of the body. It is nearly all derived from the food and drink, but a small quantity is actually formed in the body. The water of the body serves to make certain tissues soft and flexible, to dissolve the nutrient matter taken in, and to assist processes of secretion and excretion.

**Carbon dioxide** ($CO_2$), or carbonic acid gas, is formed continuously in the body by the oxidation of carbon, so that it is present in all the tissues, including the blood. From these tissues it is being continuously removed or excreted in ways to be afterwards described.

**Hydrochloric acid** ($HCl$), a compound of the gas hydrogen with the gas chlorine, exists in small quantity in the stomach. It belongs to the class of bodies called "acids" (see Glossary). Acids are compounds which hydrogen forms with other elements, chiefly non-metallic elements. Many acids contain oxygen in addition. Thus, sulphuric acid ($H_2SO_4$) is a compound of hydrogen, sulphur, and oxygen.

**Sodium chloride** ($NaCl$) is a compound of the metal sodium with the non-metallic elementary gas called chlorine. Its usual name is common salt. It belongs to a class of chemical compounds termed "salts," the term "salt" being used by chemists to denote compounds in which the hydrogen of an acid has been replaced in part or altogether by a metal. Sodium chloride exists in the blood as well as in many other liquids of the body.

**Calcium carbonate** ($CaCO_3$) is a salt composed of the elements calcium, carbon, and oxygen. It enters into the composition of bone.

**Calcium phosphate** ($Ca_3P_2O_8$) consists of calcium, phosphorus, and oxygen. It forms a considerable part of bone.

Other inorganic salts exist in the body, the more important of which will be mentioned later. It may be remarked here that when a body is cremated or burnt, various compound gases, chiefly carbon dioxide, water vapour, and ammonia are formed and sent into the atmosphere, while most of the inorganic salts, being incombustible, remain to form the **ashes.**

The organic compounds of the body belong, for the most part, to three great groups: **Proteids, carbohydrates,** and **fats.**

**Proteids** are complex organic compounds of carbon, hydrogen, oxygen, nitrogen, and sulphur. As they are the only organic compounds characterized by the presence of nitrogen, they are often referred to as **nitrogenous compounds.** The type of this important class of bodies is the substance forming the white of an egg, and called albumen or albumin, and so these bodies are often also referred to as **albuminous substances.** The fibrin of blood and the casein of milk are other examples of proteids. Proteid bodies form the most important constituents of living cells. The proteids will be considered in more detail in the chapter on Food.

**Carbohydrates** are organic compounds of carbon, hydrogen, and oxygen, in which there is always the same proportion of hydrogen and oxygen as in water, *i.e.* two atoms of hydrogen to one of oxygen. The substances known as starches and sugars belong to the carbohydrates. A kind of starch called glycogen is found in the liver, and the sugar called grape-sugar exists in blood and other tissues.

**Fat** is an organic compound consisting of carbon, hydrogen, and oxygen; but the oxygen is smaller in proportion to the hydrogen than in the carbohydrates. The proportion of fat in the body varies greatly, but there is always some present.

We may describe and classify the five great classes of chemical compounds composing the body as follows:—

| | | Composed of |
|---|---|---|
| **Inorganic compounds** | 1. Water ... ... | Hydrogen and oxygen. |
| | 2. Mineral salts ... | Two or more of hydrogen, oxygen, carbon, calcium, phosphorus, potassium, sodium, sulphur, chlorine, magnesium, iron, silicon, fluorine. |
| **Organic compounds** | 3. Proteids (nitrogenous) | Carbon, hydrogen, oxygen, and nitrogen, with traces of sulphur and phosphorus. |
| | 4. Carbohydrates (non-nitrogenous) | Carbon, hydrogen, and oxygen. |
| | 5. Fats (non-nitrogenous) | Carbon, hydrogen, and oxygen. |

**8. Life: a Process of Waste and Renewal.**—We have seen that, considered from the chemist's point of view, the body consists of a certain number of chemical compounds, and we shall soon learn that during life these substances are continually being consumed, and must therefore be continually replaced. We now know that the main compounds entering into the composition of the cells and tissues of the body form the five groups: **Water, mineral salts, proteids** (nitrogenous compounds), **carbohydrates** (starches and sugars), and **fats.** The last three groups are complicated organic compounds, and under the action of the oxygen of the air taken in by the lungs and carried to all parts by the blood, these complex organic compounds are, after having been made a part of living tissue, at last reduced to simpler compounds in the processes that go on in the living body. These simpler compounds are in large part then removed from the body by excretory organs. Our food must therefore consist essentially of the same five classes of bodies, *i.e.* these compounds must be found in the materials of the food that we eat in order that the continual waste of body tissue may be made good.

Alterations in the composition of matter that go on through the action of the oxygen of the air, we call in ordinary language **burning** or **combustion.** The gas from the pipe, the oil in the lamp, and the wood or coal in the grate, after they are kindled, burn by uniting with the oxygen of the air. The process can be perceived by our senses; and the products of the combustion of the gas, oil, or coal can be collected. These products are carbon dioxide and water; any incombustible portion of the wood, etc., remains as mineral ash. Combustion or burning is, in fact, only rapid *oxidation*, accompanied by light and heat.

In our bodies a kind of burning of the complex chemical compounds goes on, only it is much slower burning or oxidation than in the case of the lamp or fire. But we know it occurs. We recognize it by the results—the formation of water, carbon dioxide, and other compounds, as well as by the production of heat. The food materials absorbed are used to build up tissue that afterwards undergoes waste by oxidation, and thus produces heat and supplies the power to do work. Oxidation of tissue made from absorbed food is the source of all the warmth and energy that we possess in our bodies while life lasts.

The human body may be compared in some respects with an engine. By the burning of wood and coal heat is generated, and this heat produces steam, which by its expansive force is made to move wheels and produce other kinds of motion. In this combustion gaseous products are formed, and the incombustible mineral matter remains as ash. In a similar way the oxidation of our absorbed food in all parts of the body produces heat, and enables us to execute muscular movements and perform other kinds of work. The source of the energy or power to do work is thus the same in both. Yet there are differences between the engine and a living body. The wear and tear of an engine must be made good by an outside agent ; but the body replaces, by its own action, the wear and tear of its substance. A living body is a self-repairing machine. Again, when the fuel of an engine is burnt up, and new material is not at once supplied, the engine stops and oxidation ceases. But in the case of the body, when the food taken at a meal is all consumed, the body does not stop at once. It goes on for a time at the expense of its own substance or tissues. Sooner or later, however, new fuel, in the shape of food, must be supplied, or the body becomes cold and still. The food taken in the body is thus used both to supply heat and other forms of energy, as well as to build up its substance. This constant waste and renewal of the cells and tissues of the body goes on until death occurs, and then the body decays. *Decay*, however, is in reality an exceedingly slow process of oxidation, during which the complex compounds of the tissues are broken up for the most part into water, carbon dioxide, and ammonia gas, an incombustible residue of mineral ash being then left behind.

# CHAPTER II.

## *THE GENERAL BUILD OF THE BODY.*

**9. Regions of the Body.**—The body of man, viewed as a whole, presents to us a front, anterior or **ventral** (Lat. *venter*, the belly) surface, and a back, posterior or **dorsal** (Lat. *dorsum*, the back) surface. Its most obvious division is into **head**, **trunk**, and **limbs.** The bones of the head form what is called the **skull.** The head is made up of a relatively large bony box, called the **cranium**, which encloses the brain, and of a portion termed the **face.** The cranium or brain-case is covered, except in front, with a hairy skin, known as the **scalp**, while the face proper, not including the forehead, which is really a part of the cranium, is the portion of the head lying in front of the ear, and includes the jaws, mouth, and certain organs of sense. The trunk is the thick part of the body without the head and limbs.

Connecting the head to the trunk is the stalk-like **neck.** In the front of the neck there lies a tube, called the **trachea**, leading to the lungs; behind this is a tube called the **gullet**, leading to the stomach; and at the back of the neck are seven superposed bones, on the topmost of which the cranium rests. These bones of the neck form the upper part of a larger number which pass down the hinder part of the trunk to form the **spinal or vertebral column.** Each of the bones of the spinal column is termed a **vertebra** (pl. **vertebræ**), and consists mainly of a ring, the front part of which is a thickened mass, forming a short piece termed the **body** of the vertebra. The bodies of the vertebræ, with the attached ring, are placed one above another, with pads of gristle or cartilage separating one vertebra from another, and forming the whole into a slightly flexible column, while the row of hollow rings, called the **arches** of the vertebræ, form a long canal or tube, termed the **spinal canal.** From each ring of a vertebra pieces of bone, called *processes*, project sideways and backwards. In the canal or tube formed by the overlying arches or rings of the vertebræ, lies the spinal cord or marrow, which is continuous with the brain lying in the cranium. The arrangement will be understood from Fig. 6, and by looking at the cut side of one of the longitudinal halves into which a butcher divides a sheep. The cavity of the cranium, and the spinal canal passing through the vertebral column, form, in fact, what is known, from its position, as the **dorsal tube** of the body (Lat. *dorsum*, back), or, from its contents, the **neural tube** (Gk. *neuron*, a nerve), for in this cavity lie the central parts of the nervous system, *i.e.*, the brain and spinal cord. From these central masses branches, called nerves, pass off to all the organs, as will shortly be explained.

**10. The Body considered as a Double Tube.**—The whole body of man and other higher animals may be regarded as a double tube, that is, as two tubes placed (considering the erect position of man) one behind the other (in the rabbit or sheep) one above the other. The first tube is formed, as just explained, by the skull, and by the overlying arches of the vertebræ or bones of the spinal column. It is known as the neural tube, or dorsal tube, is wide at the top and narrower beneath, and contains the brain and spinal cord. The second tube lies in front of the backbone or spine, and is formed by the body walls. It is known as the **ventral** tube (Lat. *venter*, belly). The ribs, with the breast-bone in front, form its chief boundaries above, while below it is bounded for the most part by the soft walls of the abdomen or belly. This double-tube structure of the body is illustrated by Fig. 6, which represents the cut surface of the body divided longitudinally, the black portions representing the cut surfaces of the bones of the skull, the vertebræ, and other bones. The brain and spinal cord are represented in the dorsal tube, but no organs are represented in the wider ventral tube in front. The dotted line indicates a thin muscular partition arching across the ventral tube and dividing it into a cavity above, called the chest, or thorax, and a cavity below called the abdomen. A digestive tube, beginning at the mouth, runs right through the ventral tube, and the ventral tube also contains other organs concerned in the digestion of food, the organs of respiration, the heart and organs of circulation, certain excretory organs, and other parts concerned in the vital functions. Before giving a more exact account of the position of these contents of the ventral tube, it will be well to get some general ideas of the bony skeleton of the body.

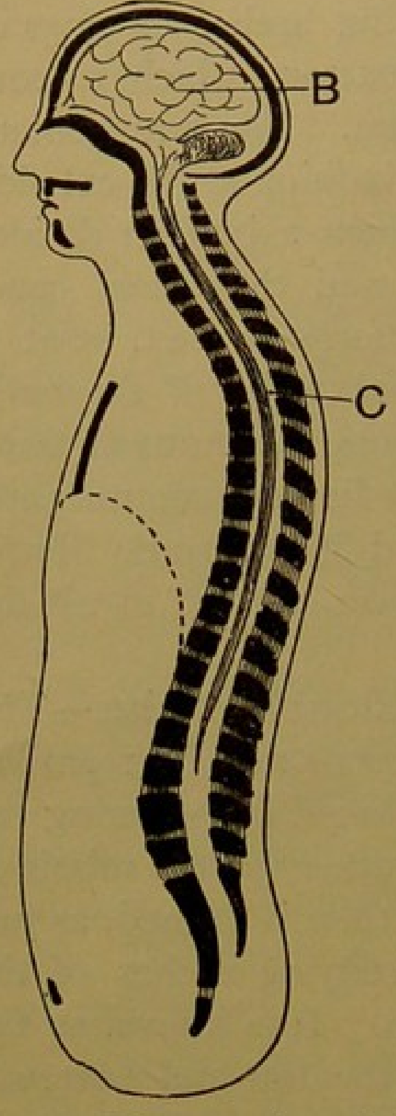



FIG. 6.—Diagrammatic vertical section of the body to show its two great tubes. B, brain, and C, spinal cord in the dorsal tube. The wide ventral tube lies in front, divided into two by the dotted line that represents the diaphragm. Bones black.

**11. General Description of the Skeleton.**—The skeleton forms the hard framework of the body, and is composed of a number of separate bones united together at joints of various kinds. Pads or other forms of cartilage (gristle) often come between the ends of the bones that meet, while tough fibrous bands, called **ligaments**, bind bone to bone at the joints in the living body.

We may here regard the skeleton as made up of head, trunk, and limbs. The bones of the head form the skull, and include the **cranium**, which encloses the brain and the bones of the **face.** The skull rests on the **vertebral column.** At the bottom of the hinder part of the cranium is a foramen or hole that leads into the spinal canal, running down through the vertebræ.

The bones of the trunk include the backbone, or **vertebral column**, and the bones of the chest, or **thorax.** The backbone consists of thirty-three vertebræ. The first seven vertebræ lie in the neck; the next twelve vertebræ are in the back, and are jointed to the ribs behind; and the next five vertebræ are in the lumbar regions, or loins. Below the lumbar vertebræ are five vertebræ that unite together to form a broad curved bone called the **sacrum.** At the end of the sacrum is a small pointed bone formed out of four vertebræ called the **coccyx.**

Forming the bony cage of the thorax are twelve **ribs** on each side, each rib being jointed to a dorsal vertebra behind, while ten on each side are fastened by a piece of cartilage to a slender flat bone in front, called the **sternum**, or breast-bone. Notice how the ribs get shorter above, that the first seven ribs on each side have each a separate piece of cartilage uniting them to the sternum, that the next three are united by the same piece of cartilage, and that the last two ribs on each side do not reach the sternum in any way. Notice also the shape of each rib, and how the ribs slope downwards, the cartilage of the lower ones, however, running upwards (see Figs. 7 and 19).

The collar-bone, or **clavicle**, passes from the top of the sternum outwards to join a projection on a broad flat bone at the back of the thorax, called the shoulder-blade, or **scapula.** At the outer angle of the scapula is a hollow, into which the rounded head of the arm-bone or **humerus** fits. To the lower end of the humerus are connected the two bones of the lower arm, called the **ulna** and **radius**, the connection forming the elbow-joint. At the wrist the radius is jointed to several small bones, called **carpal bones.** In the palm of the hand there are five bones, called **metacarpal bones**, one leading to each finger and one to the thumb. In each finger there are three finger-bones, or **phalanges**, but only two in the thumb.

At the lower end of the trunk there is a girdle or basin of bones, called the **pelvis.** The pelvis is formed behind by the **sacrum** and **coccyx.** From the sacrum two large curved hip-bones arch forward and meet in front, thus completing the bony basin with sloping sides, but without the narrow bottom (see Figs. 7 and 26).

In the leg we have, in the upper part or thigh, the largest bone of the body, called the thigh-bone, or **femur.** At its

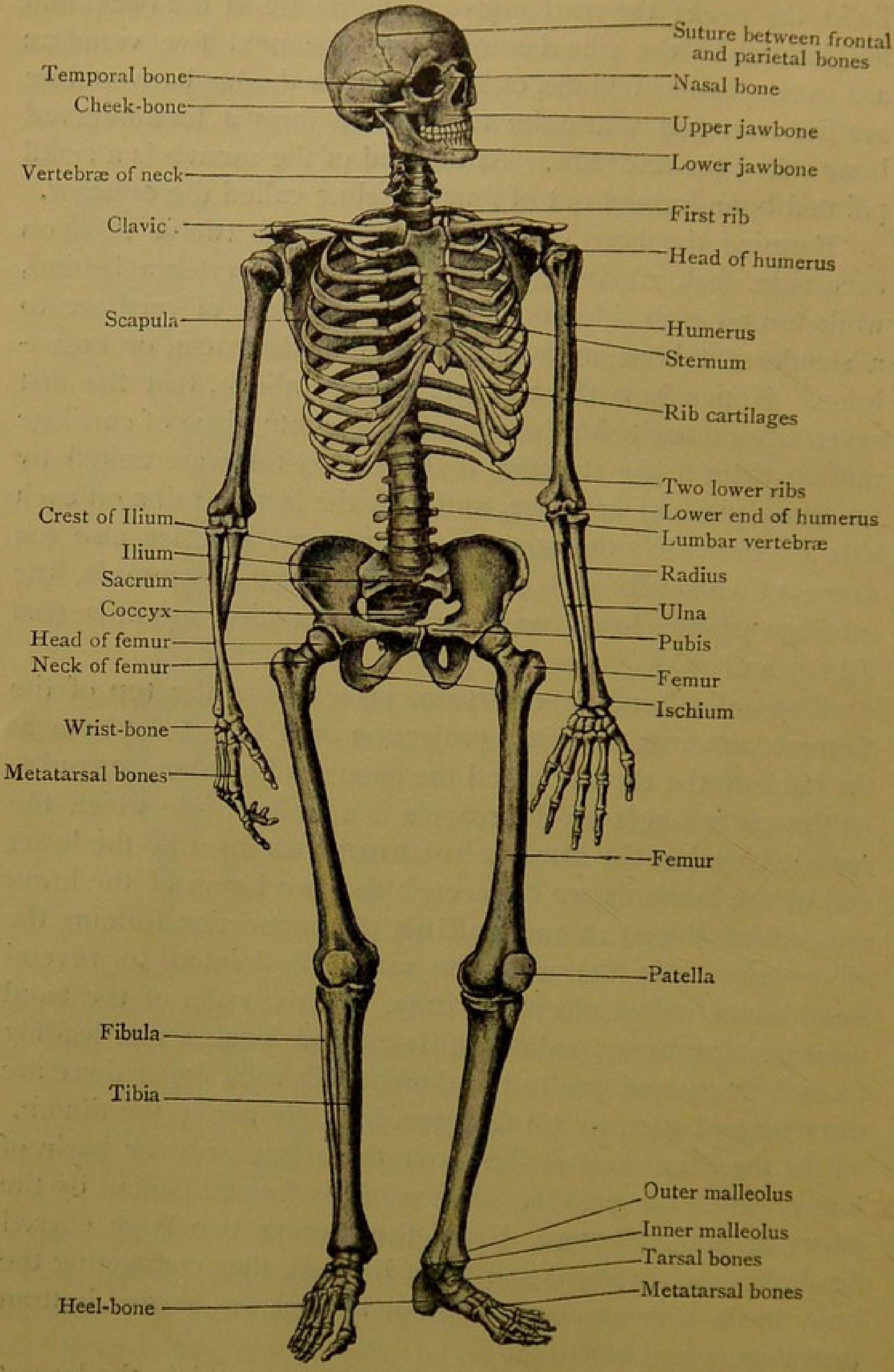



FIG. 7.—The skeleton.

upper end the rounded head of the femur fits into a cup-shaped cavity in the hip-bone. At the lower end the femur is jointed at the knee to the shin-bone, or **tibia**, which forms the inner bone of the leg proper. Attached to the outside of the tibia is the splint-bone, or **fibula**. Lying within a tendon in front of the knee-joint is the knee-cap, or **patella**. In the foot we find the ankle, or **tarsus**, formed of seven bones, the most prominent of which is the heel-bone; the sole or metatarsus formed, like the palm of the hand, of five bones; and the toe-bones or **phalanges** of the toes, each toe having three phalanges, except the big toe, which has only two.

A fuller description of the bones will be given in the next chapter.

**12. The Thorax and its Viscera.**—In front of the portion of the dorsal tube enclosed by the vertebræ there lies, in the trunk, a much wider cavity, often termed from its position the **ventral tube**. This great cavity of the trunk opposite the backbone is subdivided into two compartments by a transverse arched muscular partition called the **midriff**, or **diaphragm**. The upper compartment of the great cavity of the trunk is called the chest, or **thorax**, and the lower the belly, or **abdomen**, so that the diaphragm forms the arched floor of the thorax, but the concave roof of the abdomen. The cavity of the thorax has the shape of a blunt cone, with the narrower end upwards and the broad lower end sloping downwards and backwards. Its walls are made up of bones, cartilage, and muscles. The skeleton part of the thorax is a kind of open bony cage formed of the twelve dorsal vertebræ behind, the twelve hoop-shaped ribs passing from the vertebræ on each side (twenty-four in all), and the sternum, or breast-bone, in front. As just explained, the ribs do not all reach the sternum in front, but ten on each side are connected with it directly or indirectly by cartilages. Between these bones and cartilages, as well as over them, lie muscles, and the whole is covered on the outside by skin. There is thus at the back of the thorax the twelve dorsal vertebræ, the hinder parts of the ribs, some dorsal muscles, and part of the intercostal muscles; at the sides of the thorax the walls are made up of ribs and intercostal muscles; and at the front there are the front portions of the ribs, the costal cartilages, the sternum, and the muscles lying

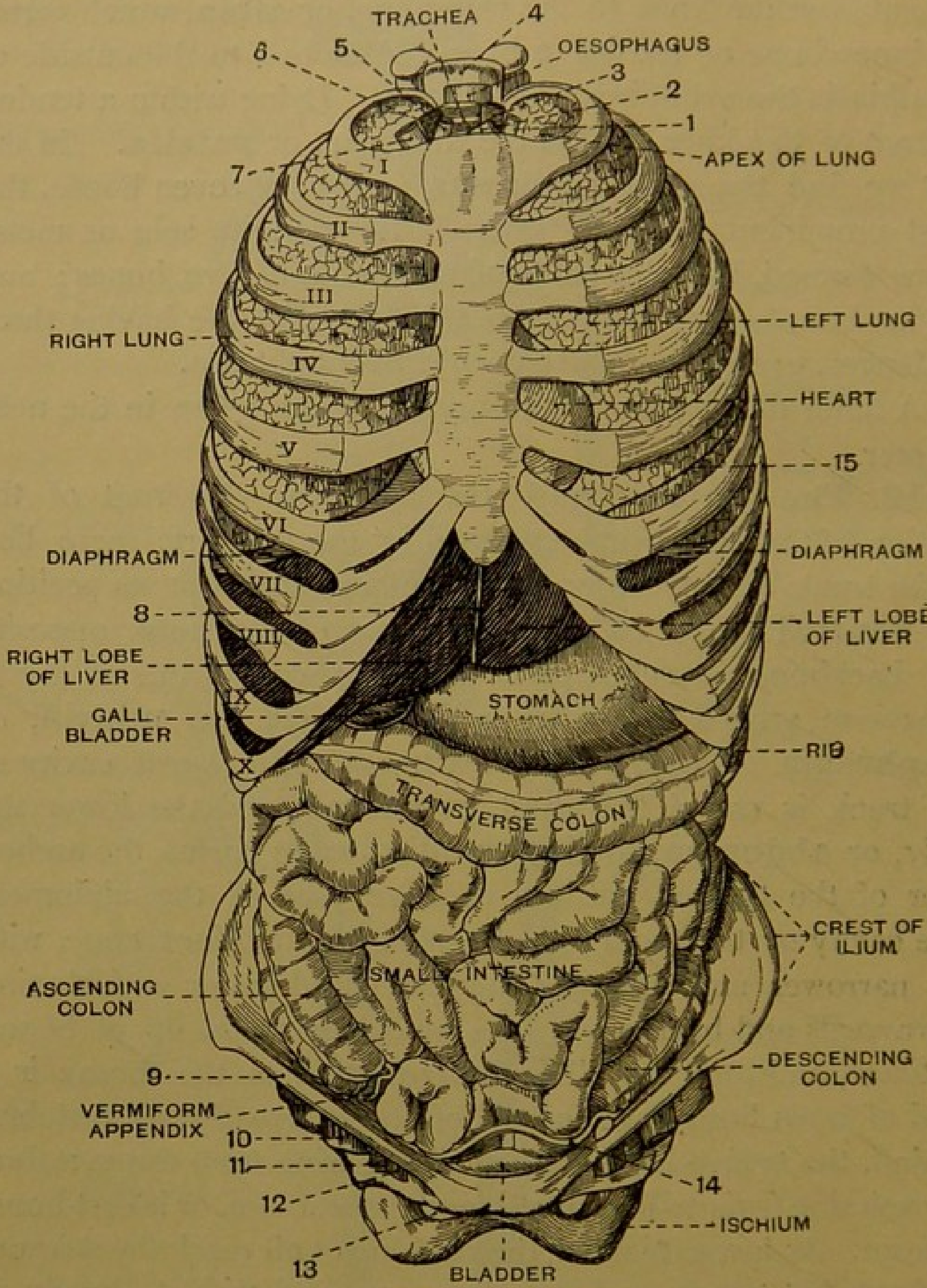



FIG. 8.—The viscera of the trunk (thorax and abdomen), seen from the front, the skin and overlying muscles being removed. Names are attached to the various viscera. The Roman numerals indicate the various ribs, I being the first. The figures 1, 2, 3, 5, 6, 7, indicate the great blood-vessels in the root of the neck; 4 is the 7th vertebra of the neck; 8, a ligament between the two great lobes of the liver; 9 is Poupart's ligament (par. 45); 10, a muscle passing beneath Poupart's ligament; 11, the femoral artery; 12, the femoral vein; 13, the obturator foramen; 14, the cut edge of the peritoneum.

between. Above, the thorax runs to a narrower end, owing to a gradual diminution in length of the higher ribs, and this upper end is closed by the first short pair of ribs and the muscles and vessels in the root of the neck. Below, the thorax is wide, and has for its floor the diaphragm, a thin sheet of

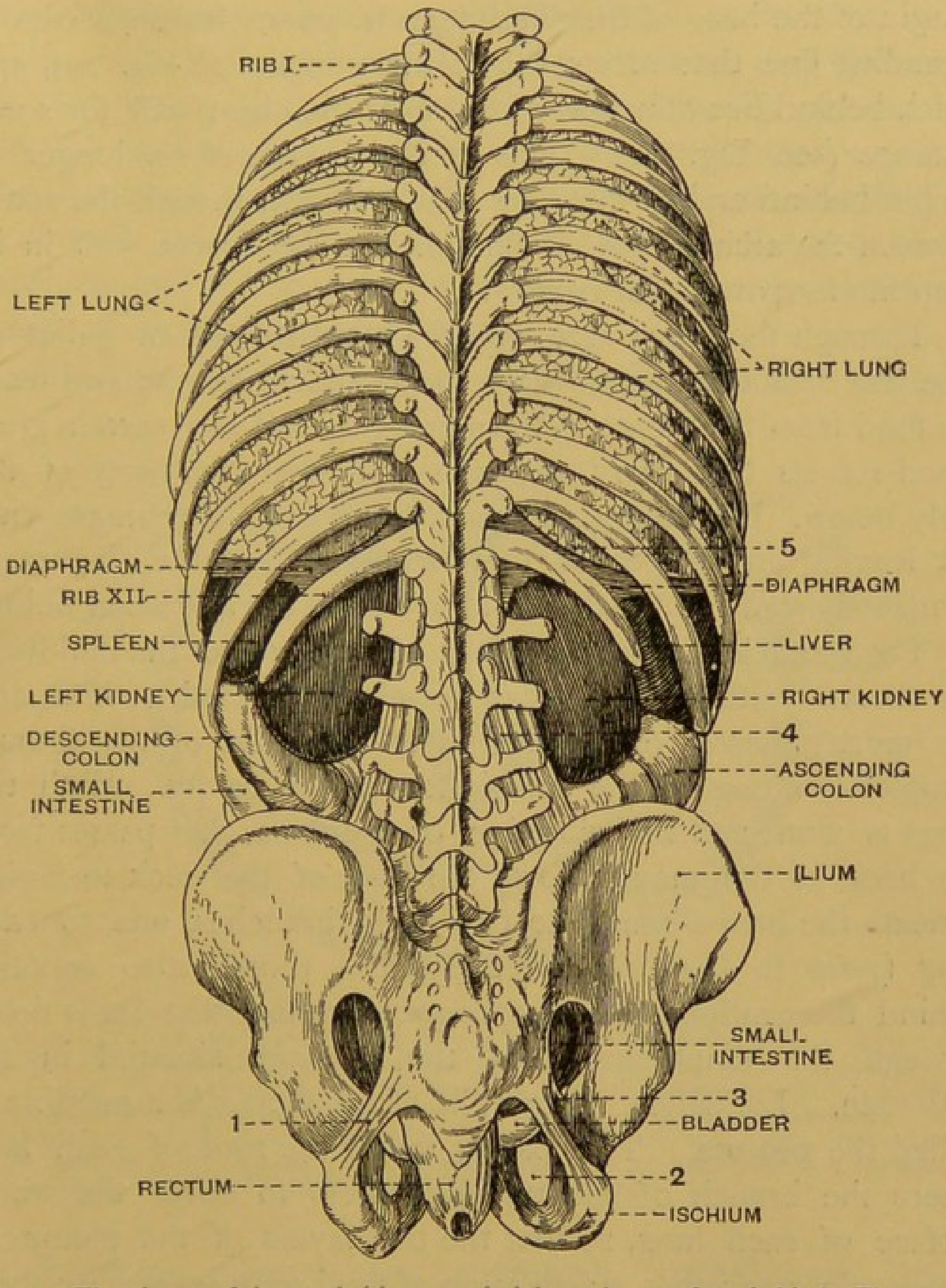



FIG. 9.—The viscera of the trunk (thorax and abdomen), seen from behind. The various viscera are indicated by their names. 1, a ligament (the sacrosciatic) passing from the sacrum to the ischium across the opening from below into the pelvis; 2, the obturator foramen ; 3, a ligament ; 4, psoas muscle in loin ; 5, lower margin of lung.

muscular fibres springing from the outside margin of the thorax and passing upwards and inwards to a central tendon. The diaphragm thus forms an arched partition, convex above and concave below. It is attached behind to the lower dorsal vertebræ, at the sides to the lower ribs, and in front to the ascending costal cartilages and to the sternum. Hence the margin of the base of the diaphragm is, on each side, a curved ascending line that meets the sternum in front (Fig. 19), and which behind lies at a lower level near the chest wall for some distance (see Fig. 91). The thorax is, therefore, longer or deeper behind and at the sides than in front, though the space between the arch of the diaphragm and the thorax wall in its deep hinder part is but narrow.

Through the diaphragm pass the **œsophagus**, or gullet—a tube that runs downwards close to the spinal column and leads the food from the mouth to the stomach—and also certain great blood-vessels that carry blood to and from the parts of the body below. But these tubes pass through the diaphragm without leaving any spaces on their sides, so that the diaphragm completely shuts off the thorax above from the abdomen below.

The thoracic viscera include the **heart**, about the middle of the thorax, with certain great vessels connected with it, and the spongy masses of the **lungs** at the sides of the thorax, completely filling up the remainder of the cavity. With the lungs is connected the windpipe, or **trachea**, that passes from the back of the mouth down the front of the neck to divide beneath the breast-bone into two main branches, one to each lung (refer to Figs. 63 and 86). The thorax also contains behind the windpipe the œsophagus or gullet, that leads down through the diaphragm into the stomach situated in the abdomen. Lining the inner walls of the thorax is a membrane called the **pleura**. This passes on at the root of each lung where the branch of the trachea enters to cover the whole surface of each lung, so that the two layers of the pleura lie almost close together, a thin layer of fluid only separating them and keeping their surface moist (Fig. 90).

**13. The Abdomen and its Viscera.**—The boundary walls of the abdomen are formed by the arched diaphragm above, by the lower part of the vertebral column, and by the muscles of the loins behind; at the sides and in front by thin sheets of muscles and the skin, while below is the pelvic basin of bones formed by the two hip-bones with the sacrum and coccyx. The lowest portion of the abdomen, or that part enclosed by the pelvis, is often spoken of as the **pelvic cavity**. A thin membrane, called the **peritoneum**, lines the inner sides of the walls of the abdominal cavity, covering also the large intestine, where it comes in contact with this, but passing out from the back to reach and envelop the small intestines, and then returning to continue its course. This double fold of peritoneum thus attaches the small intestines to the back of the abdomen, and is known as the **mesentery**. In the mesentery run many blood-vessels and nerves.

The lower half of the trunk forming the abdomen contains

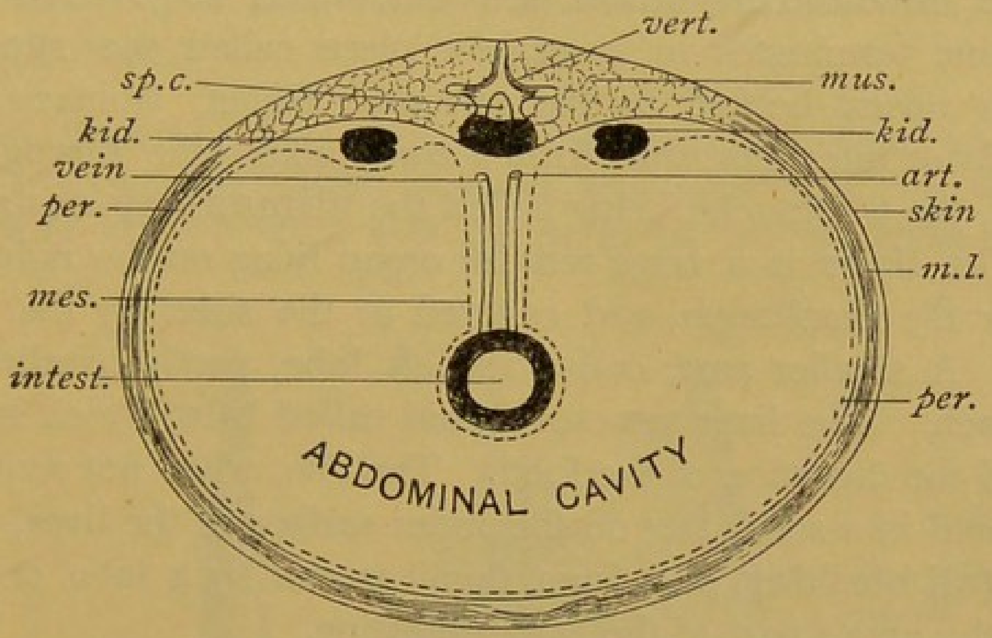



FIG. 10.—Diagrammatic cross-section of the abdomen. The trunk is supposed cut across in the region of the abdomen, and the intestines are only indicated as a section of a tube, though they really occupy all the abdominal cavity not taken up by the other organs. The section indicates how the walls of the abdomen are made up, how they are lined by the peritoneum, and how the mesentery supports the intestines. *Per.*, peritoneum; *m.l.*, muscular layers of the thin abdominal wall; *art.*, artery passing to intestine; *kid.*, kidney; *mus.*, thick muscles of the back; *vert.*, a vertebra in section; *sp.c.*, spinal cord in section; *mes.*, mesentery.

the following viscera: the **stomach, intestines, liver, pancreas, spleen, kidneys**, and **bladder**, most of these organs being surrounded and supported by the folds of peritoneum. The form and situation of each abdominal organ may now be briefly described.

The **stomach** lies underneath the arched diaphragm on the left side, its main portion being under cover of the lower ribs on this side (see Fig. 8). Leading into it above is the food pipe, or gullet, which has passed from the back of the mouth, and then behind the trachea and heart through the diaphragm. The stomach, which is a muscular and membranous bag, passes below into the **small intestines**, which are about twenty feet in length. The small intestines, after coiling about in all directions, terminate towards the front on the right side just under cover of the lower part of the hip-bone by passing into the dilated beginning of the large intestine called the **cæcum.** From the short cæcum, the large intestine passes up the right side as the **ascending colon**, across below the liver and stomach as the **transverse colon**, and down the left side as the **descending colon** (see Figs. 8 and 103). The large intestine terminates in a straight piece called the **rectum**, which opens behind to the outside. Gullet, stomach, and bowels or intestines, thus form a continuous tube through the trunk, the whole tube being called the **alimentary canal.**

The **liver** is a large reddish organ lying on the right side under the diaphragm, and covered at the sides by the lower ribs. A smaller part, called its left lobe, partly overlies the stomach. The liver secretes a fluid called **bile**, which is used to aid the digestion of the food. The bile, when not required, is stored in a small bag on the under surface of the liver, called the **gall-bladder**, and from this it passes by a tube or duct into the upper part of the small intestine.

The **pancreas**, or **sweetbread**, is an organ shaped like a dog's tongue, which lies partly behind and below the stomach, so that it cannot be seen until the stomach and transverse colon are raised or removed (see Fig. 103). It secretes a fluid, the pancreatic juice that passes along a duct into the first part of the intestine to aid in digestion.

The **spleen** is a small, oval, dark-red body, placed behind and to the left of the stomach, and not visible from the front. It is an elongated, dark-red body, and on pushing aside the stomach blood-vessels may be seen entering and leaving its concave side, which is turned towards the right (Figs. 9 and 118).

The **kidneys** are two oval or bean-shaped organs about four inches long, which lie behind the intestines, outside the peritoneum, at the back of the abdomen on each side of the spinal column, and opposite the last dorsal and upper two lumbar vertebræ (see Figs. 9 and 120). They are embedded in the fat of the loin, the part of the body behind the last rib at the back. The function of the kidneys is to excrete certain impurities that have accumulated in the blood. These impurities, dissolved in water, are conveyed from the kidneys by two tubes, called the **ureters**. The ureters pass to a membranous bag lying in the pelvis at the front of the rectum, known as the **bladder**, and into this they convey continuously the urine as it is secreted by the kidneys (Fig. 9 and 120). From the bladder, which lies towards the front in the lower part of the abdomen, a tube, starting at its lower end, and called the **urethra**, passes to the outside.

**14. The Limbs.**—The limbs of the human body consist of two pairs, the upper limbs, or **arms**, and the lower limbs, or **legs**. The arms are connected with the upper part of the trunk at the

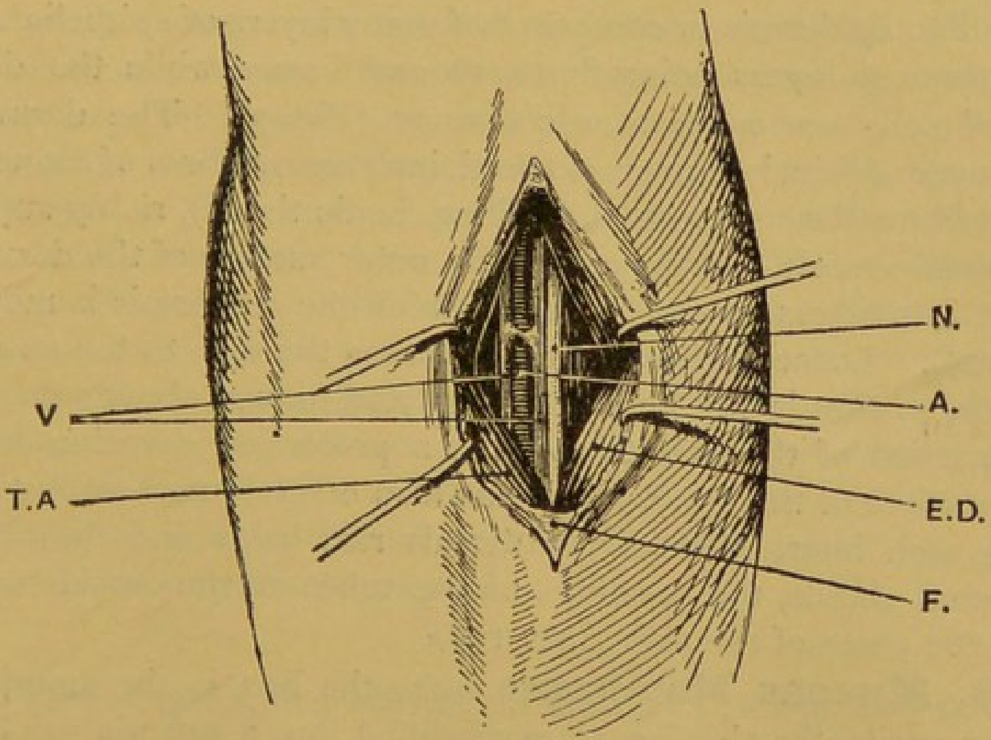



FIG. 11.—An incision in a limb, showing beneath the skin and among muscles (TA and ED) an artery, A; veins, V; and nerve, N. F is a fascia or muscular sheath. (*From Cheyne and Burghard's "Manual."*)

shoulder-joints, and the legs are united to the trunk at the hip-joints. Like other parts of the body they are covered by a slightly hairy skin. Beneath the skin of the limbs we find a thin layer of fat and masses of flesh, termed **muscles**, and among the muscles are found blood-vessels and whitish cords, termed **nerves**. The blood-vessels are either **arteries** conveying blood from the heart, or **veins** taking it back to the heart, the two being connected by smaller vessels invisible to the naked eye, and called **capillaries**. From the minute capillaries in all parts some of the liquid part of the blood passes through the thin walls into the surrounding tissue, where it is known as **lymph**. The nerves of a limb are all connected with other nerves that have their central connection in the spinal cord. In the central part of the limbs we shall find a bone or bones, to which the muscles are attached. The limbs are thus solid structures ; for, cutting one across we should see at the cut end the surrounding skin, beneath this a layer of subcutaneous fat, then the cut ends of muscles, blood-vessels, and nerves, and in the centre the cut end of a bone. Further details regarding the limbs will be supplied later.

**15. The Skin.**—A few remarks may be made here about the outer covering of the body, called the skin, leaving its fuller treatment until Chapter XV. Under the microscope the skin is seen to consist of two layers or coats, an outer layer called the **epidermis**, or **cuticle**, and a deeper layer called the **dermis**, corium, or true skin. The epidermis is composed of many layers of epithelial cells, the outermost layers being flattened and horny, while the deeper layer of cells are cubical or columnar (Fig. 3). The dermis, or inner layer of skin, is a mass of felted, interlacing fibres of connective tissue (white fibrous tissue and yellow elastic tissue), richly supplied with blood-vessels and nerves. The outer surface of the dermis is thrown into ridges or papillæ, over which the epidermis is moulded (Fig. 125). Loose connective tissue unites the skin to the structure beneath, so that it can be pinched up, and moved about somewhat. One function of the skin is to form a protective covering for the outer surface of the body, but it has also other important duties, as will be seen later. Out of the dermis rise hairs and the tubes of tiny sweat glands, the openings of the tubes on the outside surface being the pores of the skin (par. 125).

**16. Mucous Membrane.**—On the lips, in the mouth, and in the nostrils, the skin becomes modified into a soft pinkish lining, known as **mucous membrane**, and this mucous membrane forms the lining of the whole alimentary canal, the air passages, and every other tube communicating with the exterior. Under the microscope mucous membrane is seen to consist of two layers like the skin, but the outer layer of epithelial cells is thinner than in the skin, and the surface is kept moist by a thin, rather slimy, liquid, called **mucus**.

The cells forming the outer epithelial layer of mucous membrane are of different shapes in different parts of the alimentary canal and air passages. Often this epithelial layer is but one cell in thickness, though in some parts, as in the mouth, the epithelium layer of the mucous membrane consists of several layers of cells. Beneath this epithelium of a mucous membrane is a dermis or corium of fibrous tissue, richly supplied with blood-vessels corresponding to the second coat of skin. Below the dermis of a mucous membrane there is often a thin layer of muscular tissue. Some of the cells of a mucous membrane epithelium have the power of forming and setting free the slimy liquid, called *mucus*, which keeps the surface moist.

**17. Glands.**—In certain parts of mucous membranes, especially that lining the alimentary canal, pits or depressions formed by an infolding of the outer layer of epithelial cells occur. These run down into the deeper tissue, where they end blindly. A tiny tube opening into the alimentary canal is thus formed. Such a tube often spreads out inwardly into a sac, or it forms a coil, or it branches in various ways. The minute tube, or duct, and its branches are lined by a single layer of cubical epithelial cells, and around the tube and its branches are minute blood-vessels in the surrounding tissue. The cells of such tubes and their branches separate or secrete from the blood of the surrounding capillaries, or rather from the blood lymph that has escaped from the capillaries, a fluid which is discharged at the surface of the mucous membrane into the part of the canal where the minute tube opens. A simple or branched tube lined by active epithelial cells that separate a fluid from the blood is called a **secreting gland**. In other words, a **gland** is a recess or pouch in a mucous membrane lined by secreting cells, and opening into a larger tube or cavity by a duct. According to the way it branches it receives various names. If it forms coils it is called a *convoluted tubular gland*, if it forms many branches that end in dilated sacs, it is called a *racemose gland* (Lat. *racemus*, a bunch of grapes).

In some cases many clusters of branched tubes and pouches are bound together into a large mass, so as to form a separate organ with many small and one large duct. The kidneys and the salivary glands, for example, are large compound tubular glands, and the pancreas is a large racemose gland.

Many of the glands of the body are connected with the alimentary canal, and their functions vary with their positions.

A large number of simple tubular glands lie in all parts of the wall of the alimentary tube. The cells of many of these simple glands secrete mucus, which is discharged into some

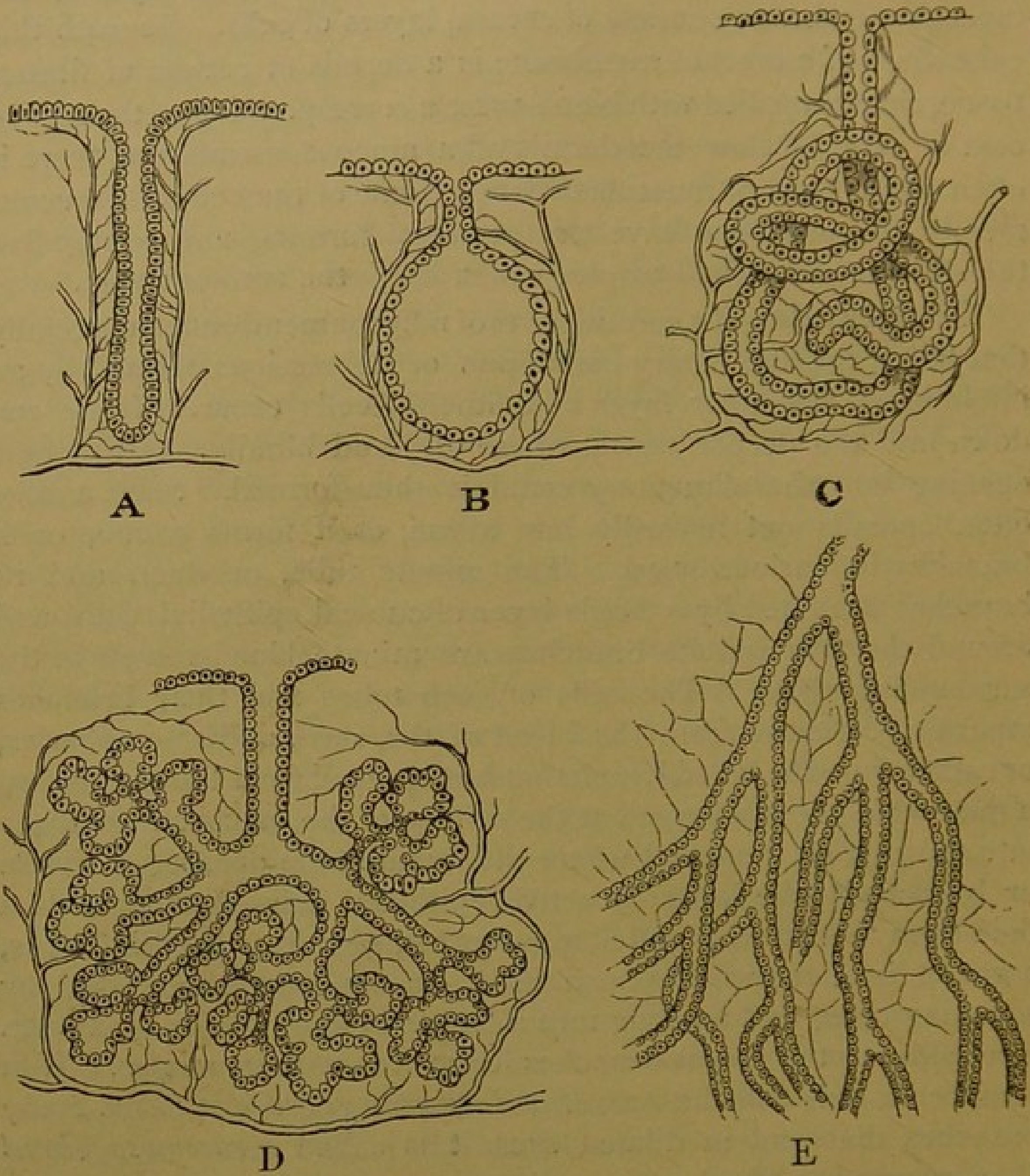



FIG. 12.—Diagram plans to illustrate the microscopic structure of secreting glands. A, a simple tubular gland, the single layer of cells of the tube having, on the outside, connective tissue containing fine blood-vessels; B, a simple saccular gland; C, a convoluted tubular gland; D, a racemose gland; E, a compound tubular gland. In each case the surrounding blood-vessels are indicated, and the duct or tube along which the secretion passes. (*From Gray's "Anatomy."*)

part of the alimentary canal; the cells of other simple glands in special parts of the canal secrete a special fluid, *e.g.* gastric juice from tubular glands in the stomach (Fig. 106), intestinal juice from tubular glands in the intestines. In the case of the separate glandular masses lying away from the canal and connected with it by comparatively large ducts, the secreting cells of the gland are confined to the blind tubes, or **acini**, while the tubular passage forming the *duct* leading to the surface within the alimentary tube, is lined by simple non-secreting epithelial cells. Such a duct is the tube leading from the pancreas into the duodenum (Fig. 103).

**18. The Nervous System.**—An important part of the body is known as the nervous system. The chief portion of the nervous system is termed the **cerebro-spinal system**, and consists of the **brain** and **spinal** cord, with **nerves** connecting the brain and spinal cord with the muscles and the organs of special sense (eyes, ear, tongue, nose, skin). The brain occupies the cavity of the cranium. It is divided into **cerebrum**, or large brain, and **cerebellum**, or small brain. The brain consists of white and grey nervous matter arranged in definite

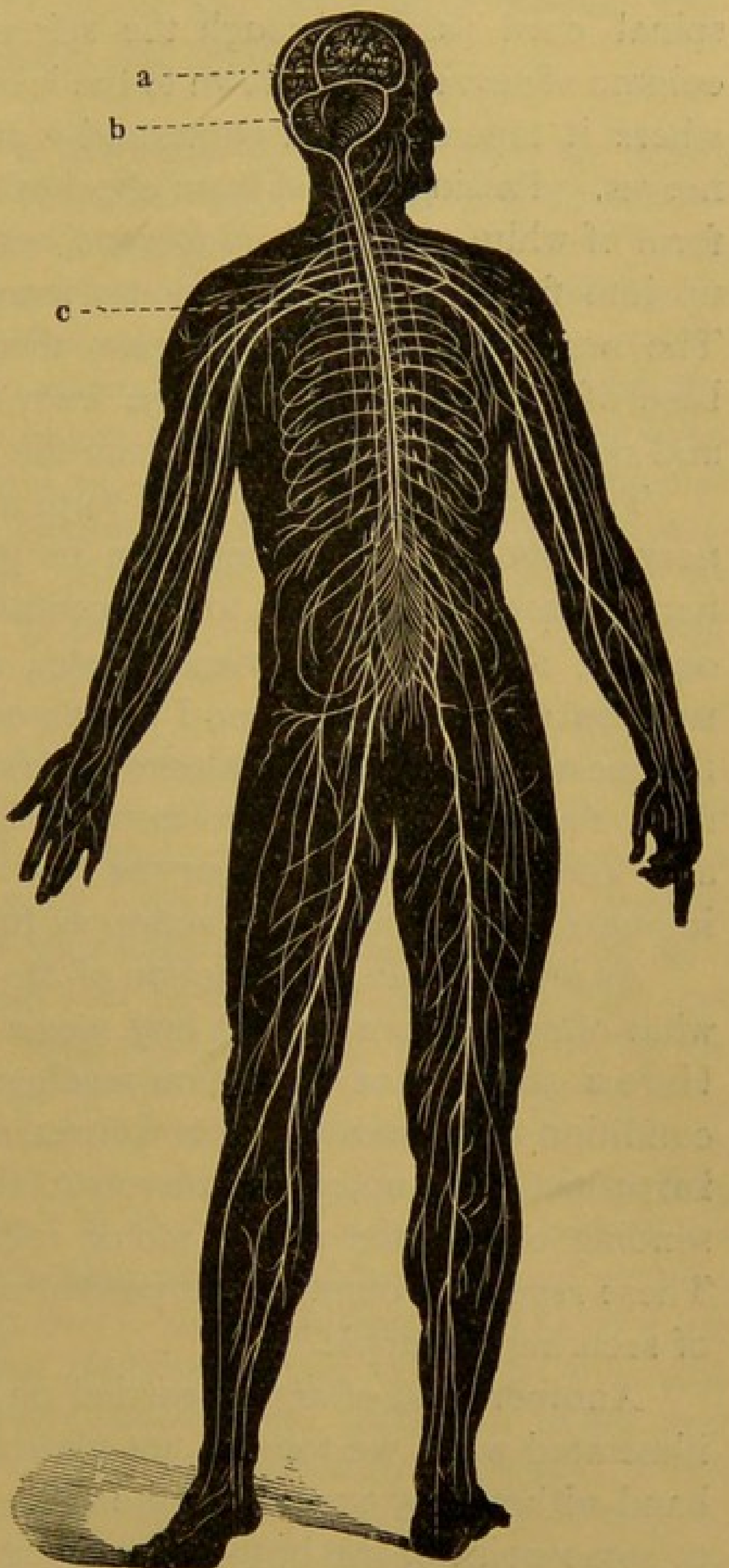



FIG. 13.—General view of the nervous system. *a*, cerebrum in two hemispheres; *b*, cerebellum; *c*, spinal cord, with spinal nerves passing to all parts.

folds and forms. Behind, the brain passes into the spinal cord, the first part of which is inside the cranium, and is known as the **medulla**, or **spinal bulb**. After leaving the cranium the spinal cord passes through the spinal canal, as a cylindrical column of nerve matter, down to the level of the lumbar vertebra, where it tapers off to a point, and is surrounded by a brush of nerves. Passing to and from the brain and spinal cord, in the form of white cords, are numerous nerves, and these breaking up into finer and finer branches reach all parts of the body. The nerves from the brain pass through small holes at the base of the cranium, and those from the spinal canal pass in and out through passages between the vertebræ.

The brain and spinal cord form a central system, and the nerves connected with them can be put into two classes: (1) nerves carrying impulses to the central system from the sense-organs; skin, muscles, viscera, etc., and known as **afferent nerves** (Lat. *af*, to; *fero*, I carry), or when we are aware of the message as **sensory nerves**; (2) nerves carrying impulses from the central system to muscles, glands, and other organs, and known as **efferent nerves** (Lat. *ef*, out of), or when the impulse leads to muscular action as **motor nerves**.

As an example of the action of the nervous system, consider what often happens when a boy sees a ripe apple in his garden. Here a stimulus or excitation reaches the eye, and a disturbed condition of the sensory nerve fibres, called a sensory **nervous impulse**, is set up, which travels to the brain and leads to the sending out by the will of motor impulses to certain muscles. These result in voluntary, purposeful movements with the object of securing the apple.

Another kind of action carried on by the nervous system is illustrated when we touch a hot plate and instantly withdraw the hand without any exercise of the will. Afferent impulses, started at some point of the body, pass along to a nerve centre in the brain or spinal cord, and from this centre an impulse is reflected which results in a movement independent of the will. Such a direct motor reaction following the stimulation of a sensory nerve, and without the influence of the will, is called a **reflex action** (par. 154).

The nervous system is, in fact, the great regulating and co-ordinating system of the body. It co-ordinates the action of parts of the body with one another, and also co-ordinates the action of parts of the body, or the body as a whole, with relation to external influences and conditions.

**19. Dissection of a Rabbit.**—Obtain a recently killed rabbit. Compare it with your own body. Notice that its head is connected to the bony spine at the back in such a way that it can be made to nod and to turn a little from side to side. Examine its fore limbs and note that they are jointed in three places, corresponding to the shoulder, elbow, and wrist in man. Find the corresponding parts of the hinder limb, noticing how near the knee is placed to the trunk. Feel the sternum and ribs and the softer wall below the end of the sternum, thus recognizing from the outside thorax and abdomen. Now fasten the animal down on its back on a board, fixing it by passing nails through its paws after extending its limbs. Pick up the skin and cut through it in the middle line from the chin over the breast-bone to near the root of the tail. Pull the skin apart, cutting it across in one or two places, and notice the filmy connective tissue binding it to the parts beneath. The thorax and abdomen are still closed, but there can be seen the muscles of the neck, large muscles covering the sternum and ribs, and the thin muscular walls of the abdomen. Pinch up a part of the thin abdominal wall near the middle, and then cut through this part with scissors, continuing the cut forward to the sternum and back to the end of the abdomen. Make two or three cross-cuts through the abdominal wall and fasten back the flaps. The viscera of the abdomen are now exposed. On gently pulling down the brownish-red liver at the upper or anterior end of the abdomen, a thin arched partition passing across the trunk may be noticed. This arched partition is the **diaphragm.** The liver lies beneath the diaphragm, but the greater part of it is to the right. It consists of several portions, called lobes. Attached to the liver beneath, the **gall-bladder**, filled with bile, may be readily found. Beneath the diaphragm, towards the left side and partly overlapped by the liver, is a greyish-white pouch, the **stomach.** Notice the small intestine lying in several coils in the middle of the abdomen. The large dark-coloured tube lying near the lower part of the abdomen is the part of the large intestine called the **cæcum.** This part is much longer and larger than the corresponding part in man. The puckered tube running across the lower part of the abdomen is a part of the large intestine known as the **colon**. The **bladder** may be found at the bottom of the abdomen towards the front. Now pick up a coil of the small intestine and note the **mesentery** attached, a thin transparent membrane binding the intestine to the back of the abdomen, and richly supplied with blood-vessels. By tearing through the thin mesentery the coils of the small intestine may be removed from the abdomen, and it will then be seen to be connected above to the stomach by a thin portion called the **duodenum**. Below the small intestine is continuous with the cæcum, and the other parts of the large intestine called the colon. The large intestine will be found on being pulled out to end in a piece leading to the outside called the **rectum**. In the loop of the duodenum below the stomach may be found the **pancreas**, which, in the rabbit, appears as an irregular greyish-white mass. On the left side, just below the stomach, may be found the **spleen**, a small dark-red organ. On removing the intestines there will have been noticed, a little above the middle of the abdomen, on each side of the backbone, a dark-red organ partly covered by fat. These are the kidneys. From each a fine whitish tube, the **ureter**, leads to the bladder in the pelvis. Now cut open the stomach, remove the partly digested food, and find the tube entering it above on the left. This is the **œsophagus**, or gullet, that passes from the back of the mouth down through the thorax. Cut into the small intestine, and note that it is a narrow tube lined by a soft slimy inner layer, called **mucous membrane**. Compare its mucous membrane with that of the stomach. Cut out a piece of the small intestine, wash it with salt water. On examining the inner surface with a hand lens projections like the pile of velvet may be noticed. These are the **villi** of the small intestine.

Turn now to the thorax, which has been left as a closed cavity with the skin removed. Looking from below through the thin diaphragm, the lungs may be seen in contact with it, as they still fill the whole cavity of the chest not occupied by the other organs. On puncturing the diaphragm or any other part of the thoracic wall, however, they collapse. Make a hole through the diaphragm on the left and notice the collapse of the left lung. To open the thorax, cut the costal cartilages on each side, without injuring any structure beneath, with a stout pair of scissors, and remove a portion of the sternum, ribs, and intercostal muscles. A little to the left of the middle line will be seen the **heart**, within a thin bag called the **pericardium**. Open the pericardium and find the vessels from the base of the heart. The largest, firmest tube is of lighter colour than the others. This is the great artery called the **aorta**. Coming up to the heart from below may be found a darker vessel, the **inferior vena cava**, which brings blood to the heart from the lower limbs and lower parts of the trunk. A similar vein, the **superior vena cava**, may be found above. Find the stout tube in the front of the neck called the **trachea**, or windpipe. Pass a glass tube into the windpipe through the mouth and blow. Notice that the lungs expand, but on ceasing to blow they collapse again. Cut off a piece of lung and throw it into water. It floats, for its cavities still contain some air.

Now examine one of the hind limbs of the animal. Remove the skin and note the fleshy part beneath. The flesh consists of muscles running down the limb. Some of these can be separated from one another by tearing through the **connective tissue** that binds them together. Between the muscles at the back of the leg may be found a small white glistening cord, the **sciatic nerve.** On following this nerve it will be found to give off branches. Blood-vessels may be also noted among and in the muscles. Find the tough whitish cords fastening the muscles to the bones. These are **tendons.** Remove the muscles from the thigh and leg bones, and notice that these two parts are still held together at the movable joint connecting the two parts of the limb by stout bands of fibrous tissue. These are the **ligaments** of the joint. Cut through the ligaments binding the bones together at the joint and examine the mode in which the end of one bone fits into the other.

## CHAPTER III.

### *THE SKELETON OR BONY FRAMEWORK.*

**20. The Human Skeleton.**—The whole of the bones of an animal in their natural position form the **skeleton**, and the reader has already a general idea of its parts (Fig. 7). We now proceed to a fuller description.

The human skeleton consists of rather more than two hundred bones, variously united together so as to form **joints**, or **articulations**. The chief uses of the bones are: (1) to give stability to the shape of the body; (2) to support the soft parts; (3) to protect important organs; (4) to give attachment to the muscles; and (5) to act as levers when force is exerted upon them by attached muscles.

With the aid of the description and figures in the text and a set of dried bones or a **skeleton** (on which the bones are wired together at the joints), the reader will now be able to learn in more detail the form and position of the chief bones.

The principal parts of the skeleton are: (1) the spinal column, with the appended bony thorax; (2) the skull; (3) the bones of the upper limbs or arms, with the scapula (shoulder-blade) and clavicle (collar-bone), to which each limb is connected above; (4) the bones of the legs, with the connected pelvic bones at the upper end.

**21. The Vertebral Column.**—The vertebral column, which is also known as the **backbone**, or **spinal column**, consists of a pillar of thirty-three superposed bones, each of which is called a **vertebra** (pl. **vertebræ**). These vertebræ are named and grouped according to their position as follows:—
7, cervical, or neck vertebræ; 12, dorsal, or thoracic vertebræ; 5,

lumbar vertebræ; 5, sacral vertebræ; and 4, coccygeal vertebræ. Only twenty-six of these, however, in the adult state are separate, for the five sacral vertebræ are then fused together to form one bone, called the **sacrum**, and the four last are fused together to form the **coccyx**. Each of the separate vertebræ, except the two upper ones, is constructed on the same plan; for each consists in front of a short cylinder or disc called the **body**, to the back of which a ring of bone, called the **neural arch**, is attached (Fig. 15). The neural arch bears three projections or processes, two **lateral** or side processes, and one **spinous** process. The spinous processes point downwards, and are the parts most readily felt down the middle of the back (Figs. 9 and 14). These processes serve as places of attachment for ligaments and muscles, and in the case of the dorsal vertebræ the lateral ones also serve, together with the bodies of the vertebræ, as points of attachment for the ribs behind. Between the bodies of the vertebræ are pads of cartilage or gristle, known as **intervertebral cartilages**. These aid in binding the vertebræ together, and as buffers to distribute jars and shocks. Ligaments pass from the bodies, arches, and processes of one vertebra to another, so that the whole is firmly bound together into a long flexible column with a tube running down the centre.

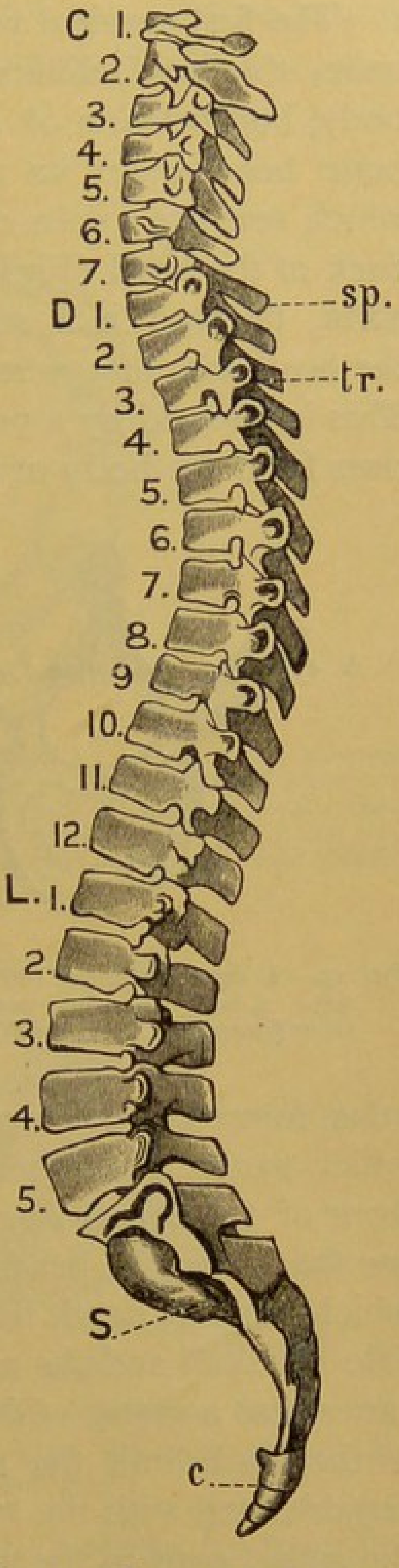



FIG. 14.—The vertebral column, viewed from the left side. C 1, first cervical vertebra; D 1, first dorsal vertebra; L 1, first lumbar vertebra; S, first sacral vertebra; *c*, first coccygeal vertebra. (*From Notter and Firth's "Practical Domestic Hygiene."*)

The first cervical vertebra, known as the **atlas**, because it bears the head, differs from those just described. It has no body, but consists of a thickness on each side and a ring of bone bearing on its upper surface two articular surfaces, on which rest two knobs or condyles of the occipital bone at the back of the head (Fig. 17). The second vertebra is called the **axis**, because it is so connected with the first as to allow the head and first vertebra to turn from one side to the other. This is effected by a process called the **odontoid peg**, which rises from the body of the axis and fits into a small ring of the

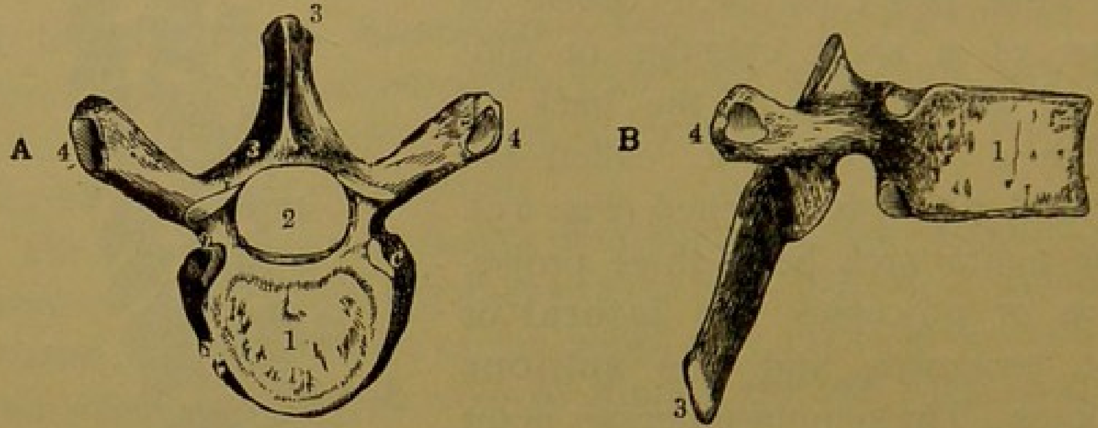



FIG. 15.—A dorsal vertebra (6th). A, viewed from above; B, viewed from the right side. 1, body; 2, spinal cavity; 3, spinous process; 4, lateral processes. (*Reduced from Quain's "Anatomy."*)

atlas, formed by a strong, fibrous, transverse band or ligament, which passes across behind the anterior part of the arch and in front of the neural ring (the dotted line in Fig. 17). We thus see that when the head is nodded, the skull rocks on the atlas, which remains fixed, but when the head is turned from side to side the skull and the atlas move together round the odontoid process as a pivot. *Check ligaments*, from the odontoid process to the skull, limit the amount of turning of which the head is capable, and with the transverse ligament prevent any injury to the spinal cord in the spinal canal.

It will be now understood how the spinal rings or neural arches of the vertebræ, placed one above another, form a long bony tube or canal. In this **spinal canal** lies the long, roundish mass of nervous matter called the **spinal cord.** From the spinal cord there arises, by two roots on each side, thirty-one spinal nerves, which pass out from the cord at intervals left at the sides between the vertebræ, and then ramify backwards and forwards in various parts of the body.

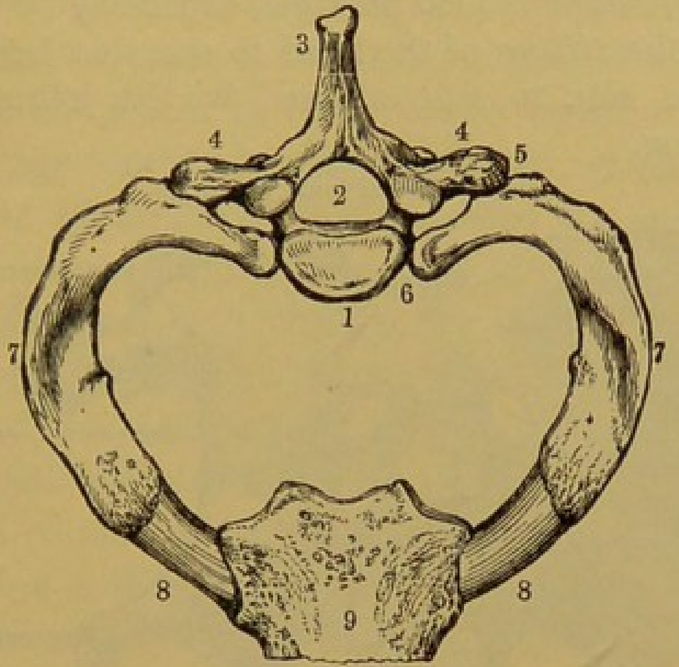



FIG. 16.—First dorsal vertebra, with the first pair of ribs, and a portion of the sternum. 1, body of the vertebra; 2, spinal cavity; 3, spinous process; 4, lateral processes; 5, articular facet of lateral process; 6, articular facet for the head of the rib (these two facets form, with the rib, movable joints); 7, ribs; 8, cartilage or gristle connecting the ribs with the sternum; 9, sternum, or breast-bone. (*From Quain's "Anatomy."*)

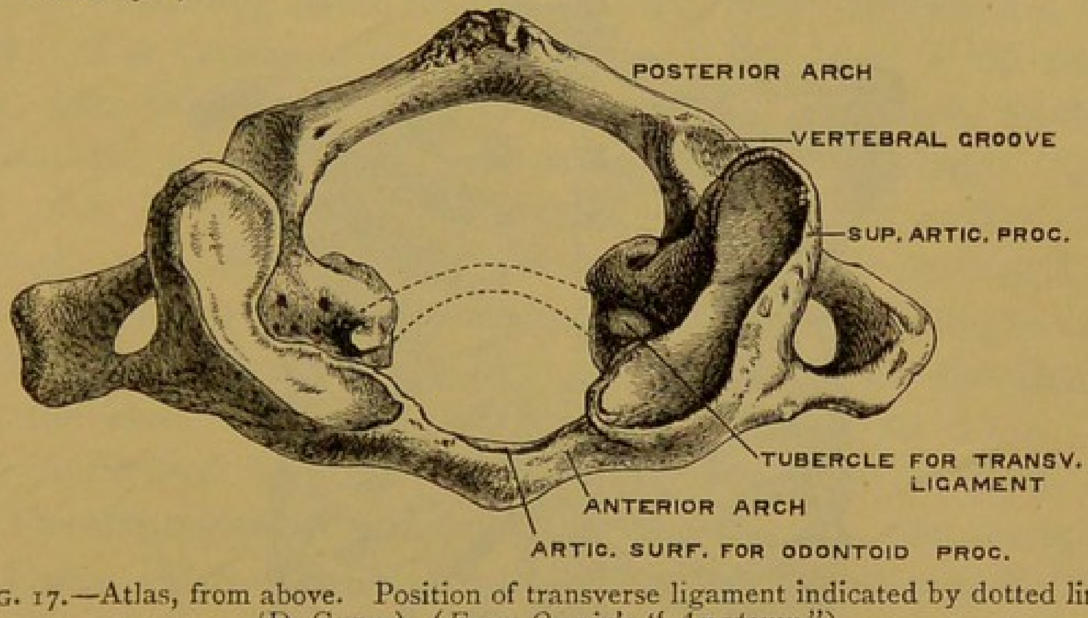



FIG. 17.—Atlas, from above. Position of transverse ligament indicated by dotted line. (D. Gunn.) (*From Quain's "Anatomy."*)

An examination of a skeleton or of Fig. 14 shows that the spinal column is not straight, but has a sinuous curvature, forwards in the neck and loins and backwards in the dorsal and sacral regions. Owing to this curvature the weight of the trunk and head is well distributed, partly in front and partly behind. At its lower end the column itself is supported between the two hip-bones, and through these the weight of the body is transmitted to the legs. The united vertebræ, with the intervening pads of cartilage, form a number of partially movable joints, so that they allow the back to be bent to a certain extent forwards and backwards. Some side to side movement is also possible, especially at the upper end of the column, the *tilting* of the head to one side being due to the movement from side to side allowed by the joints between the cervical vertebræ.

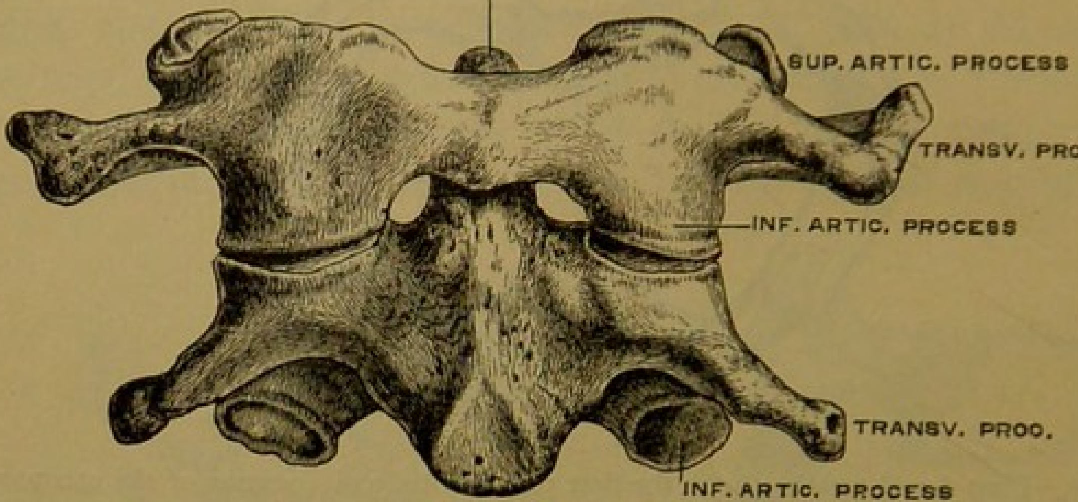



FIG. 18.—Atlas and axis, from before. (D. Gunn.) (*From Quain's "Anatomy."*)

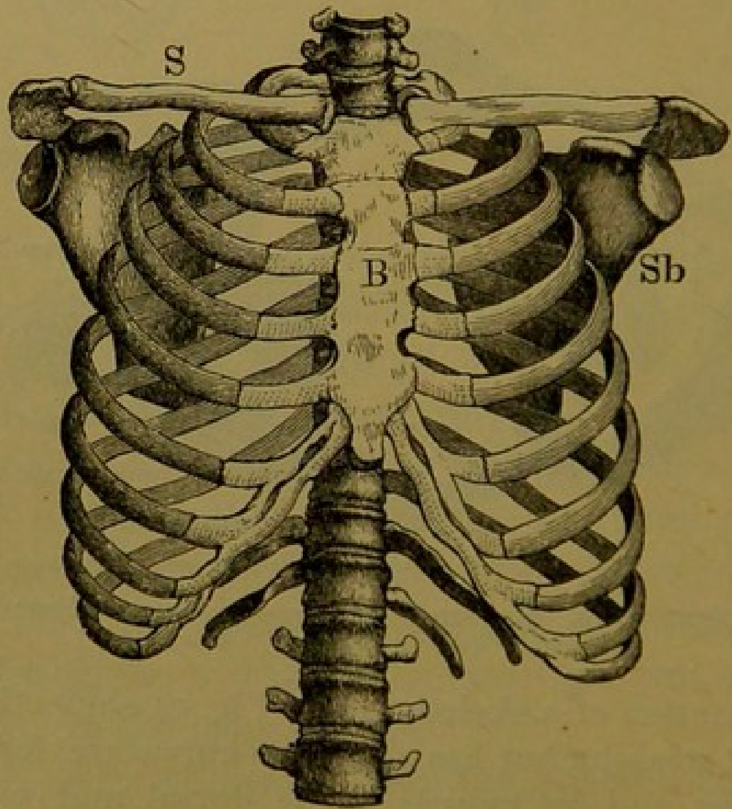



FIG. 19.—Front view of bones of thorax. B, sternum, or breast-bone ; S, clavicle, or collar-bone ; Sb, scapula, or shoulder-blade. (The costal cartilage connecting the ribs with the sternum is of lighter shade.)

**22. The Thorax.**—The bony thorax is a conical cage formed by the twelve dorsal vertebræ at the back, the breast-bone or sternum in front, and the twelve curved bones on each side, called the ribs (Fig. 19). Each rib is jointed behind to the corresponding dorsal vertebra at two places (Fig. 16), so that each dorsal vertebra is united to a pair of ribs. The first seven ribs are connected in front to the sternum by a separate piece of cartilage—**costal cartilage** (Lat. *costa*, a rib). The next three are connected to each other by their own cartilages, and then to the cartilage of the seventh pair. The last two ribs, the eleventh and twelfth, are shorter than the others, and not connected at all in front, terminating in the muscular wall of the belly, and being called the "floating ribs." The ribs do not lie horizontally, but incline downwards somewhat. At the upper end of the thorax the ribs become shorter, the first pair forming but a short arch under the clavicle, or collar-bone. In life the intervals between the ribs, called the **intercostal spaces**, are filled in by flat muscles, called the **intercostal muscles.**

The **sternum** is a flat bone, six or seven inches long, shaped something like a dagger, with the broad end nearest the neck. The cartilages of the first seven ribs meet it on each side, but its lower, narrow end, formed of cartilage, reaches beyond the attachment of the seventh costal cartilage. One end of a collar-bone is articulated to the upper end of the sternum on each side, and passes outward and backward to unite with a process of the scapula, called the acromion process.

**23. The Skull.**—The bones of the head form the **skull,** and the skull rests upon the topmost vertebra, the atlas. It may be divided into two parts, the **cranium** and the **face.**

The **cranium** is the large hollow bony case that contains the brain. It consists of eight bones firmly locked together by saw-like edges called **sutures.**

The eight bones of the skull are—

(*a*) The **frontal bone,** forming the front of the cranium.

(*b*) The two **parietal bones,** forming part of the side-walls and the roof.

(*c*) The two **temporal bones** around the temples.

(*d*) The **occipital bone,** forming the back and a part of the floor or base. Its lower portion is perforated by a large hole called the **foramen magnum**, through which the brain unites with the spinal cord. On each side of this hole is a rounded knob, or condyle, and these fit into two depressions on the atlas, so as to form the articulation that allows the head to *nod* (par. 43).

(*e*) The **sphenoid bone**, forming a part of the base of the skull towards the front.

(*f*) The small **ethmoid bone**, forming part of the base between the sockets of the eyes.

The bones of the face are fourteen in number, and all these,

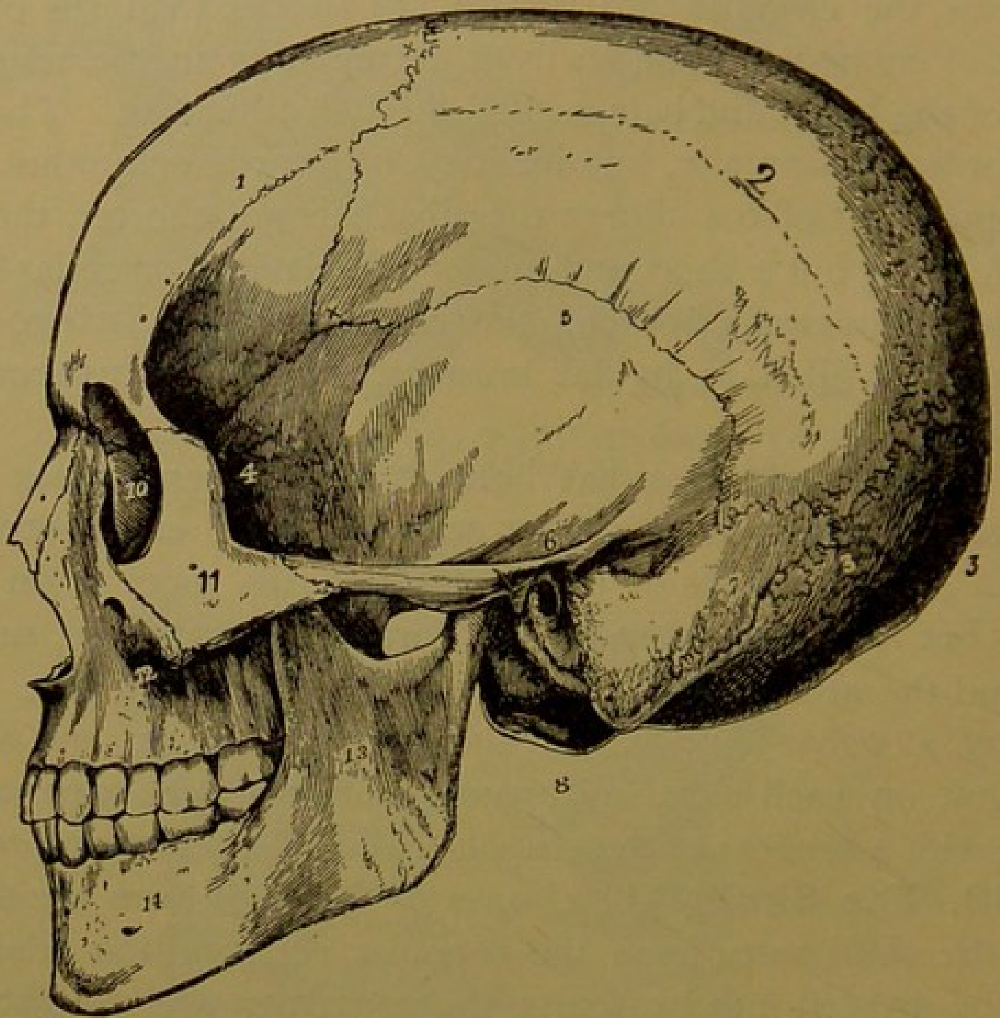



FIG. 20.—Side view of the skull. 1, frontal bone; 2, parietal bone; 3 and 8, occipital bone; 4, wing of the sphenoid bone; 5, 6, and 7, temporal bone; 10, lachrymal bone, in the inner wall of the orbit; 11, malar bone; 12, superior maxillary; 13 and 14, inferior maxillary; XX, coronal suture. (*From Quain's "Anatomy."*)

except the lower jaw or mandible, are firmly united to the bones of the skull. These fourteen bones of the face are—

(*a*) Two **superior maxillary bones**, forming the upper jaw and a portion of the palate, or roof of the mouth.

(*b*) Two **palatal bones**, forming the hinder part of the palate, and united in the middle.

(*c*) Two **small nasal bones** between the sockets of the eyes, and forming the upper hard bridge of the nose.

(*d*) Two small **lachrymal bones** in the inner part of the orbit of the eyes, each grooved for a duct that leads tears from the eyes into the nose.

(*e*) Two inferior **turbinate bones**, one in each nostril chamber above the hard palate.

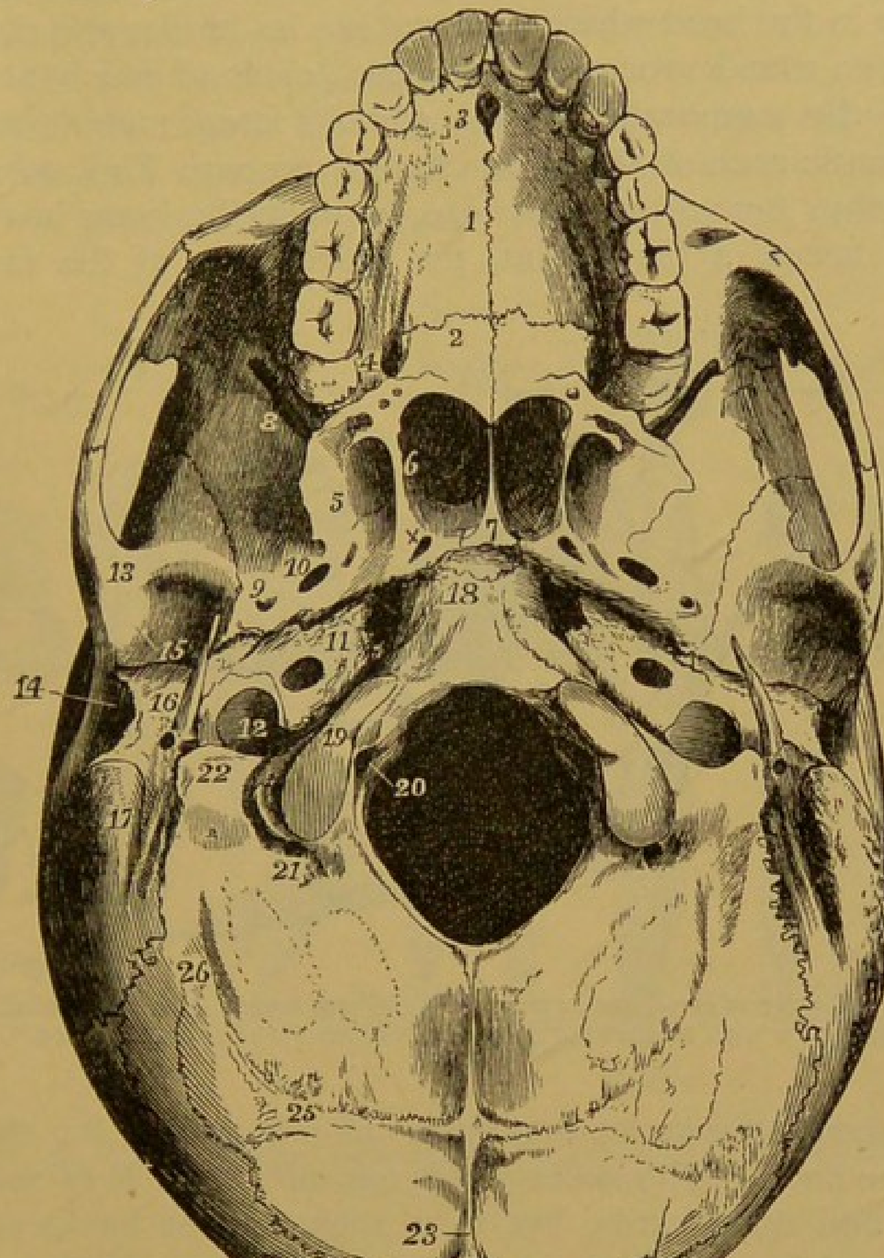



FIG. 21.—Under surface of the skull, showing its various bones, the bony prominences and the foramina (holes) for blood-vessels and nerves. 1, palate plate of the superior maxillary bone; 2, palate plate of the palate bone; 7, vomer bone between the openings of the hinder nostrils; 12, jugular foramen; 14, entrance to ear; 15, glenoid fossa; 19, condyle of occipital bone; 20, is placed in the foramen magnum. (*From Quain's "Anatomy."*)

(*f*) One small **vomer bone**, forming a middle partition in the nasal cavity.

(*g*) Two **malar** or **cheek-bones**, forming the prominences of the cheek and sending an arch (the **zygomatic arch**, or zygoma) backwards to join the temporal bone. The figure 6 in Fig. 21 is on the temporal bone over the root of the zygoma, beneath which is the entrance to the ear.

(*h*) The **inferior maxillary bone**, or mandible, forming the lower part of the chin and lower parts of the cheeks. This is the only bone in the head which is movable. Its hinder and upper part ends in two round processes (condyles), each of which fits into a hollow of the temporal bone (the glenoid fossa) under the ends of the zygomatic arch of the malar bone (compare Figs. 20 and 22). There is thus formed on each side, between the lower jaw and the temporal bones, a hinge-joint, the movements of the jaw being

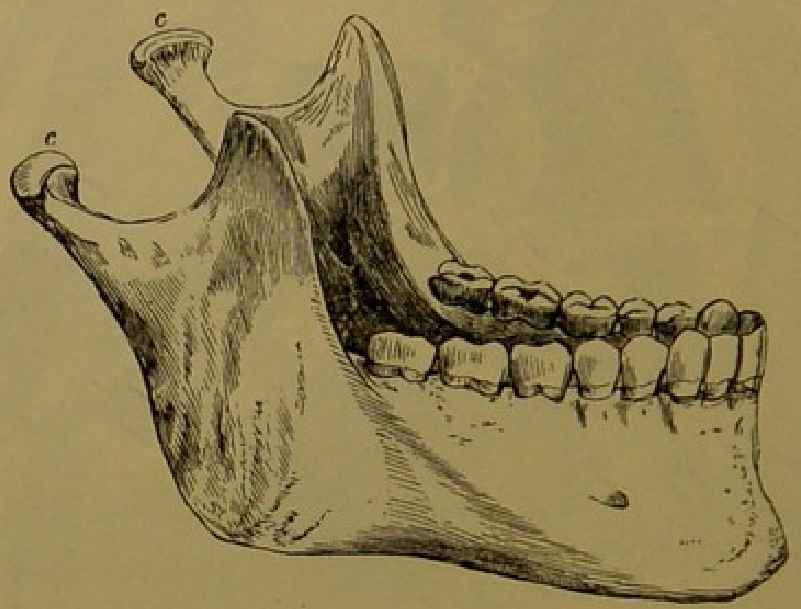



FIG. 22.—The lower jaw-bone or inferior maxillary bone. *c*, the condyles, which articulate with the temporal bones. (*From Quain's "Anatomy."*)

brought about by muscles that form the soft part of the cheek and part of the neck. The lower jaw is not only capable of movement upwards and downwards, but to a slight extent backwards and forwards and from side to side, thus enabling us to bite and grind our food.

The **orbits** of the eyes are the deep sockets in which these organs are placed. Each is formed mainly by the frontal bone above, the upper jaw-bone below, and the cheek-bone at the outer side, and the lachrymal bone at the inner side. A hole at the back leads into the cranium.

**24. The Teeth.**—Fastened in sockets in the upper and lower jaw-bones are the teeth. Each tooth consists of a visible part called the **crown**, a short **neck** embedded in a fold of fibrous tissue covered by mucous membrane and called the **gum**, and one or more **fangs** buried in a bony socket in the jaw-bone (Fig. 22). In the adult the full number of teeth is thirty-two, sixteen in each jaw. The teeth are similar in character in each jaw, and in each half of each jaw; but each side of the jaw has teeth that differ in form, and that are called by different names (see Fig. 23, and examine the mouth of an adult, or your own mouth before a looking-glass). The front teeth, or four central teeth of each jaw (two on each side of the middle line), have sharp chisel-like edges, and are called **incisors**; and on each side of the incisors there is, in each half of the jaw, a longer pointed tooth called the **canine** tooth

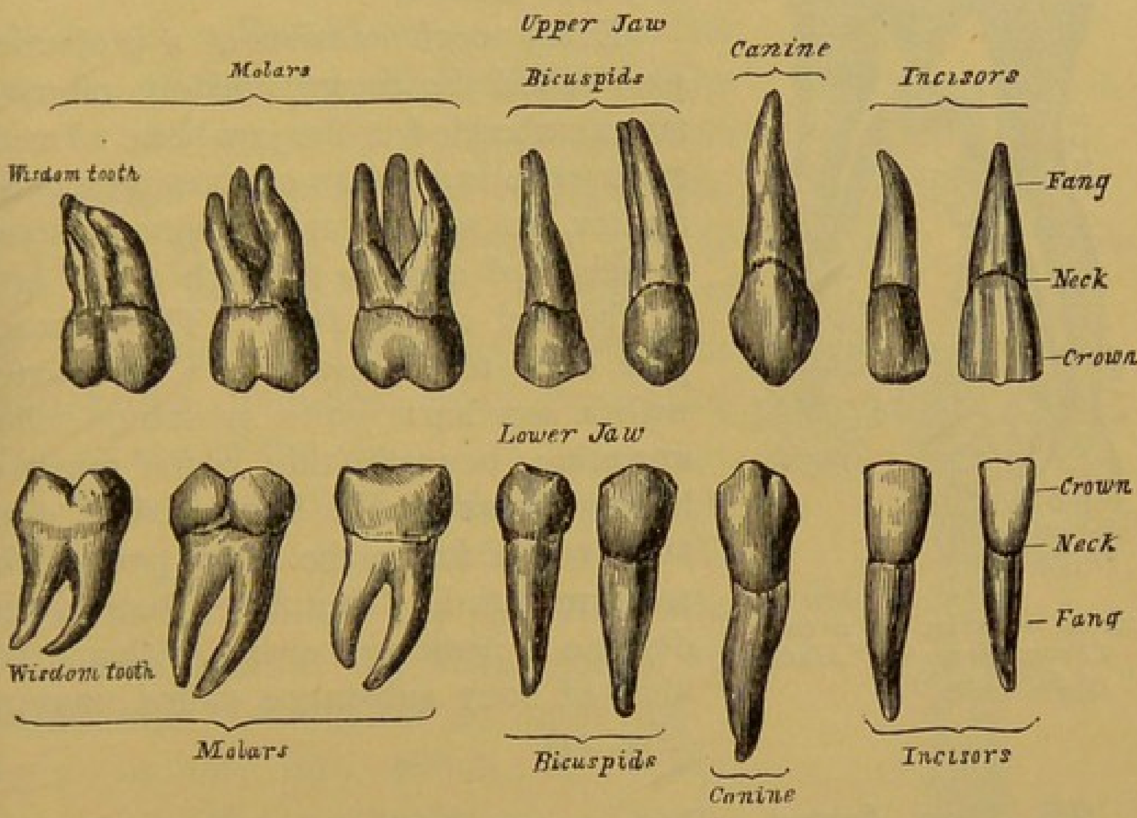



FIG. 23.—The permanent teeth, removed from the jaws. (*From Wilson's "Manual of Health Science."*)

(Lat. *canis*, a dog). The two upper canine teeth are sometimes called the "eye-teeth." Behind the canine teeth on each side are teeth with two cusps or points, called the **bicuspid** or **pre-molar** teeth. Behind the bicuspid teeth on each side are broad teeth with four or five cusps, which are called **molar** teeth. The last of the molars, or grinding teeth, does not often appear until after the twentieth year, and these last molars are known as **wisdom** teeth.

The following table, or dental ormula, tabulates the number and arrangement of the teeth, the initials indicating the kind of teeth, those of the upper jaw being written like the numerator of a fraction, and those of the lower jaw as the denominator, while a dash or thin line separates the teeth of each half of each jaw:—

$$I\,\frac{2-2}{2-2},\ C\,\frac{1-1}{1-1},\ P\,\frac{2-2}{2-2},\ M\,\frac{3-3}{3-3} = 32.$$

The teeth above described are known as the permanent teeth, for they displace and follow a set of teeth that appear in early life, known as the **milk** teeth. The milk teeth are only twenty in number, as they do not include any true molars.

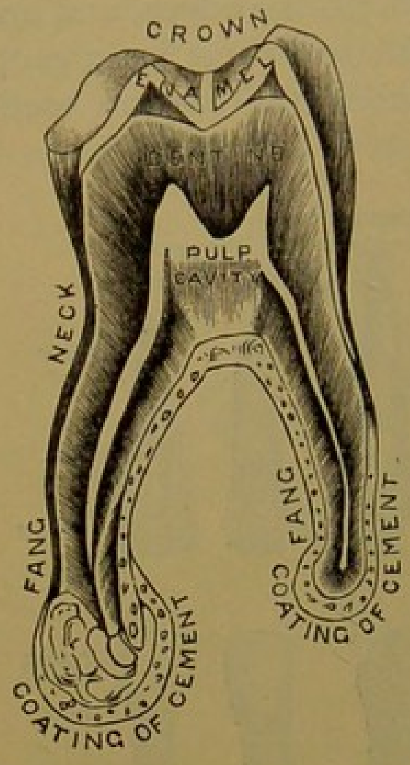


FIG. 24.—Section of a tooth. (*From Barnett's "Making of the Body."*)

Every tooth consists of a projecting part called the crown, and one or more fangs embedded in the jaw-bone. Inside each tooth is a hollow containing a pulpy matter, to which are supplied blood-vessels and a nerve through a tiny hole at the end of the fang. The exposed part of a tooth, the crown, is coated with a very hard white substance called **enamel**; beneath this is the mass of hard substance, like bone, called **dentine**, which forms the main part of the solid material. The fang part of the dentine is, however, covered with another kind of bony substance called **cement** (Fig. 24).

**25. The Arms.**—Each upper limb, or arm, consists of shoulder, upper arm, forearm, wrist, and hand. The bones of the shoulder are the **clavicle**, or collar-bone, and the **scapula**, or shoulder-blade, and the two together form the **shoulder girdle.** The **clavicle** is a long bone shaped like an italic ~ that passes from its articulation with the top of the sternum outwards to a process of the scapula (Fig. 19), as may be readily traced on your own body. It serves to keep the shoulders from falling forward. The **scapula** is a flat, triangular bone with ridges, and lies on the back of the thorax, where it has freedom of motion, as it is not united to either ribs or spine, but is kept in place mainly by muscles. At its outer angle it has a shallow hollow, lined with cartilage—the

**glenoid cavity**—into which the rounded head of the **humerus** is fixed by ligaments to form the shoulder-joint—a ball-and-socket joint that allows free movement in various planes. The **humerus** is the long round bone of the upper arm. As just mentioned, it articulates above by its rounded head with the scapula. Its lower end is spread out to form on the outer and inner sides condyles, with which the two bones of the forearm are articulated. The bones of the forearm are the **ulna** and the **radius.** The ulna is the inner bone of the forearm (little-finger side), and at its upper end is deeply grooved from side to side to articulate with the inner condyle of the humerus. A projection called the **olecranon process** forms the sharp prominence of the elbow.

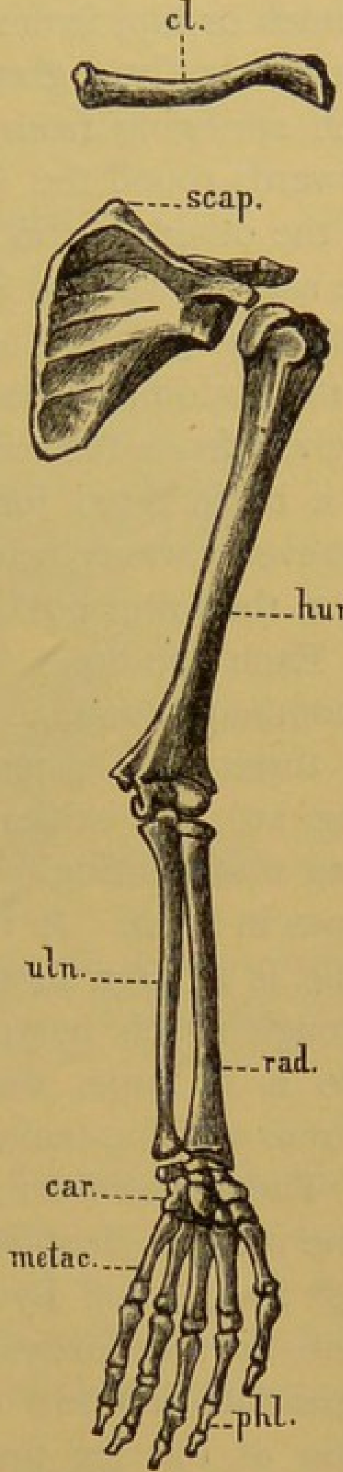



FIG. 25.—Bones of the upper limb. (*From Notter and Firth's "Practical Domestic Hygiene."*)

The radius is the outer bone of the forearm (thumb side), and has at the upper end a shallow cup that articulates with the humerus. Its lower end is enlarged, and contains on its inner side a slight hollow, into which the lower, narrow end of the ulna fits.

The **carpus**, or wrist, consists of two rows of small bones, four in each row, with the upper row united to the radius. These small bones are bound together by ligaments, and allow a slight gliding movement over one another. The second row of carpal bones articulates with the fine bones in the palm of the hand. These are termed **metacarpal bones**, and should be traced from the wrist to each digit. At their outer end they are united by a transverse ligament. The bones of the **digits**, or fingers, called the **phalanges** of the fingers, are united to the metacarpal bones of the palm. There are three phalanges in each finger, and two in the thumb.

**26. The Lower Limbs.**—Each lower limb consists of haunch or hip, femur or thigh, leg, ankle, and foot. The hip-bone, or **pelvic girdle**, on each side consists of a strong bony arch springing from the sacrum and passing downwards and forwards round the lower part of the trunk to meet its fellow on the other side in front. The two hip-bones, therefore, with the sacrum wedged between, form a complete girdle of bones called the **pelvis**, the sloping sides of which receive the weight of the abdominal viscera. The name pelvis (Lat. *pelvis*, basin) is given from the resemblance which this belt of bones shows to a basin tilted forward and with the bottom out. In life, however, various ligaments, from sacrum to ischium, etc., largely fill in the lower outlet (see Figs. 9 and 32).

Each hip-bone is known as the **os innominatum**, or innominate bone, and consists, until about the eighteenth year, of three bones, termed the **ilium**, **ischium**, and **pubes** (Fig. 26), the ischium being the lower portion on which one rests when sitting. A pad of cartilage unites the two pubic bones in front. In the lower and front part of the great hip-bone is a large foramen, or hole, the **obturator foramen**, through which nerves and blood-vessels pass, while on each side is a large, deep cup called the **acetabulum**. The sacrum and hip-bones are articulated together immovably.

The acetabulum receives the round head of the long thigh-bone into its deep socket, and in the living body the head is kept in position by strong ligaments. The **femur**, or thigh-bone, is the longest bone in the body. Its lower end is expanded into two condyles, which articulate with the inner bone of the leg proper. The leg below the knee has two bones, the inner, called the **tibia**, and the outer, called the **fibula** (Fig. 7). The tibia is the larger, and articulates above with the femur to form the hinge-joint, called the knee-joint. Its anterior border is popularly known as the **shin**. In front of the knee-joint, within a tendon of the great muscles from the thigh, lies the small flat bone called the **patella**, or knee-cap (Fig. 7).

The foot, like the hand, consists of three parts: **ankle**, or **tarsus**, **metatarsus**, and **digits** or toes. The tarsal bones are seven, the largest, called the **os calcis**, or heel-bone, projecting backwards to form the heel. The five metatarsal bones succeed those of the tarsus, and form the sole of the foot. To these succeed the fourteen **phalanges** of the toes,

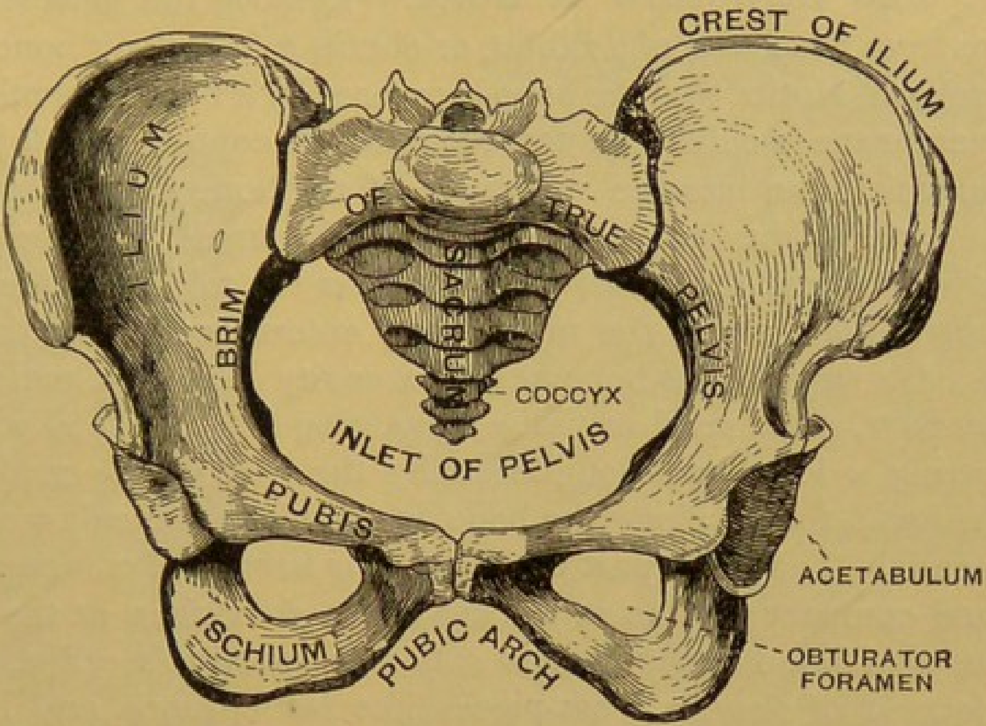



FIG. 26.—The bony pelvis, consisting of sacrum and coccyx, with the two innominate bones, each of the latter being formed of ilium, ischium, and pubes. (A plane from the upper margin of the sacrum to the upper margin of the two pubic bones divides the pelvic cavity into two spaces, the true pelvis below this plane, and the false pelvis above, as the latter really belongs to the abdomen.)

each toe having three phalanges, except the great toe, which has only two. The foot has an arched form, the bones being supported by strong ligaments beneath, and this arched form is peculiar to man. It is thus admirably adapted for supporting the body and furnishing a certain amount of elastic spring.

On comparing an arm with a leg, we see that the skeleton part of the limbs is arranged on the same general plan. Shoulder-blade (scapula) corresponds to hip-bone (os innominatum), humerus to femur, and the lower arm and leg have each two bones. An important difference is that the shoulder-blade is not like the hip-bone, articulated with bones of the trunk, but only united with it by means of muscles. Wrist and ankle have each small irregular bones—eight carpal bones, seven tarsal bones; while hand and foot have each five metacarpal bones and fourteen phalanges. Connected with the arm, however, is the clavicle, or collar-bone, while there is no corresponding piece connected with the leg. At the knee, too, we have the patella, a *sesamoid* bone, *i.e.* small independent bone developed in a tendon, but no corresponding bone at the elbow. The similarities and differences of the joints in the extremities are described in the next chapter.

**27. The Structure of Bone.**—Remove the muscles and tendons from the femur of a rabbit, or obtain a fresh long bone from the butcher. Notice that the bone is covered by a fibrous membrane. This membrane is called the **periosteum.** It contains small blood-vessels, which run into the substance of the bone through minute holes. Strip off the periosteum, and note the small bleeding points on the bone where the vessels enter. Near the middle of the bone is a larger hole, where the main artery enters and the main vein leaves. On sawing the bone across, a cavity is seen in which lies the **marrow**, a soft reddish tissue containing fat and blood-vessels. On cutting a long bone longitudinally the marrow or medullary canal is found to run along the bone, but not into the enlargements at the ends. The outer part of the bone is hard and compact, this hard and compact part being thicker in the shaft than at the ends. The mass of bone at the ends is soft and spongy (see Fig. 34, 1). It is formed of slender cross-pieces like lattice-work, and is said to be *cancellous* (Lat. *cancellare*, to make like lattice-work). The marrow of the central canal of the bone extends into this cancellous tissue. The fibres or bars of this spongy tissue of the bones are arranged in a definite way so as best to support the pressure and strain exerted on the bone. Some of the bars or spicules of bone in the cancellous part are arranged as struts to bear pressure, and some as stays to unite the struts together. This is represented somewhat diagrammatically in Fig. 27. Many bones have no canal with marrow within, but have only a thin, hard, compact outside beneath the periosteum, and spongy or cancellous tissue within. Such are the vertebræ, ribs, and many small bones. In the compact part of the bone the blood-vessels run in very small channels, mostly of microscopic size, which are called after their discoverer, **Haversian canals.** These are best examined in a dry bone, that is, one from which the periosteum, marrow, and other soft tissue has decayed away. A very thin section of dry, compact bone made longitudinally shows under the microscope the Haversian canals, which are seen as fine, branching, and communicating tubes running along the length of the bone, and by the side numerous dark spaces called **lacunæ**, from which the lines radiate (see Fig. 28). In the living bone minute blood-vessels and nerves run in the Haversian canal, and these communicate externally with the periosteum, and internally with the marrow. The lacunæ are spaces between concentric cylindrical laminæ, or sheets of bone fitting into one another round the Haversian canal. In life the

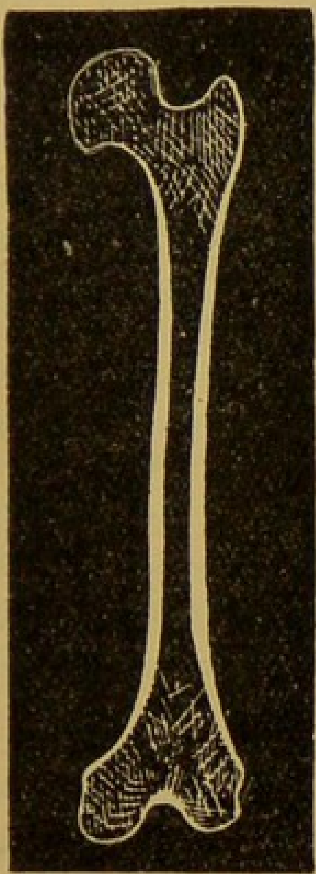


FIG. 27. — Diagrammatic representation of the lattice - work in the spongy head of a femur cut longitudinally. The lighter outside portion indicates the outer compact layer of bone.

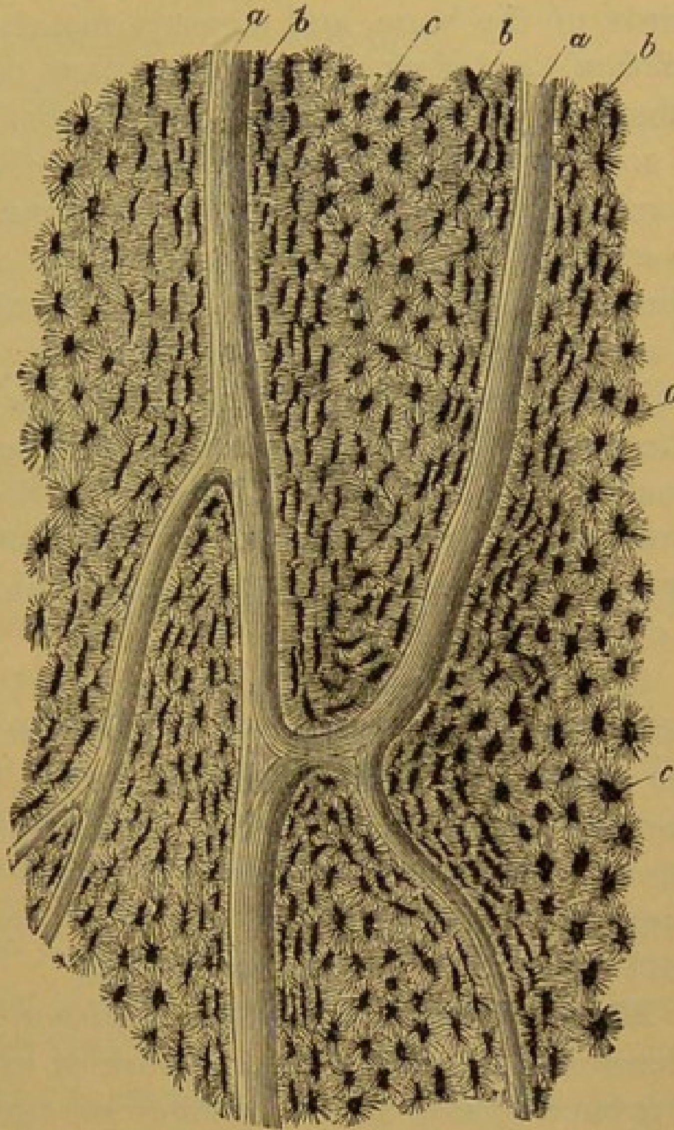



FIG. 28. — Minute structure of bone. Section parallel to the surface from the shaft of the femur magnified one hundred times. *a*, Haversian canals; *b* and *c*, lacunæ. (*From Gray's "Anatomy."*)

lacunæ are occupied by bone-cells. The radiating lines from each lacuna are very minute channels, by which fluid that has exuded from the vessels in the Haversian canal can reach and nourish the surrounding bone. A *cross*-section of compact bone under the microscope shows the cut ends of the Haversian canals, and the cut ends of the several concentric laminated tubes or sheets of bone surrounding them with the lacunæ between the sheets and the radiating canaliculi. The smallest laminated tube is next to the Haversian canal, the others increasing in diameter outwards, four to six in number.

**28. Composition of Bone.**—Bone consists of mineral matter and animal or organic matter in close association. The mineral matter gives hardness and rigidity to the bone, and the animal matter tenacity. The mineral matter forms about two-thirds of the bone, and consists mainly of *calcium phosphate* and *calcium carbonate*. The chief part of the organic matter is a substance that yields **gelatine** on boiling. If a bone is allowed to soak for a few days in a large quantity of dilute acid, the earthy or mineral matter becomes dissolved out of it and the bone becomes so soft and flexible that it can be bent and twisted into any shape. The reader should prepare such a **decalcified** bone, as it is called. If a bone be placed on a bright-red fire the animal matter is burnt out, being oxidized into carbon dioxide and water, which pass off. The bone keeps its shape, but is now very brittle, and can easily be crushed into a mass of white ash. Bone ash, as already stated, consists mainly of calcium phosphate and calcium carbonate. The former compound is a source from which the element phosphorus is obtained.

**29. Cartilage.**—Cartilage or gristle is a tough, flexible, and somewhat elastic substance, so that it yields a little to pressure, but recovers its shape when the stress is removed. It has a thin vascular membrane, but the cartilage itself has neither vessels nor nerves. Seen in thin sections it is bluish-white and semi-transparent. There are three kinds of cartilage—hyaline cartilage, white fibro-cartilage, and yellow fibro-cartilage.

**Hyaline cartilage** (Gk. *hualinos*, of glass) shows under the microscope a uniform groundwork or matrix resembling the surface of ground glass, and a number of cartilage cells in this matrix. The cells are nucleated, and are often arranged in pairs or groups of four or eight, for in the growth of cartilage each cell divides into two, and later, each of these two again divides. Hyaline cartilage occurs in the following parts of the body :—the cartilage connecting the ribs to the breast-bone, the cartilage of the nose, the cartilage tipping the ends of the bones at the joints, in the larynx, in the trachea and large bronchial tubes.

**White fibro-cartilage** shows under the microscope a ground-work or matrix of fine, wavy, parallel fibres, in which lie nucleated cells. It occurs as (*a*) connecting cartilage forming the main part of the discs between the vertebræ, (*b*) as discs between the articular cartilages of certain joints, *e.g.* the knee, (*c*) as a rim round the edge of the cup at the shoulder- and hip-joints, thus deepening the cavity.

**Yellow fibro-cartilage** has a matrix of fine, elastic, interlacing fibres, and in this the cartilage cells lie. It is more flexible and elastic than the other kinds of cartilage. It occurs in the epiglottis and parts of the larynx, and also in the outer ear. Cartilage has

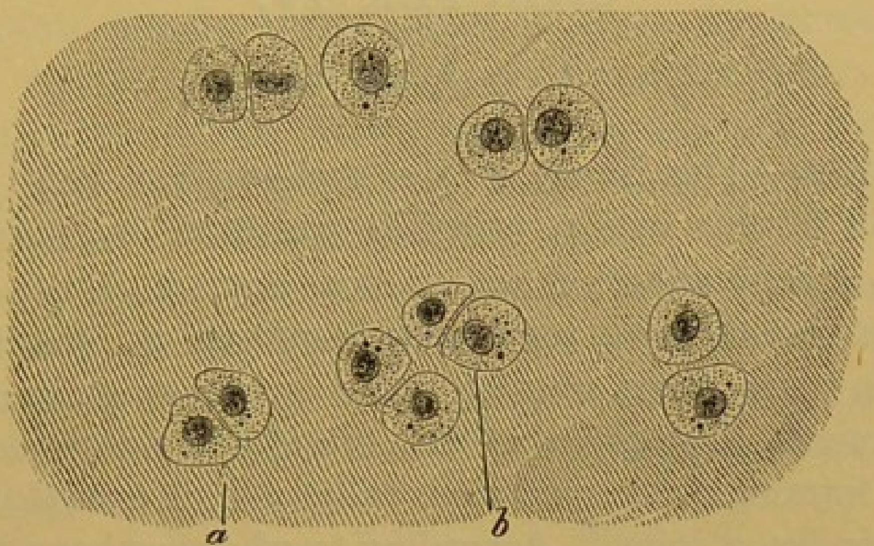



FIG. 29.—Articular hyaline cartilage, showing nucleated cells in glassy matrix. *a*, group of two cells; *b*, group of four cells. (*From Quain's "Anatomy."*)

several important uses. In early life the skeleton is cartilaginous, but this temporary cartilage is in due time replaced by bone. The permanent cartilage of the body fulfils important purposes indicated by its position. Thus it assists in binding bones together, and yet allows a certain degree of movement; it acts as a buffer to deaden shocks; it reduces friction at joints; it serves to keep open and maintain the shape of tubes, as in the trachea; it forms attachments for muscles and ligaments; and it serves to deepen joint cavities. The costal or rib cartilages form an important part of the framework of the thorax, and impart elasticity to its walls.

# CHAPTER IV.

## *JOINTS.*

**30. Joints.**—The bones of the skeleton are kept together by tough, fibrous bands, called **ligaments**, by atmospheric pressure, and by adhesion due to close contact. They are connected in various ways, sometimes admitting no movement at all, but in other cases allowing more or less range and variety of movement. The union of two contiguous bones along with the parts forming the connection is called a joint, or **articulation** (Lat. *articulus*, a joint). According to what has been just said, we may divide joints into **immovable joints** and **movable joints.** As examples of immovable joints may be mentioned the bones of the skull, which are firmly united to one another by interlocking processes and indentations, named **sutures.** Movable joints may be divided into four classes, according to the kind of movement that they allow. The four classes of movable joints are :—

(1) **Gliding joints**, which allow only a small amount of movement. Such joints are formed between nearly flat surfaces, as in the vertebral column, where an elastic pad of cartilage lies between each pair of vertebræ attached to their bodies, and only allows the slight movement that follows its stretching or compression. The articulation of the bones of the wrist are also examples of gliding joints.

(2) **Hinge-joints**, which allow a backward and forward movement in one plane like a hinge, owing to the working of rounded surfaces of one bone fitting into corresponding hollows of the other. Examples of such joints are at the elbow, the knee, the ankle, and those between the phalanges of the fingers and toes.

(3) **Ball-and-socket joints**, in which a rounded surface fits into a cup and allows great freedom of movement in many planes. The joints at the shoulder and hip are examples of ball-and-socket joints.

(4) **Pivot-joints**, where a peg or process forms a pivot round which another bone can turn or rotate. This is best seen in the joint between the atlas and axis vertebræ. There is also at the elbow, besides a hinge-joint between the humerus and the ulna, a pivot-joint between the ulna and the radius.

The last three kinds, where there is considerable movement, are sometimes called **perfect** or true joints, as distinguished from the others that are **imperfect** joints.

Consider *the structures entering into a freely movable joint.*

Besides the bones that come together at a complete joint, and the muscles that move the joint, the following parts enter into the articulation. The ends of the bones that come together are covered with a layer of **cartilage**, the free surface of which is smooth. To aid in keeping the adjoining bones together, tough bands of fibrous tissue, called **ligaments**, pass from one bone to another. One of the ligaments forms a sort of loose bag all round the joint, and is called the capsular ligament, or **capsule.** This capsule is lined by a delicate membrane, called the **synovial membrane** (Fig. 30), for it secretes a viscid fluid like the white of egg, called **synovia**, that serves to lubricate the heads of the bones and to prevent friction. The synovial membrane of a joint is so disposed that it lines the inner surface of the capsular ligaments enclosing the joints, and is reflected over the necks of the bones as far as the articular cartilage. It does not cover the articular cartilage, but a fold

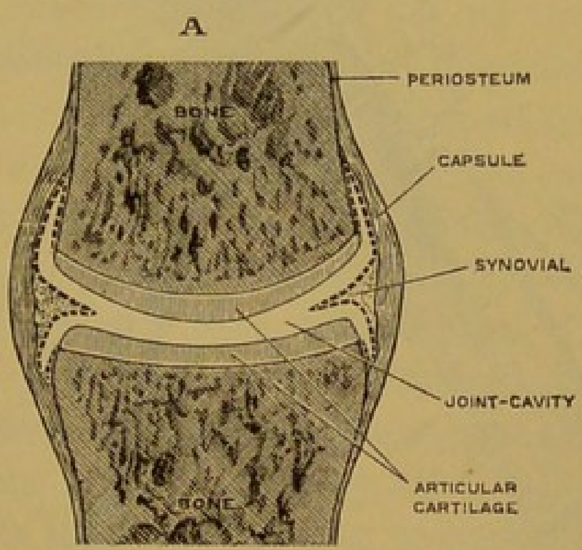



FIG. 30.—Section showing structure of a joint. The dotted line represents the synovial membrane. The articular surfaces are in reality in contact. (*From Quain's "Anatomy."*)

from the capsular lining may pass some distance into the space between the ends (Fig. 30). A few joints have a pad of cartilage between the articular cartilages, and then this inter-articular cartilage is covered on both its surfaces, by synovial membrane. The reader should dissect the shoulder- and knee-joints of a sheep or rabbit. Observe the ligaments and their arrangement, note the thin layer of cartilage tipping the smooth articular surfaces and observe the liquid synovia. The various movements at his own joints should also be carefully examined with the help of the following descriptions :—

**31. The Shoulder-joint.**—The upper end of the humerus terminates in a round head tipped with cartilage, and this head

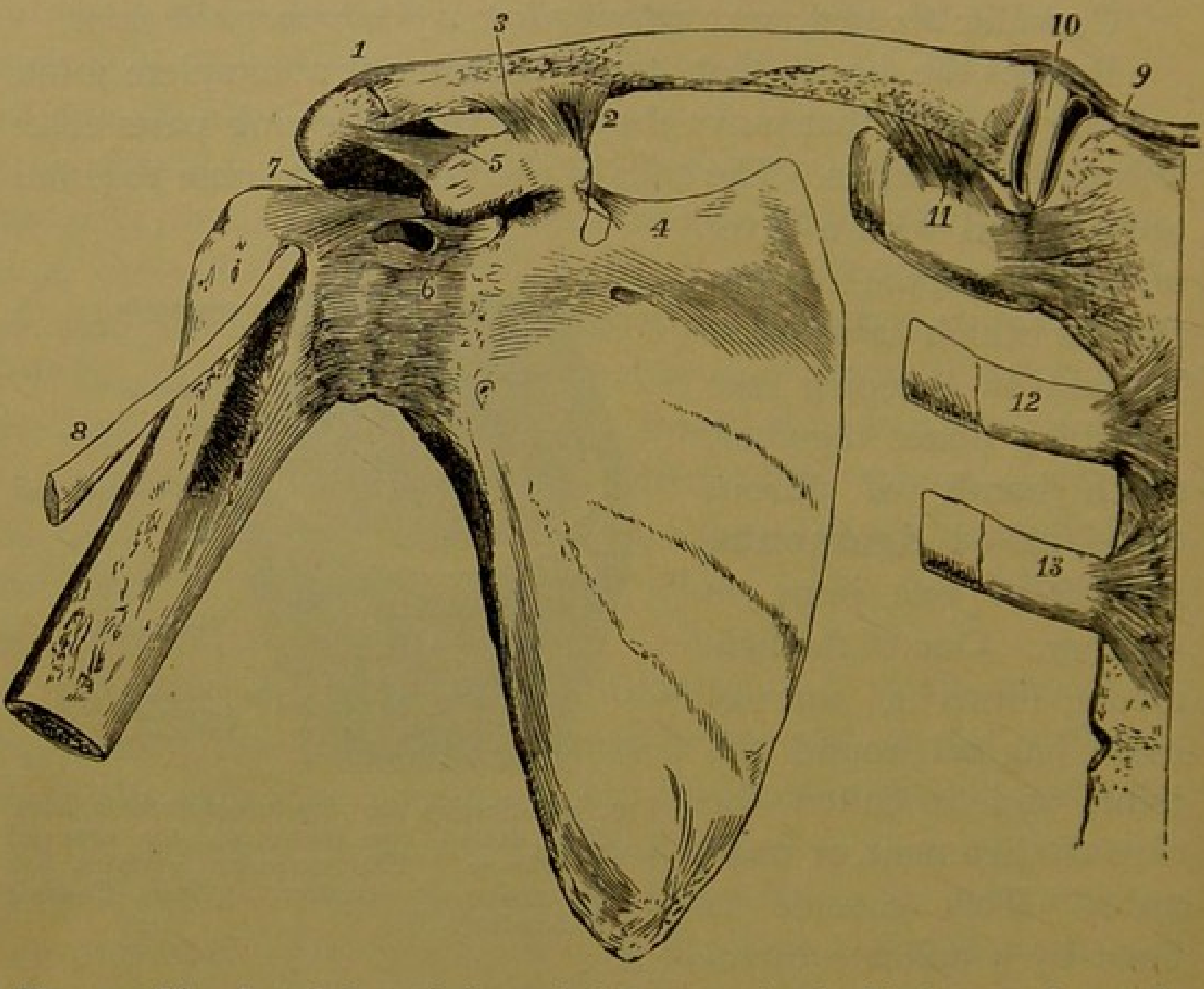



FIG. 31.—View from before of the articulations of the shoulder-bones. 6, capsular ligament of shoulder-joint from humerus to scapula (for head of humerus and glenoid cavity, see Fig. 52); 7, ligament; 8, one of the tendons of the biceps muscle; 1, articulation of clavicle with acromion process of scapula; 2, 3, 4, 5, ligaments; 10, a disc of cartilage at the articulation of the clavicle with the sternum; 9, 11, ligaments; 12, 13, cartilage and small part of the front of the second and third ribs. (*From Quain's "Anatomy."*)

fits into a shallow, cup-like cavity of the scapula, also covered with cartilage (see Fig. 52), and called the **glenoid cavity** of the scapula. The connection thus made is enclosed in a capsular ligament that passes from the head of the humerus to the cup of the scapula, forming a loose bag all round that is lined by synovial membrane. Other band-like ligaments also pass from one bone to another. The whole arrangement forms a ball-and-socket joint. By means of muscles attached to the scapula and clavicle the arm can be raised, lowered, moved sideways at all heights, and the limb swung round in a cone, the circular base of which is the hand and the apex of which is at the shoulder. When the arm is raised into line with the shoulder the humerus comes in contact with the scapula, and in the further upward movement the scapula moves also. It will be seen from Fig. 31 that the articulation of the clavicle with the sternum or breast-bone in front, and with the acromion process of the scapula at the outer end, permits a slight gliding motion of this bone.

**32. The Hip-joint.**—Another example of a ball-and-socket joint is found at the hip. The upper end of the femur has on its inner side a ball-like head, connected by a neck to the main shaft of the bone. This cartilage-tipped head fits into the deep cup of the hip-bone, called the **acetabulum**, the bony cup being further deepened by a rim of cartilage all round it. A round ligament, the *ligamentum teres*, passes from the head to the bottom of the cup inside the joint. The capsular ligament (9 and 10, Fig. 32), lined by synovial membrane and secreting the lubricating synovia, surrounds the joint. Other ligaments pass over the capsule from hip-bone to thigh-bone. By means of muscles in front the leg is flexed at the hip. Large muscles attached behind to the hip-bone straighten it again, a ligament passing from the ilium in front to the hip-bone below preventing the leg from being bent back at the hips. Other muscles move it in other directions, but the circular base of the cone of movement is not so large as in the case of the arm owing to the greater depth of the cup.

The ligaments of the hip-joint serve mainly to check and regulate the movements, and not so much to keep the head in the socket. This is effected by the strong muscles that pass between the lower part of the trunk and the thigh, and by the outer atmospheric pressure transmitted through the soft parts to the air-tight joint. If all the muscles and ligaments of this joint be cut in a dead body, the head of the femur still remains firmly held in the acetabulum by this atmospheric pressure. We may turn it about but not draw it out. On boring a hole

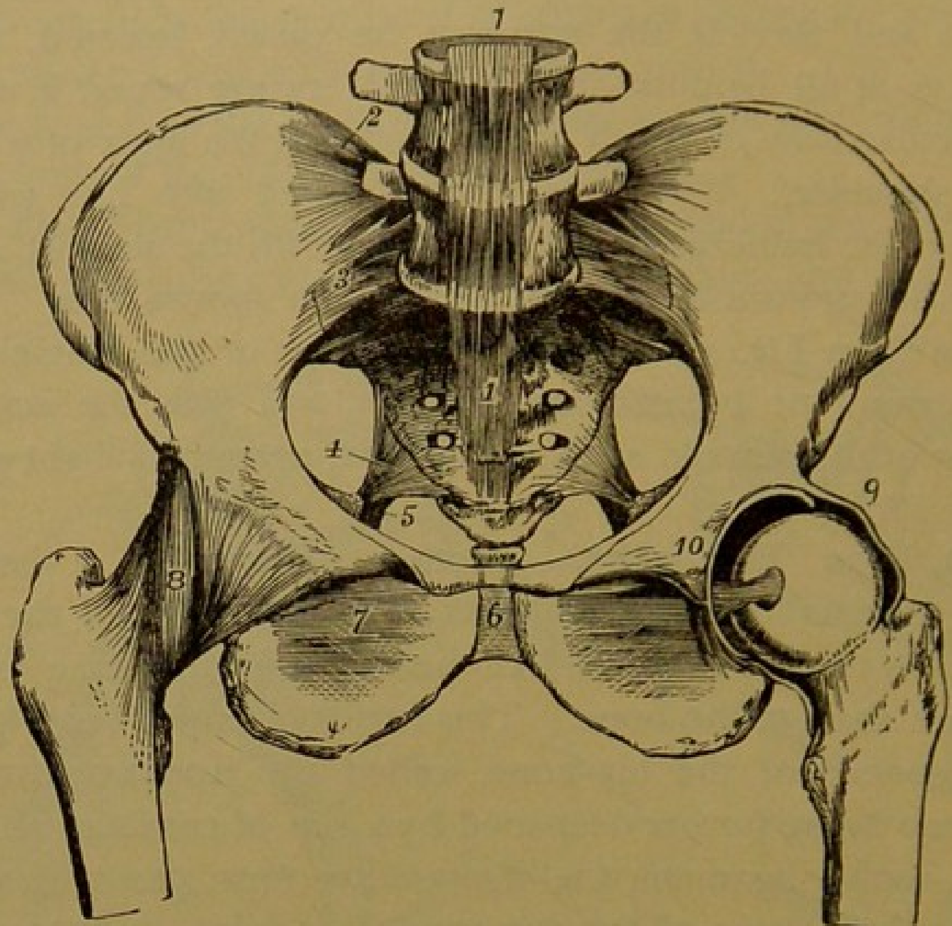


FIG. 32.—Articulations of pelvis and ball-and-socket joint of hip seen from before. See also Fig. 7. 1, ligament of vertebræ passing to sacrum; 2, 3, ligaments from vertebræ to hip-bone; 4, ligament from sacrum across the inlet of pelvis to the ischium; 6, ligament connecting pubic bones; 7, membrane crossing obturator foramen; 8, capsular ligament of hip-joint on right side, on left side the capsular ligament has been removed and the femur turned outwards to show synovial cavity and ligamentum teres; 9, 10, cut edge of capsular ligament. (*From Quain's "Anatomy."*)

into the cup from outside, we let the air into the cavity, the pressure is equalized inside and out and the rounded head comes out.

**33. The Knee-joint.**—The knee-joint is a hinge-joint between the lower end of the femur and the tibia. The fibula, or splint bone, does not enter into this joint, being fastened to the tibia on the outer side just below the knee. The femur swells at its lower end into two condyles, or bosses, forming two articular surfaces that meet and are continued in front (see Fig. 33). On the top of the tibia are two shallow articular surfaces, on which the condyles of the femur rest. These depressions are deepened by two semi-lunar fibro-cartilages on the outer edge of each. Two crucial ligaments in the joint

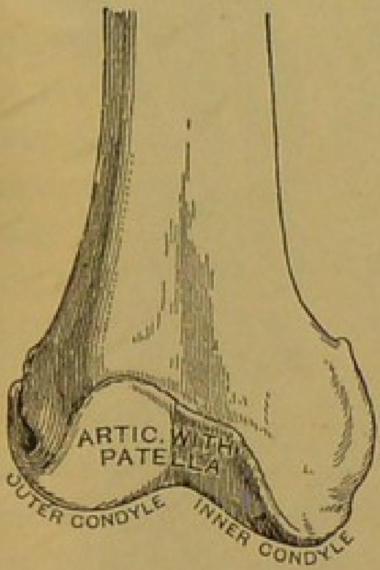



FIG. 33.—Lower portion of the front surface of right femur, showing the two articular surfaces of the condyles, and the articular surface for the patella.

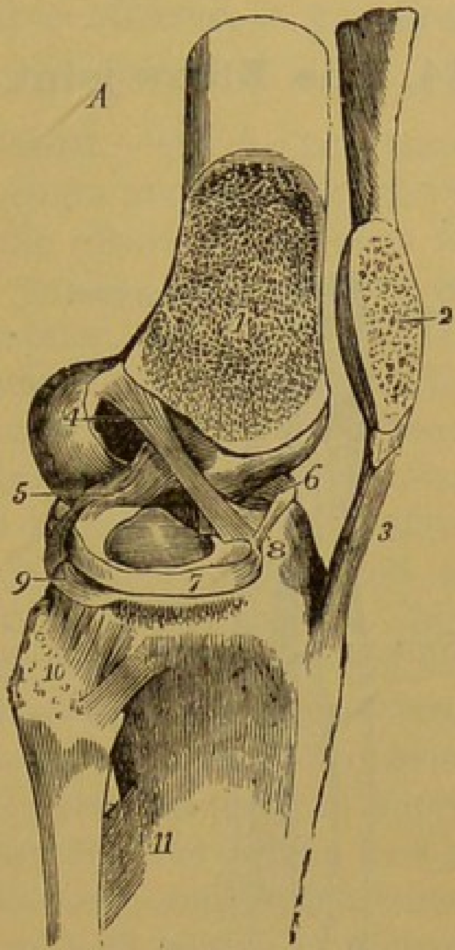



FIG. 34.—Right knee-joint with outer part of condyle of femur and half the patella sawn away. 1, sawn surface of condyle of femur; 2, sawn surface of patella in tendon of extensor muscles from front of thigh; 3, tendon of insertion (patellar ligament) of extensor muscles; 4 and 5, crucial (cross) ligaments; 6 and 7, semilunar fibro-cartilages; 9, part of articular surface of tibia; 10, head of fibula; 11, on tibia. (*From Quain's "Anatomy."*)

cross each other, and besides strengthening the union, prevent the leg from being forced forward beyond a straight line. A capsular ligament encloses the joint, while other band-like, ligaments are found at the back of the knee. The movement of the knee is that of a hinge-joint movement in one planet though there is also some gliding and rolling of the condyles of the femur on the tibia during flexion and extension. The patella, or knee-cap, also shares in the movement at the knee. This triangular bone lies in front in the tendon of the extensor muscle that straightens the leg and that is inserted on the tibia. Its inner surface is smooth, covered by synovial membrane, and plays on the articular surface of the front of the femur when the leg is bent.

**34. The Elbow-joint.**—The elbow-joint is a hinge-joint.

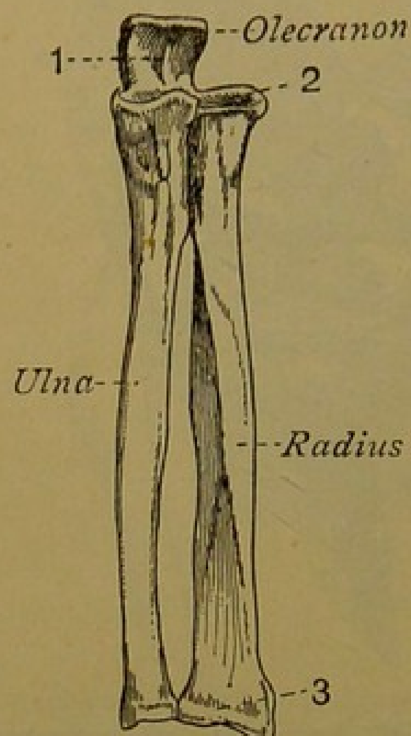



FIG. 35.—Front view of radius and ulna. 1, cavity in olecranon process for humerus; 2, cavity in radius for humerus; 3, surface of radius for wrist-bones.

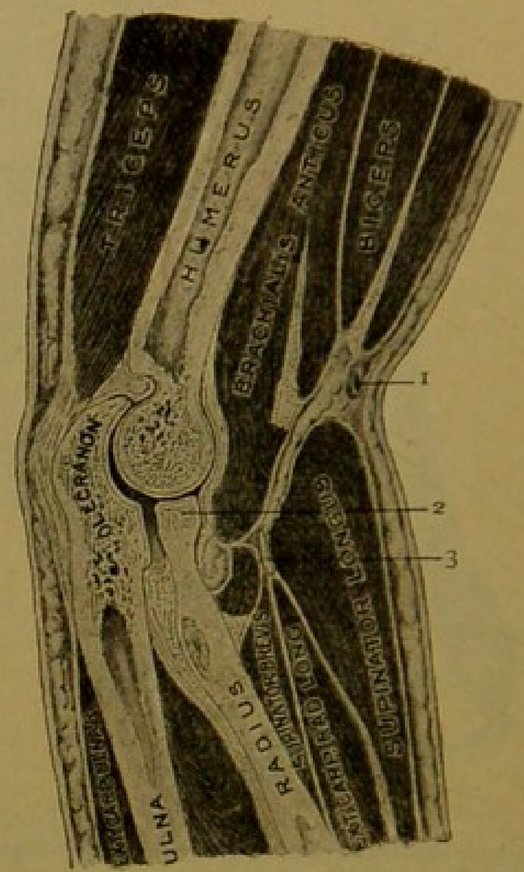



FIG. 36.—Longitudinal section of the elbow-joint. 1, cut end of vein; 2, head of radius; 3, radial nerve. (*Reduced from Gray's "Anatomy."*)

The humerus terminates below in a broad rounded end divided into two parts by a ridge, and the joint is formed by the ulna articulating with the inner side of the humerus and the radius with the outer side. The upper end of the ulna rises up behind the humerus, and is called the **olecranon process.** This process forms the prominent part of the elbow, and its interior surface is concave at the side and below. The rounded end of the humerus fits into this concavity of the ulna, and also articulates with the shallow cup at the head of the radius (Fig. 36). The bones at the elbow are enclosed in a capsule strengthened by other bands of ligament. The joint thus formed between humerus above and the ulna and radius below, allows of flexion and extension only, the two bones of the lower arm both gliding on the articular surfaces at the lower end of the humerus. How this movement is effected is explained in par. 43, Fig. 52.

**35. Pronation and Supination.**—Of the two bones of the forearm the ulna is large at the elbow and small at the wrist, while the radius is rather small at the elbow and massive at the wrist. The ulna can only move in flexion and extension of the arm, but the radius has another motion, for it can roll round the ulna in part (see Fig. 7 and compare the relative positions of these two bones in the left and right arm). In the former the palm is to the front and the bones are parallel with the thumb outside; in the latter, the back of the hand is seen, and the radius lies across the ulna. It is useful to note that the lower end of the radius is always on the thumb side of the hand. To illustrate these positions let the reader place the lower arm on the table with the palm up. This position of the hand is termed **supination,** and the two bones of the forearm lie side by side, the radius being on the outside. Keep the shoulder-joint fixed and turn the hand over until its back is upwards, and notice that the radius has partly rolled round the ulna so as to bring its lower end on the inner side of the ulna. The position of the hand with the palm downwards is **pronation.** Put the hand again in supination and notice the radius revolve back and carry the hand with it. Pronation and supination of the hand are due to the articulations of the radius and the ulna with each other at the elbow and wrist. At the elbow the head of the radius is kept in position by a ring-like ligament, and this head has on its edge a smooth articular surface that moves against a concave face on the outer side of the ulna. At the broad lower end of the radius, which alone articulates with the wrist-bones, there is a shallow surface on the inner side of the radius that articulates with a covered surface at the lower end of the ulna. When the hand is turned over from supination to pronation, the ulna remains fixed, while the upper end of the radius turns on its own axis against the side of the ulna, and the lower end turns round the lower end of the ulna, which serves as its pivot. The radius thus describes a half-circle, and is brought obliquely across the front of the ulna. The lower articulation of the radius and ulna thus forms a **pivot-joint**, with the ulna as the pivot. Another instance of a pivot-joint is the articulation of the axis and atlas, the peg of the axis serving as a pivot in the turning of the head from side to side (see par. 21, Fig. 18).

**36. The Wrist-joint and the Joints of the Hand.**— The movements at the wrist consist of a number of articulations,

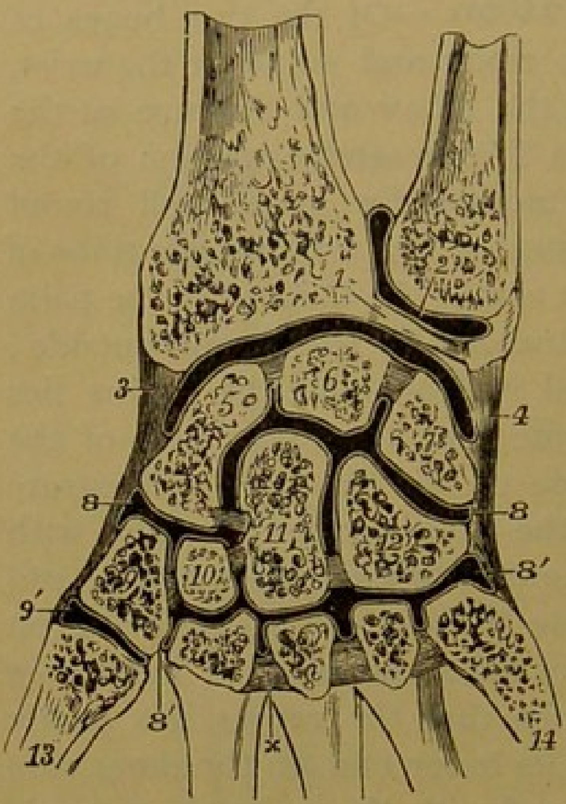



FIG. 37.—Section showing the articulations at the wrist. 1, ligament of fibro-cartilage; 2, synovial cavity at lower radio-ulnar articulation; 3 and 4, lateral ligaments; 5, 6, 7, 9, 10, 11, 12, the carpal or wrist-bones; 8 and 8′, the general synovial cavity; 9′, the separate synovial cavity of the articulation of the first metacarpal bone with a carpal bone (the trapezium); X points to one of the ligaments; 13, first, and 14, fifth metacarpal or palm bones. (*From Quain's "Anatomy."*)

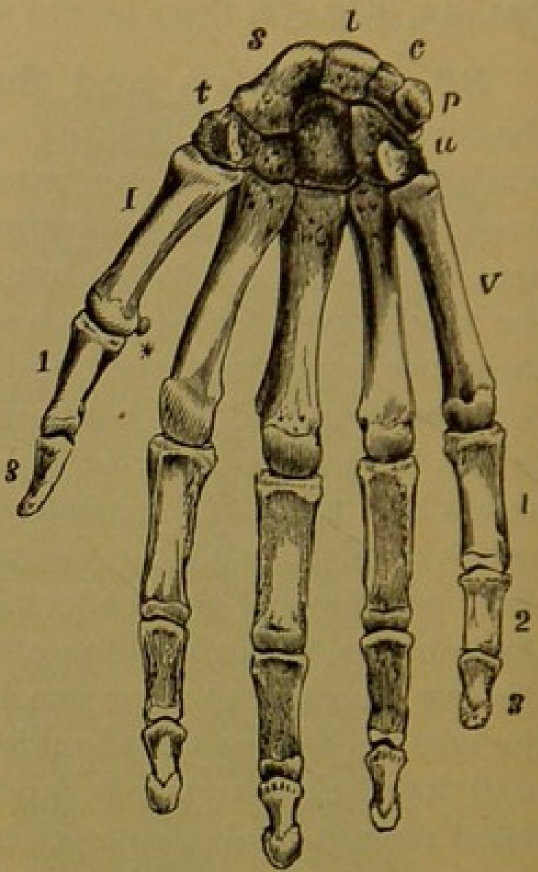



FIG. 38.—Bones of wrist and right hand from before. *s, l, c, p, u, t*, carpal bones; I to V, metacarpal bones; 1, 2, 3, the first, second, and third phalanges of the little finger; similarly for the other three fingers; 1 and 3 on other side the two phalanges of the thumb. (*From Quain's "Anatomy."*)

partly between the lower end of the radius and the three adjoining carpal bones, partly between the carpal bones themselves, and partly between the second row of carpal bones and the metacarpal bones in the palm of the hand. The ulna takes no part in the wrist-joint, as it is shut off by a stout ligamentous band (Fig. 37, 1). The lower surface of the radius is concave both from back to front and from side to side, and the three adjoining carpal bones furnish corresponding convex surfaces. There is thus at the lower end of the radius movement backwards and forwards and from side to side, so that there is here a double hinge-joint. Among the carpal bones themselves, which are bound together by various ligaments, with synovial cavities between (Fig. 37), there is a certain amount of gliding motion. Some movement can also take place between the second row of carpal bones and the metacarpal bones of the four fingers below. Between the metacarpal bone of the thumb and the wrist-bone, called the trapezium (9′, Fig. 37), to which it is articulated, there is a kind of double hinge-joint, each bone being concave and curved in directions at right angles to one another, like a saddle, so that the articular surfaces are saddle-shaped, and the joint sometimes called a **saddle-joint.** There is thus great freedom of movement at this joint, for the thumb can not only be flexed and extended, but can be carried outwards and inwards with a sweeping motion. By slightly bending the fingers the front surface of the thumb can be brought by flexion into contact with each finger-tip. The joints at the "knuckles," between the metacarpal bones of the hand and the first phalanges, are of the nature of ball-and-socket joints, as some amount of rotation is possible. The one joint of the thumb and the two joints of the fingers are simple hinge-joints.

**37. Joints of the Ankle and Foot.**—The ankle-joint is formed by the tibia and fibula above, and a bone of the ankle,

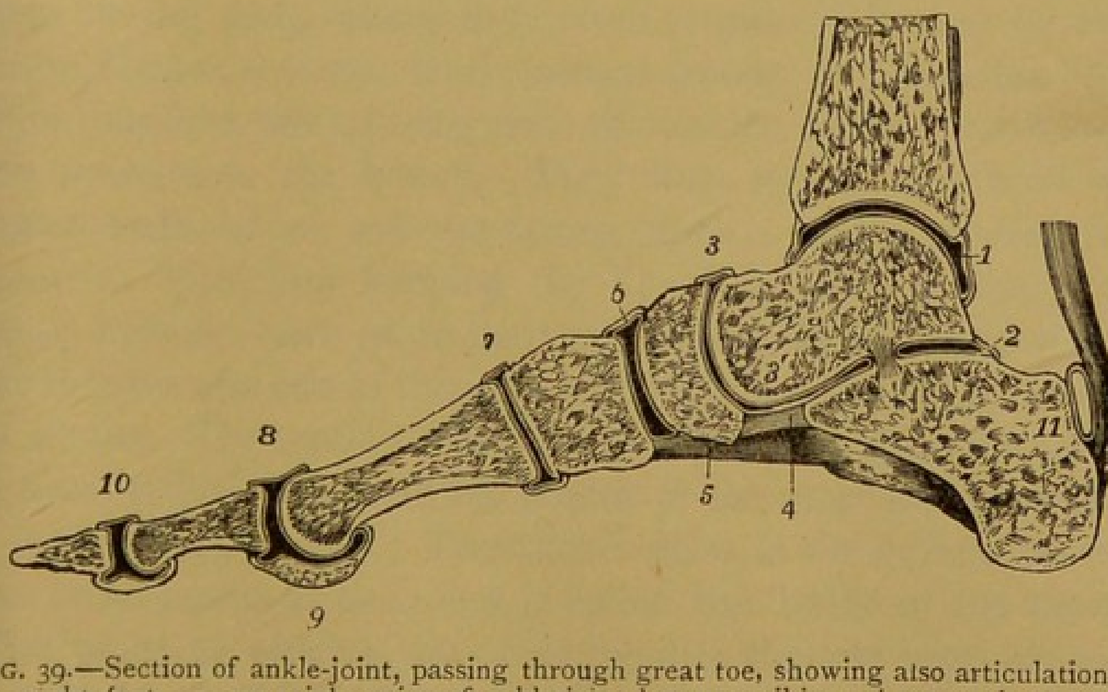



FIG. 39.—Section of ankle-joint, passing through great toe, showing also articulations of right foot. 1, synovial cavity of ankle-joint between tibia and astragalus; 2, 3, 6, 7, 8, 10, articulations; 4 and 5, ligaments; 11, on heel-bone (os calcis), to which the tendon of Achilles is attached, with synovial bursa between. (*From Quain's "Anatomy."*)

called the **astragalus**, beneath. The tibia furnishes the greater part of the articular surface, and is the bone that transmits the weight of the body to the foot. The fibula lies to the outside of the thicker tibia, and coming a little lower than the tibia, forms a prominence at the outside of the ankle, known as the *external malleolus.* A prominence on the inside, formed by the tibia, is called the *internal malleolus* (Fig. 7). A section of the ankle-joint from before backward is shown in Fig. 39. The joint is a hinge-joint, for the foot can be flexed by being bent upwards in front towards the leg, and it can be extended by being depressed toward the line of the leg.

Seven bones form the tarsus, or ankle, and these, together with the metatarsal bones, form the arch of the foot. Between these bones there is but a little gliding movement. The articulations between the metatarsal bones and the phalanges are all like those of the fingers. Each is formed by the rounded head of the metatarsal bone fitting into the cavity at the beginning of the first phalanx. The great toe cannot be opposed to the other toes in the same way as the thumb can be opposed to the fingers. The articulations in the toes are simple hinge-joints, but with a small range of movement.

# CHAPTER V.

## *MUSCLE AND MOVEMENTS OF THE BODY.*

**38. Muscles.**—The skeleton of the body, made up of numerous jointed bones and cartilages, not only acts as a framework of support, but the bones furnish points of attachment for the muscles that form what is commonly termed flesh. These muscles are really the agents that bring about movements, the muscles using the bones as levers. The mass of flesh forming the thigh, for example, consists of a number of muscles separated from each other by a delicate fibrous sheath of connective tissue, and each one is bound to those lying near it by sheaths of the same substance.

Muscles are of various shapes. The prominent ones of the limbs are usually spindle-shaped, and thus thicker in the middle than at the ends, where they often terminate in one or more white, fibrous, inelastic cords termed sinews, or **tendons.** Tendons thus form the tapering ends of muscles, and serve to connect the muscles to the bones. They must not be confused with **ligaments,** which are the strong fibrous bands passing from bone to bone, and keeping the bones in place at the joints. Some muscles have more than one tendon at one end, while in other cases one end of the muscle itself is fixed to the periosteum of a bone. The tendon (or tendons) at one end of such a muscle is fixed to one bone, and the tendon at the other end to another, a joint lying between. The thicker mass of the muscle between the attachments at each end is called the **belly** of the muscle. The point at which a muscle is fixed to the less movable bone is called the **origin** of the muscle, while the point of attachment to the more movable bone or part is called the **insertion** of



D

the muscle (Fig. 40). Thus the biceps muscle that bends the arm at the elbow-joint has its origin on the scapula, and is inserted on the radius (see Fig. 52). When it contracts the muscle shortens and thickens, pulls on the tendons, and one of these transfers the motion to the movable bone.[1] In some

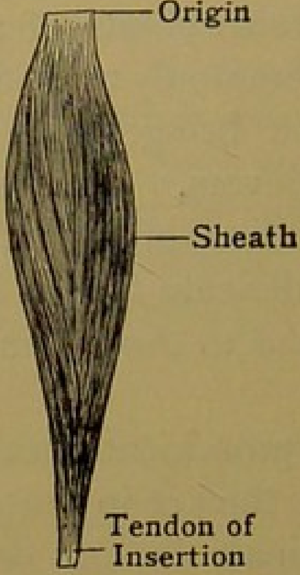



FIG. 40.—A typical muscle, the muscular tissue passing at each end into tendinous tissue.

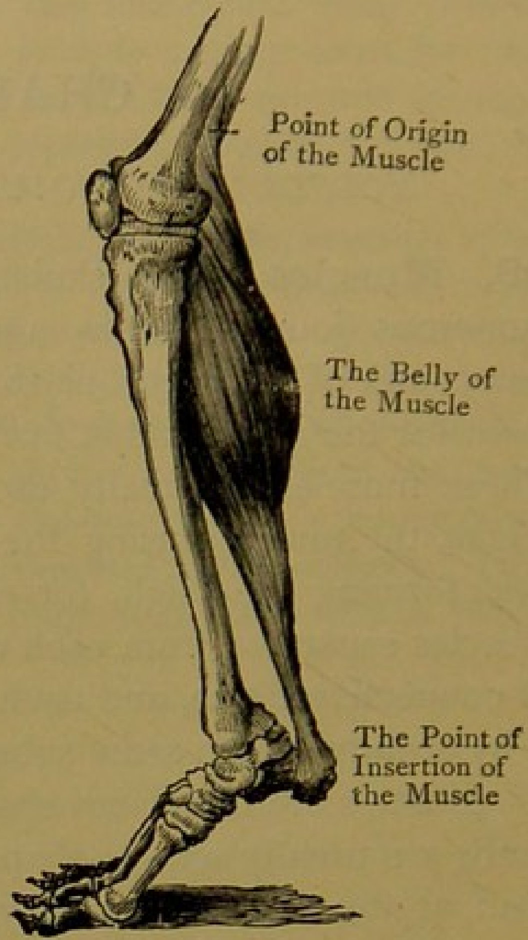



FIG. 41.—Gastrocnemius muscle raising the body on the toes.

cases the muscles are arranged in broad sheets crossing or encircling a cavity. The thin muscles forming the front of the wall of the abdomen and the arching diaphragm separating the thorax and abdomen are examples of such muscles. When such sheets of muscle contract they compress the cavity towards which their concave surface is turned. Examples also occur of

[1] To prevent friction where tendons move over bony surfaces, the tendons are often enclosed in surrounding **synovial sheaths**, the synovia lubricating the sheath in which the tendon glides. Small closed sacs containing synovia (**synovial bursæ**) are also found in various positions between parts moving on one another, as between a tendon and a bone (Fig. 39, 11).

muscular fibres arranged circularly so as to form a ring round a tube or orifice of the body, such muscles being called **sphincters** (Gk. *sphincter*, a binder).

Muscles are generally divided according as they do or do not work under the influence of the will into **voluntary muscles** and **involuntary muscles.** Most of the voluntary muscles have attachment to bones of the skeleton, while involuntary muscles often form part of the coat of various tubes in the body.

**39. Muscular Tissue.**—A muscle consists of a substance called muscular tissue, bound together by a web of connective tissue, and it has nerves to stimulate it, and blood-vessels to nourish it. Muscular tissue is of two kinds, called respectively **striped muscular tissue** and **unstriped muscular tissue.** The voluntary muscles consist of the first kind of tissue, and the involuntary muscles of the other kind. An ordinary skeletal muscle presents to the naked eye a fibrous appearance, and by careful examination such a muscle may be divided into small longitudinal bundles termed **fasciculi,** each fasciculus being covered by a sheath of membrane which is derived from the sheath known as **fascia,** which invests the whole muscle. Each fasciculus, or bundle, of muscular tissue is just large enough to be seen by the naked eye, and is found when examined under the microscope to consist of a number of fine muscular fibres running lengthwise and fitting together along the length of the bundle. Each single fibre consists of a semi-fluid substance termed muscle plasma, and is surrounded by a transparent elastic sheath called the **sarcolemma** of the fibre. Such a fibre is on the average about an inch in length, but only $\frac{1}{400}$ inch in diameter, and when seen under the microscope shows alternate dim and light cross stripes, and this microscopic appearance gave rise to the name striped or **striated muscular tissue** (see Figs. 43 and 44).

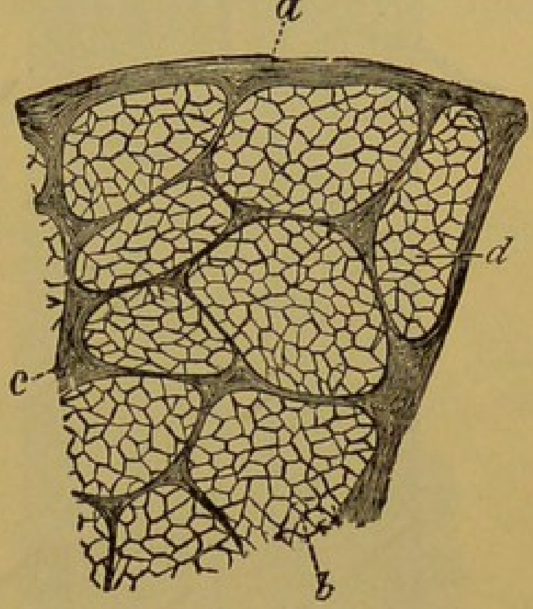



FIG. 42.—Cross-section of a skeletal muscle, showing cut ends of nine fasciculi, and cut ends of numerous fibres magnified fifty times. *a*, external sheath or fascia of muscle from which partitions as *c* pass in between the fasciculi; *b*, fasciculus; *d*, a single muscular fibre. (*From Gray's "Anatomy."*)

The various membranes that penetrate between muscles and their parts convey small arteries that break up into fine capillaries between the fibres. The capillaries do not enter the muscle fibres, for the nourishment that the latter need passes in solution by diffusion through the fine walls of the capillaries, the fluid so separated from the blood being called **lymph** (par. 68). The capillaries between the fibres reunite into veins that pass away from the muscle. Nerves and nerve fibres also pass to the muscles in a similar way, the nerves dividing until a single nerve fibre passes to

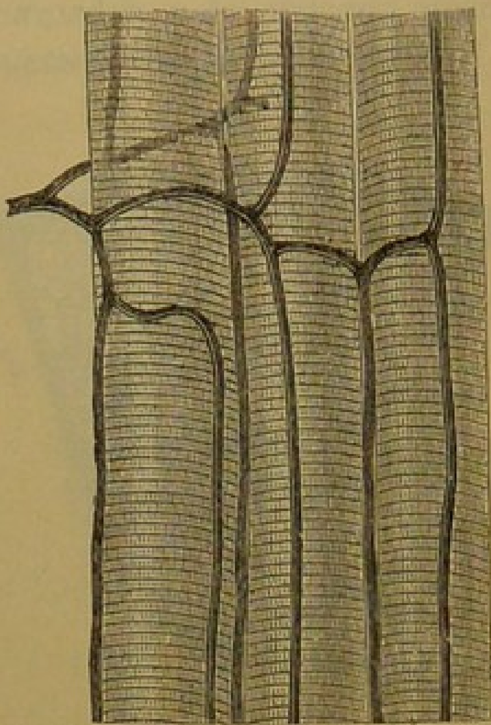


FIG. 43.—Capillary blood-vessels running over and between muscle fibres, as seen under the microscope (portions of three striped fibres are shown), with their sheaths of sarcolemma. (*From Quain's "Anatomy."*)

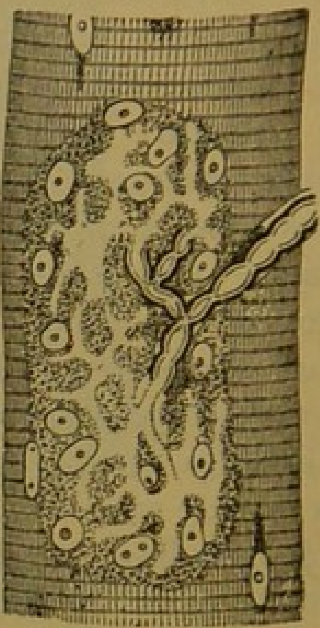


FIG. 44.—End-plate or motor nerve-ending on muscular fibre of a lizard. (Kühne.) (*From Quain's "Anatomy."*)

each muscular fibre, on which it spreads out to form what is known as an **end-plate.** As already stated, many skeletal muscles consisting of striped muscular tissue terminate in tendons, formed in part by the union of the connective tissue sheaths, and in part by a change of the substance of the fibres themselves into similar tissue (Fig. 40). Sometimes a muscle ends abruptly in a broad, blunt end of connective tissue fibrils. Tendons thus consist of dense connective tissue fibrils arranged parallel to one another. They are firmly fastened to the periosteum of a bone, and possess great tensile strength.

We shall learn later that nerves consist of bundles of fine nerve fibres. The motor nerves passing to voluntary or striped muscles pass in between the muscular bundles, break up into branches, one fibre at last going to each muscular fibre, where it terminates after piercing the sarcolemma in an expansion or cushion of protoplasmic substance termed an **end-plate** (Fig. 44). In the involuntary or unstriped muscular tissue the nerve fibres terminate as a rule in a fine plexus or network. Muscles have also sensory or afferent fibres that carry impulses away from the muscle to the central nervous system, as well as fibres that pass to the coats of the small arteries.

**40. Unstriped or plain muscular tissue** consists of fibres that do not show alternate light and dark striations, the fibres

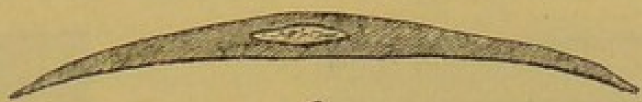



FIG. 45.—A spindle contractile fibre-cell of plain or unstriped muscular tissue, showing nucleus, *c*.

being much shorter than those of striped muscular tissue. Each fibre of this tissue is, in fact, a spindle-shaped cell with an oval nucleus. Plain muscular fibres are never attached to bones. They are found along with other tissues in the walls of the alimentary canal, round the walls of blood-vessels, in the bladder, and in the ducts of glands. The involuntary muscular tissue receives its nerve supply from the sympathetic system, and contracts but slowly and feebly compared with the action of the voluntary muscles.

The cardiac muscular tissue (Gk. *kardia*, the heart), of which the heart largely consists, differs from both striated and plain muscular tissue. Each fibre is a short quadrangular cell without any sheath, but showing faint transverse striation. The fibre cells are arranged end to end in columns, and have generally branches uniting with neighbouring cells. They are bound together in bundles by connective tissue, which convey blood-vessels and nerves to the heart itself. Though showing faint striæ, cardiac muscle is involuntary.

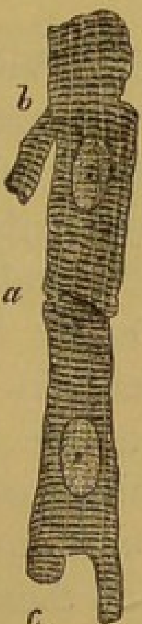
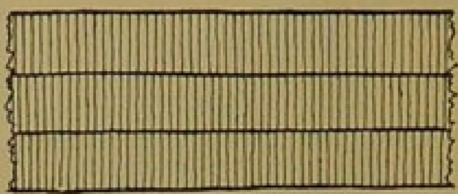



FIG. 46.—Two muscular fibre-cells from heart. *a*, line of junction between two branching cells, *b* and *c*. (*From Quain's "Anatomy."*)

**41. The Contraction of Muscle.**—A voluntary muscle on being excited or stimulated either directly or through the nerve passing to it, "contracts" by drawing its ends nearer together and becoming harder and thicker in the middle, though it does not become smaller in bulk. Each single fibre forming the muscle becomes shorter and thicker, and as all the fibres contract at the same time, the muscle contracts as a whole. Ordinarily a muscle fibre contracts owing to a nervous impulse reaching its end-plate, and then causing in some unknown way the contractable substance of the fibre to contract.

The contracted state of a muscle can only endure a short time, as relaxation soon takes place, and it returns to its usual

*a.*



*b.*

FIG. 47.—Diagrammatic figure of parts of three striped muscular fibres. *a*, at rest; *b*, contracted.

length. With short intervals of rest, however, repeated contractions may be brought about. The involuntary muscles, consisting of plain muscular fibres, contract slowly and relax slowly, while striped muscle can contract suddenly and be suddenly relaxed.

During life, a muscle, like other living tissues, is taking oxygen and nutriment from the blood, and its complex compounds are constantly being oxidized into simpler substances, of which carbon dioxide is the chief. This oxidation leads to the production of energy in the form of heat. At every contraction there is increased oxidation, increase of carbon dioxide, and other waste products, and increase of heat. Some of the heat energy is transformed into the mechanical work that the muscle does.

When an animal is killed, the death of the body, as a whole, takes place, but many of the tissues do not die at once, as they still show their characteristic properties. This is well shown with a cold-blooded animal like a frog. After cutting off the head of a frog, the animal, as a whole, is dead, but the muscular and some other tissues are still alive. Strip the skin from a leg of the decapitated frog, the muscles are exposed. Prick one of the muscles with a needle and it twitches, that is, contracts and relaxes rapidly. Pull the muscles apart at the back of the thigh and a white cord, the sciatic nerve, can be found. This gives off branches to the leg muscles. Pinch the nerve or touch it with a hot needle and the muscles below contract. The excitement, or *stimulus*, as it is called, applied to the nerve causes a change to pass along it, termed a **nervous impulse**, and this nervous impulse sets up contraction in those muscle fibres to which the fibres of the nerve are distributed. After a time, or at once if plunged into water at about 120° F., the muscle becomes stiff, opaque, and inelastic, and it will no longer respond to any stimulation. It is now dead muscle. We thus see that after an animal dies some of its tissues may still live on for a time. All dead animals become stiff after a time, owing to the death of the muscles. This stiffness is known as **rigor mortis**, or the stiffness of death.

Living muscle thus differs from dead muscle in several ways—(1) living muscle is irritable and will respond to stimuli, while dead muscle cannot be made to contract; (2) living muscle is clear, red, soft, and elastic, while dead muscle is opaque, firm, and inelastic; (3) living muscle has an alkaline reaction, but dead muscle becomes acid owing to the formation of an acid, termed sarcolactic acid. The difference of consistence between living and dead muscle depends on the fact that living muscle contains a liquid part, called **muscle plasma**, while in dead muscle a great part of this substance has clotted into a soft solid, called **myosin**.[1] Thus, when a muscle dies, myosin is formed out of muscle plasma, and when the myosin forms, the muscle becomes dull and firm, the limbs and trunk stiff and rigid. After some hours the stiffness passes off as the myosin begins to undergo decomposition.

The muscles using the bones as levers produce motions of

[1] The muscle plasma of living muscle consists of water, containing in solution certain proteids and small quantities of inorganic salts. One of its proteids is called myosinogen, and after death the muscle plasma coagulates, forming myosin and muscle serum. The myosin is the clot formed out of the previously soluble myosinogen. In the same way blood plasma coagulates, giving rise to fibrin from fibrinogen and to blood serum (par. 48).

different kinds, and it now becomes necessary to understand the mechanics of levers.

**42. Levers.**—A lever is a rigid bar or rod capable of turning about a fixed point called a **fulcrum.** The force causing the turning movement is termed the **power**; a resistance of any kind is spoken of as a **weight.** The portion of the lever measured from the fulcrum to the power is called the power arm; and the portion of the lever measured from the fulcrum to the resistance, or weight, is called the weight arm.

Try the following experiment: arrange a **lever** so as to turn about a point C as in the figure. When the arms are equal, it will be found that a weight at W will be balanced by an equal weight at P. But when a weight of 2 lbs. say is placed at W, it will be found that 1 lb. at P will balance it, if the arm PC is twice the arm WC. If the power arm be made three times as long as the weight arm, then a weight at W will be balanced by one-third the force or weight at P. And generally we shall find—

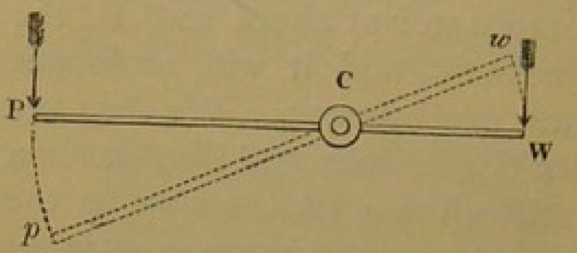


FIG. 48.—A lever turning about a fulcrum at C. (*From Tate's "Elements of Mechanism."*)

Power × its arm = weight × its arm.

On moving the lever from its position, it will be found, however, that when the force at P is less than the resistance or weight at W, P will move through a corresponding greater distance than W. In the figure, the small arc P*p* is twice as great as the arc W*w*. Conversely, when the weight arm is the longer, the power will be correspondingly greater, and move through the less distance, and the motion of power and resistance take place in the same time. And generally, therefore—

Power × space it passes thro' = weight × space it passes thro'.

We thus see why it is possible to overcome great resistances by a lever when we exert a small force through a great distance, and why it is also possible with a lever to move a small weight rapidly through a great distance by a great power moving through a small distance.

Levers are often, for the sake of reference, divided into three classes, according as the fulcrum, weight, or power is in the middle.

(1) When the fulcrum is between the force or power and the resistance or weight, the lever is said to be of the **first order.**

(2) When the resistance or weight is between the power and the fulcrum, the lever is of the **second order.**

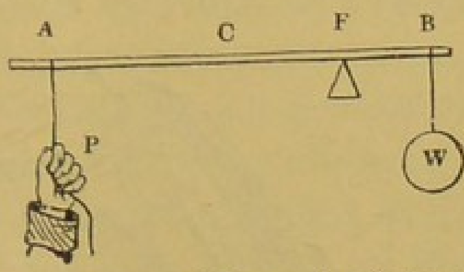



FIG. 49.—Lever of first order (fulcrum in the middle). (*From Tate's "Mechanism."*)

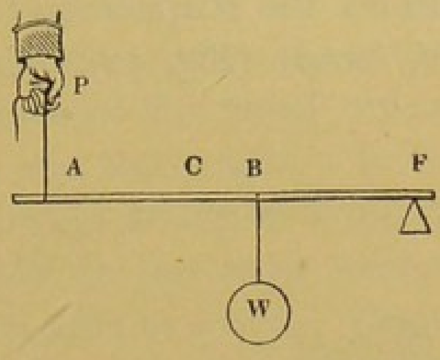



FIG. 50.—Lever of second order (weight in the middle). (*From Tate's "Mechanism."*)

(3) When the force or power is between the weight and the fulcrum, the lever is of the **third order.**

The order of the letters F, W, P indicates the middle position in order of the three kinds of levers.

In all kinds of levers, however, the rules and statements just given hold good. Now a bone often acts as a lever. The fulcrum is at the joint where the movement takes place; the place of insertion of the muscle which moves them is the point of application of the power, while the "weight" is the resistance at the distal end of the bone. In the movement produced, the point of insertion and all attached to it is made to come nearer the origin, which remains fixed, or nearly so. The commonest kind of lever in the body is the third kind, with the power nearer to the fulcrum than to the weight, so that there is a gain of speed by a power greater than the resistance, for rapidity of motion is often required, and is more useful to an animal in the struggles for life than the slow movement of a heavy weight.

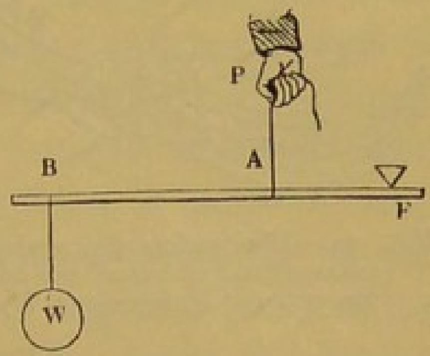



FIG. 51.—Lever of third order (power in the middle). (*From Tate's "Mechanism."*)

**43. Examples of the Levers of the Body and Muscular Action.**—Consider the bending or flexion of the forearm. This is mainly effected by the power supplied by the biceps muscle. (Another muscle, the *brachialis anticus*, shown in Fig. 57, passes from the shaft of the humerus to a process of the ulna and aids in the movement.) The biceps is the large muscle lying in front of the humerus, and has its fixed point or origin on the scapula by two heads or tendons (Lat. *bi*, two; *caput*, head) (Fig. 52). It is inserted on the radius by a

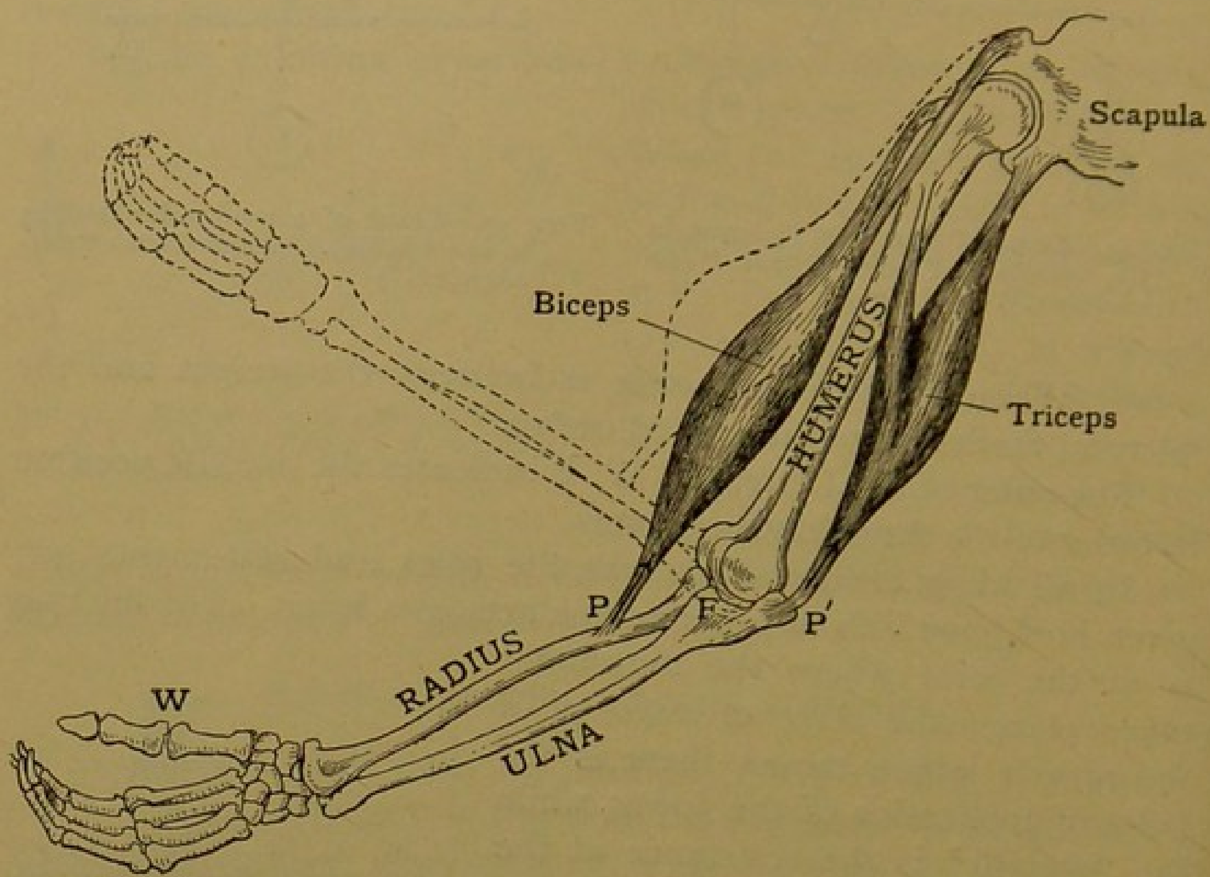



FIG. 52.—Illustrating the action of the biceps muscle in raising the hand, and the antagonistic action of the triceps muscle. P and P′, insertion of muscles where the power acts; F, fulcrum; W, weight, or resistance.

single tendon at a distance of an inch and a half below the elbow-joint. Between the origin and insertion lies the belly of the muscle, free from attachment to bone. Place the left hand on the front surface of the right upper arm, and then draw up the right forearm, when the biceps muscle will be felt to become shorter, thicker, and harder. Straighten the arm and bend it a second time with the hand pressed on the front of the elbow. Here the tense tendon of the biceps passing across the elbow to its insertion on the radius can be felt. When the biceps contracts it pulls on both ends; but as the scapula is fixed, the force is spent in drawing up the radius and with it the ulna and the hand, the radius and ulna turning as on a hinge at the elbow articulation. The elbow-joint is the fulcrum; the power is the force supplied by the contracting muscle and applied at its insertion on the radius, while the resistance is the weight of the forearm and hand with anything else the latter may contain. This is evidently an example of a lever of the third order, for the power acts between the fulcrum and the weight. It is also clear that a small movement of the biceps acting at P will cause a considerable movement of the hand in the same time, thus obtaining in this class of lever a great gain in speed. Compare the distance moved by P and W in Fig. 52. A large range of movement is obtained by a small amount of muscular contraction, and to effect this advantage the pull of the muscle at its insertion on the radius must be many times greater than the weight to be raised.

Consider now the straightening or extension of the forearm. This is effected by a muscle called the triceps muscle, lying at the back of the arm, and the action of which opposes that of the biceps. Its origin is partly a tendon attached to the scapula, and partly two attachments at the upper end of the humerus. Its insertion is where the tendon at its lower end is attached to the upper end of the ulna, a little behind and above the fulcrum at the elbow-joint. When the triceps muscle contracts and exerts its power at the upper end of the ulna, it pulls the end of the ulna upwards, and, in so doing, straightens the flexed arm. In this arrangement the ulna is acting as a lever of the first order, for the fulcrum, though close to the power, is between the power acting at the upper end of the ulna and the resistance of the weight of the hand.

The biceps muscle and the triceps are evidently so arranged as to oppose each other in action. Each furnishes an example of one of the two classes of muscles, called, from the result of their action, **flexors** and **extensors**. *Flexors are muscles which, by their contraction, bend or draw up a limb or part of a limb; extensors are muscles which, by their contraction, straighten a flexed part of the body.* Just as the forearm is flexed by the biceps and extended by the triceps, so each finger has its flexor or extensor muscles.

The whole arm is raised and abducted (drawn away from the middle line of the body) by the action of the large muscle of the shoulder, the **deltoid**; it is lowered and adducted (drawn to the middle line) by the action of the great muscle of the back, the **latissimus dorsi**, and the great muscle of the chest, the **pectoralis major** (Figs. 56 and 57). It can also be carried forward and backwards by the action of these muscles. A combination of these movements causes the arm to be circumducted, that is, made to sweep round so as to describe a conical surface. *Abductors are muscles that move parts away from the middle line of the body or a limb; adductors are muscles that move parts to the middle line; and circumductors are muscles that move a limb on an imaginary axis, so that the further end moves in a circle and the near end remains fixed.*

The bending or flexing of the leg at the knee-joint is effected by muscles at the back of the thigh, especially by the biceps of the leg (**biceps femoris**), which has a double origin on the hip-bone and on the femur. Its lower tendon is inserted below the knee-joint on the back of the fibula, and here the power acts. The knee-joint above is the fulcrum, and the resistance is the weight of the leg and foot acting at the centre of gravity a little above the ankle (lever of the third order). The extensor muscles that straighten the leg when thus bent lie in front of the thigh, the most important being the **rectus femoris**, or straight muscle of the thigh, which is inserted both on the patella and below the knee on the front of the tibia.

The head, as it nods backwards and forwards upon the fulcrum of the topmost vertebra, or atlas, is a lever of the first class, and resembles a see-saw, in which the power and weight are first at one end and then at the other. In nodding backwards, muscles springing from the back of the neck and inserted on the back of the head furnish the power, and the resistance is the weight of the skull and face in front of the fulcrum. In nodding forwards, the weight to be moved is at the back of the head, and the power is furnished by muscles in front, inserted beneath the chin. It should be noted, however, that the centre of gravity of the head lies a little in front of the fulcrum, or pivot of support on the atlas, so that the action of the muscles inserted on the back of the head is needed to keep the head upright. When the contraction of these muscles ceases, as in sleep, the head, therefore, if not otherwise supported, *nods* or falls forward.

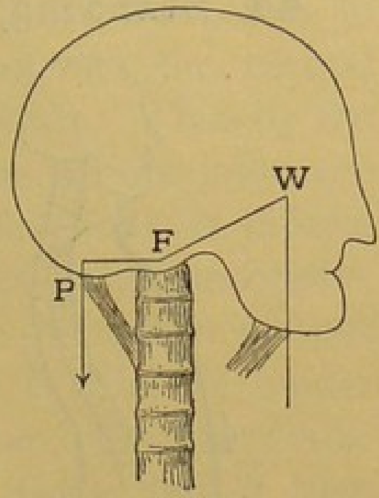



FIG. 53.—Head rocking on the atlas. Lever of the first order.

At the ankle-joint are found movements that illustrate all three kinds of levers.

(1) In tapping or pressing on the ground with the toes, the heel being raised, the ankle-joint is the fulcrum, the power is applied by the muscles cf the calf at the point where the tendon of Achilles is inserted on the heel-bone, and the weight is the resistance at the end of the toes. The fulcrum being in the middle, the foot is then used as a lever of the first class.

(2) In raising the body on the toes (standing on tip-toe), the

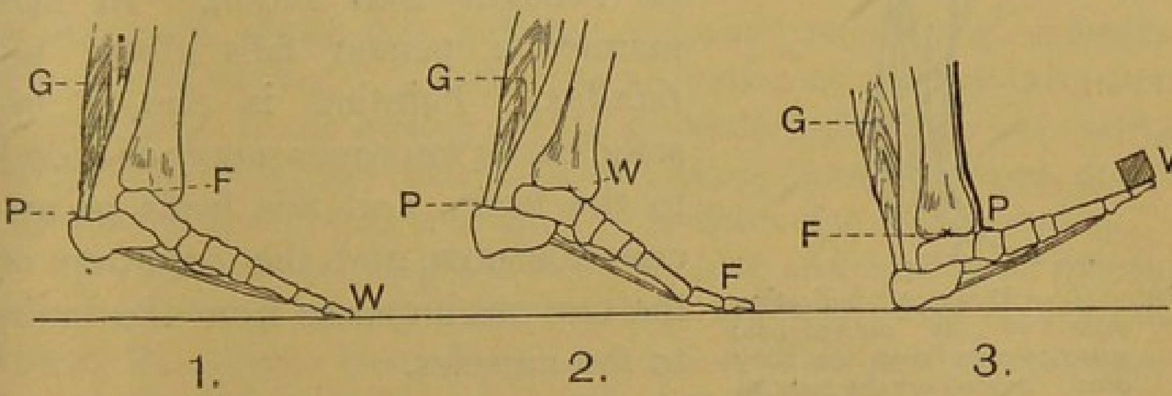



FIG. 54.—Illustrating the three kinds of levers during movements at the ankle-joint. 1, Tapping on the floor (first kind); 2, rising on toe (second kind); 3, lifting weight on toes; F, fulcrum; P, power; W, weight; G, gastrocnemius muscle.

fulcrum is the ground on which the toes rest, the power is applied by the muscles of the calf at the end of the heel-bone (Fig. 54), and the resistance or weight is the weight of the body borne at the ankle-joint. The weight being in the middle this is an example of a lever of the second class.

(3) In lifting a weight resting on the toes without raising the leg, the fulcrum is at the ankle-joint, the weight is at the toes, and the power supplied by muscles in front of the leg (black line in Fig. 54,

3) is applied at a bone of the foot, between the fulcrum and the weight—a lever of the third class.

**44. Standing, Walking, and Running.**—The erect position of the body is maintained by the opposing and carefully adjusted action of voluntary muscles in front and behind the body, though after it is once thoroughly learnt, it is done without conscious effort. Yet the contraction of the muscles is due to the nervous impulses they receive from the central nervous system. For a man struck senseless by a blow on the head receives such a shock to the brain and spinal cord that the nervous impulses to the muscles cease, the muscles relax and he falls down. On regaining consciousness the muscles can again be brought into action. In like manner a person falls down on *fainting*. Fainting is due to insufficient or improper supply of blood to the brain, and this leads to unconsciousness, and the cessation of the nervous impulses from the brain to the muscles.

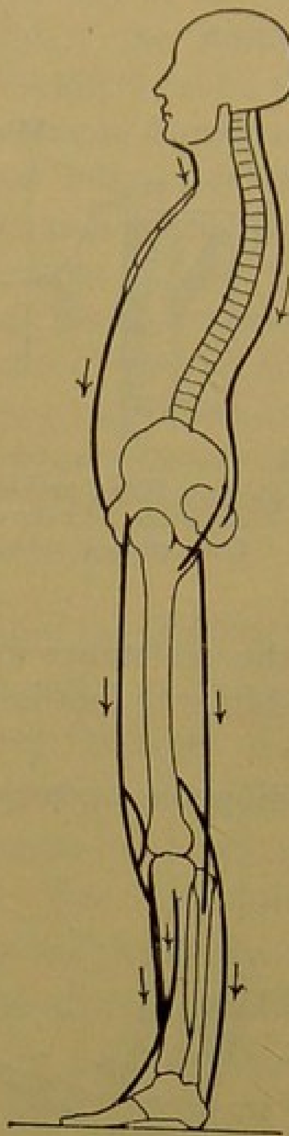


FIG. 55. — Diagram indicating some of the antagonistic muscles that keep the body erect. Behind are the muscles of the calf, the muscles at the back of the thigh, the muscles passing from the trunk to the thigh, and the muscles of the spine. In front are the muscles at the front of the leg, at the front of the thigh, in the abdominal wall, and at the front of the neck. The arrows indicate the line of action of these muscles.

When standing, the centre of gravity of the body, which lies between the sacrum and the last lumbar vertebra, falls within the base of support furnished by the feet. The ankle-joint is kept stiff by the antagonistic action of muscles behind and in front of it; others passing behind and before the knee-joint keep this from yielding; while the trunk is supported at the hip-joints by muscles passing from the trunk to the thighs before and behind. Muscles along the vertebral column tend, by their action, to pull the body backwards, but these are balanced by the action of muscles lying in the walls of the abdomen. Finally, the head is kept upright by the action of muscles at the back of the neck, which counteract the natural tendency of the head to nod or fall forwards. Thus by the combined action of flexors and extensors the various joints are kept rigid. In **walking**, the weight of the body is thrown alternately on the one limb and on the other, by the successive action of flexors and extensors. Just when the advanced foot has reached the ground, the muscles of the calf in the hinder foot contract, and, raising the body on the toes, push it forwards. This causes the leg behind to swing in front, and it then becomes the advanced basis of support, the other foot being then raised on the toes, and so on. In **running**, there is more vigorous action of the muscles, especially those of the calf and the extensors of the legs. The body is thrust forward more quickly, the heel is not placed on the ground, and for a very brief period both feet are raised from the earth.

**45. Some Important Skeletal Muscles.**—There are in the body about five hundred separate muscles of different shapes, and varying in length from a fraction of an inch (attached to little bones in the middle ear) to eighteen inches or more (along the front of the thigh). Some have already been described, and a little further description may now be useful to the young student.

Thin muscles are disposed over the face and round the mouth, and their contractions produce various kinds of facial expression. Among the muscles that aid in mastication, there are the **masseter** and **pterygoid muscles**, that pass from the cheek to the lower jaw, and a fan-shaped muscle, the **temporal muscle**, that passes from the side of the head to the lower jaw. Their fixed points are above, so that their contraction draws up the lower jaw. Opposed to them are muscles that pull down the lower jaw and open the mouth. (The muscles that move the eyeball will be explained in the chapter on the eye.) In the back are many large masses of muscle. One muscle on each side, the broad muscle of the back, **latissimus dorsi**, passes from its attachment on the crest of the hip-bone and on the spines of the lower half of the backbone to be inserted on the head of the upper arm bone (Fig. 57, and right

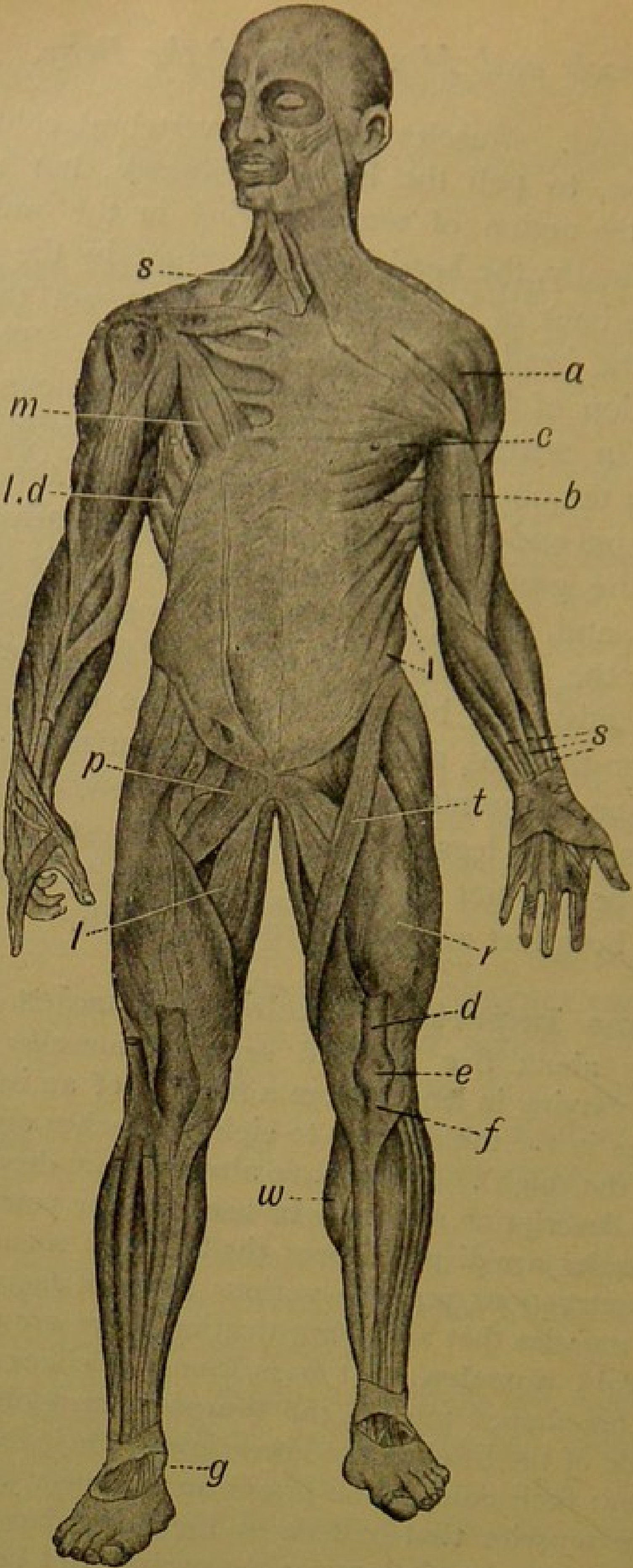



FIG. 56.—Front view of the body with the skin and subcutaneous fat removed to show the muscles. Some of the superficial muscles of the right shoulder and breast are also removed. *a*, deltoid muscle; *b*, biceps muscle; *s*, tendons of extensors of the fingers; *c*, pectoral muscle; *d*, sinew of extensor muscles of thigh; *e*, patella; *f*, tendon passing to tibia; *g*, tendon of Achilles; *w*, gastrocnemius muscle; *p*, pectineus muscle; *l*, abductor longus muscle; *t*, sartorius muscle; /, oblique abdominal muscles; *l.d*, latissimus dorsi; *m*, pectoralis minor; *v*, vastus extremus; *s*, scalene muscle.

side of Fig. 56, beneath the arm). Its chief action is to pull the elevated arm downwards and backwards, as in chopping. The **trapezius** muscle has its origin on the occipital bone and the spines of the cervical and dorsal vertebræ, and it passes outwards to be inserted on the collar-bone and the upper part of the scapula. By its contraction the shoulder can be raised and the head drawn backward. The trapezius muscle of the two sides may be seen in Fig. 57, to be so disposed that they form a sort of tippet, covering the upper part of the back. The two muscles just mentioned aid in attaching the trunk to the upper limbs behind. Two muscles arise from the front of the backbone, and passing on the hollow of the hip-bones at the back of the abdomen, go over the edge of the pelvic bones to the inner head of the femur in front. They bend the body at the hip-joint, and are known as the **psoas** and **iliacus muscles** (see Fig. 119). Opposed to them are the great gluteal muscles (gluteus maximus and gluteus medius, shown in Fig. 57), which form a large part of the buttocks. They arise from the bones of the pelvis, and are inserted on the outer prominence at the upper end of the femur. The **gluteus maximus** aids in keeping the erect position, and raises the body after stooping.

Of muscles found on the anterior surface of the trunk we may note first the large chest muscle, **pectoralis major.** It is a thick triangular muscle just beneath the skin of the breast, and springs from the front portion of the collar-bone, the breast-bone, and some cartilage of the ribs, and then converges to pass in front of the arm-pit, and to be inserted by a broad tendon on the upper part of the humerus. It aids in pulling the arm from an elevated position, and draws it forwards to the trunk. If the arm is fixed, as in using the horizontal bar, then the contraction aids the broad muscle of the back in drawing up the trunk. Beneath the pectoralis major is the **pectoralis minor** (right side of Fig. 56), which depresses the point of the shoulder-blade, thus opposing the trapezius. The great serratus muscle (**serratus magnus**) is so called (Lat. *serratus*, saw-like) because it arises by nine blunt points on the eight upper ribs. It is inserted on the hinder border of the scapula. Its action in general is to raise the ribs and assist in respiration. Other muscles of respiration are the **intercostal muscles** between the ribs (right side of Figs. 56 and 92) and the **diaphragm.** The action of these muscles is explained in the chapter on Respiration.

The walls of the abdomen are mainly formed of thin layers of muscles and fibrous sheets, running obliquely from the ribs above to the crest of the hip-bone below The fibrous sheets of the oblique muscles on each side unite together to form a broad band,

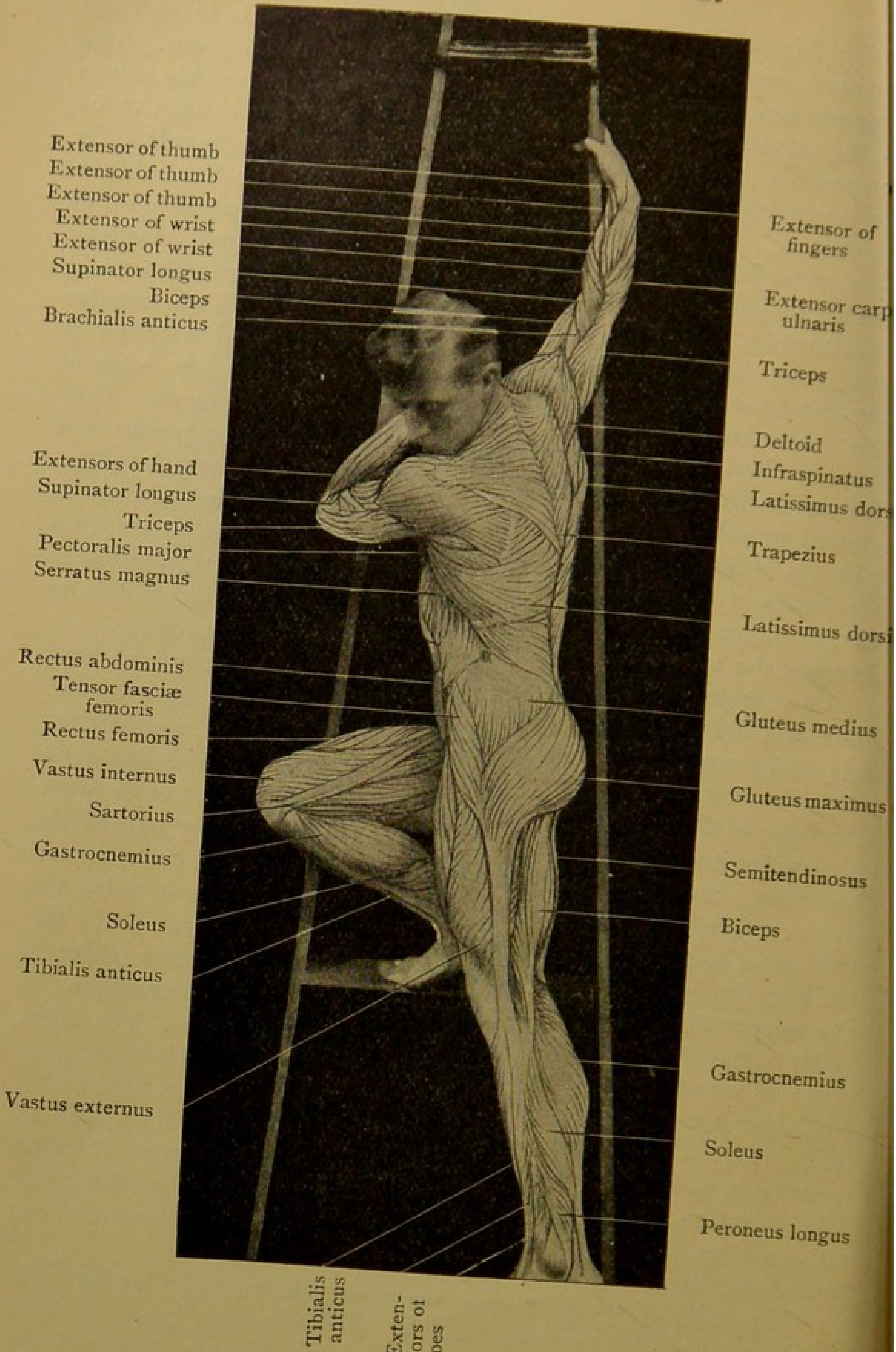



FIG. 57.—(*From Burns and Colenso's "Living Anatomy."*)

termed **Poupart's ligament**, which runs from the crest of the ilium to the projection of the pubis in front (Fig. 8). A straight muscle, **rectus abdominalis**, runs down the abdomen on each side from the ribs to the pubic bone. A white line of connective tissue, the *linea alba*, runs down the middle of the abdomen beneath the skin from the cartilage of the sternum to the pubis. The **deltoid muscle** (its form is that of the Greek letter delta, Δ) is the large triangular muscle covering the shoulder. It has its broad origin on the clavicle and on the tip and ridge of the scapula, and from here it converges down on to the upper arm, its tendon of insertion being attached to the outer half of the shaft of the humerus about the middle (see Figs. 56 and 57). By its action the arm is raised from the side and the humerus abducted or drawn from the body.

The main flexor of the upper arm at the elbow is the **biceps**, and its chief opponent is the **triceps**, by which the arm is extended or straightened at the elbow-joint, as already described (par. 43). On the front of the forearm are the bellies of the flexor muscles, which bend the hand at the wrist, and also bend the fingers. The origin of these muscles is on the humerus and ulna, about the elbow-joint, and their long tendons may be easily felt in front of the wrist as they pass on to the fingers. Some are drawn at S, Fig. 56. The opposing extensors, by which the hand and fingers are straightened, lie at the back of the forearm. The thumb has its own flexor and extensor muscles. A **pronator** muscle rises from an inner prominence of the humerus and runs obliquely across to the radius, and by its contraction causes the radius to roll over the ulna, carrying the hand with it (right arm on Fig. 7). **Supinator** muscles at the back of the forearm bring the radius back so that the palm is to the front, or upwards. The small muscles in the ball of the thumb enable it to be **abducted** or moved outwards, and **adducted** or moved inwards.

A number of muscles lying along the thigh, behind and in front, pass to their insertions below the knee, and thus act chiefly on the knee-joint. The flexors of the knee-joint are three muscles (the **biceps** of the leg, the **semitendinosus**, and the **semimembranous**) that spring from the part of the hip-bone called the ischium, and then pass downwards at the back of the leg to be inserted on the hinder part of the bones of the lower leg. Their long tendons form the "hamstrings" behind the knee. The outer hamstring is the tendon of the biceps of the leg, passing to its insertion on the head of the fibula and outer part of tibia. The **sartorius**, or tailor muscle (Lat. *sartor*, a tailor), is a long, thin muscle which has its origin on the upper part of the hip-bone in front, and then passes obliquely across the front of the thigh to the inner surface of the shaft of the tibia just below the knee-joint. Its contraction bends the hip- and knee-joints, and at the same time turns the knee outwards and thus helps to produce the posture of the tailor when at work. The extensor of the knee-joint is a large muscle occupying the whole front and sides of the thigh. It is divisible into four parts, known as the **rectus femoris, vastus externus, vastus internus,** and **crureus.** One distinct part is the rectus, or straight muscle of the thigh, which passes straight from the hip-bone to converge into a broad tendon (*d*, Fig. 56), which attaches itself to the patella, or knee-cap (*e*, Fig. 56). From the lower edge of the knee-cap the tendon passes on to the front of the tibia (*f*). The tendons of the other part of the great muscle unite with that of the rectus. When the leg is flexed at the knee, the rectus of the thigh and other parts straighten it.

At the back of the leg, below the knee, are two large muscles, the **gastrocnemius** and the **soleus.** These form the bulk of the calf of the leg, and have a common tendon, the tendon of Achilles, which is the thickest and strongest tendon in the body. The action of the gastrocnemius (and soleus) in pulling up the knee and raising the body has been already explained (par. 43). Beneath the calf muscles are the flexor muscles of the toes. In front of the foreleg is a muscle, the **tibialis anticus,** that passes from the tibia to one of the bones of the ankle. Its contraction flexes the ankle upon the leg. The extensor muscles of the toes also lie in front of the leg below the knee. On the outer side are the **peroneal** muscles, that aid in extending the foot and giving it an outward turn.

It will now be clear that motion and locomotion are alike due to muscular action, and dependent on the mechanical relations that exist between muscles, bones, and joints. Most movements are due to the action of several muscles or groups of muscles acting in co-ordination. In the case of the skeletal muscles, the muscle is usually put in action by an effort of the will, the impulse travelling along a motor nerve from some part of the brain. The power which the muscles use to execute the work they perform is derived from the oxidation of the food which has been digested and made part of the tissues (par. 86).

# CHAPTER VI.

## *THE BLOOD.*

**46. General Properties of Blood.**—Blood is a liquid that occurs in tubes or vessels of various sizes, some of which are found in all the tissues of the body with the exception of a few like cartilage, epidermis, the nails, and the hair. When drawn in quantity from a living body, it is of a bright scarlet colour if it comes from an artery; but of a dark red or reddish purple if it comes from a vein. It is not, however, a mere fluid with matter in solution like a solution of salt or sugar, for it also contains minute soft solid bodies suspended in it. When a drop of blood is spread out and examined under the microscope, we can see a large number of these bodies, termed **blood-corpuscles,** floating about in an almost colourless liquid. The corpuscles are of two kinds, red and white, the latter being relatively very few in number. The transparent yellowish fluid in which they float is termed **blood plasma.** This blood plasma is a liquid with a number of substances in solution, and as the corpuscles are also slightly heavier than the plasma, blood as a whole is heavier than water, bulk for bulk. Its specific gravity is 1055, water being 1000. Blood has a saltish taste and a faint alkaline reaction. Blood is a most important liquid. In the first place it is the great nutrient fluid for the cells and tissues of every organ of the body, having obtained its nutritive matter from the digested food in the alimentary canal. But, besides this, it carries away waste material from all parts, and this waste material is afterwards removed from it by excretory organs such as the kidneys. Another function of the blood is to carry oxygen to the tissues, as oxidation must go on in them continuously. The carbon dioxide produced by oxidation of tissue is taken into the blood stream, to be afterwards eliminated in the lungs, but these functions of the blood will be better understood after reading our later chapters.

As regards the **chemical composition** of blood as a whole, we may here state that 100 parts by weight of blood consist of 80 parts of water and 20 of solids. The solids consist chiefly of the nitrogenous compounds, hæmoglobin (10 parts) and proteids (9 parts). The other small quantity (1 part) is made of very small amounts of fats, carbohydrates, inorganic salts, and urea. The hæmoglobin of blood is found in the red corpuscles only. The proteids are (serum-albumin, paraglobulin, and fibrinogen) found chiefly in solution in the plasma. The inorganic or mineral salts of blood are mainly chlorides and phosphates of sodium and potassium.

**47. The Corpuscles of the Blood.**—A drop of blood spread out on a slide under the microscope shows, as already stated, a clear fluid in which the corpuscles are suspended. The most numerous particles are what are known as the red corpuscles, though when not seen in masses they are of a reddish-yellow colour. Human red corpuscles, when viewed singly, are seen to be *biconcave discs*, that is, they are round and flat plates like a coin, but thicker at the edges than in the middle. In diameter they are about $\frac{1}{3200}$ of an inch, and about one-fourth of this fraction in thickness. So numerous are they that a cubic millimetre of blood (*i.e.* a cube $\frac{1}{25}$ of an inch in side) contains about five millions of them, and it is to these red corpuscles that the blood owes its colour. In a freshly drawn film of blood on a slide, most of them arrange themselves in *rouleaux*, like piles of coin. They consist of a delicate, colourless, elastic envelope with coloured fluid contents, mainly a

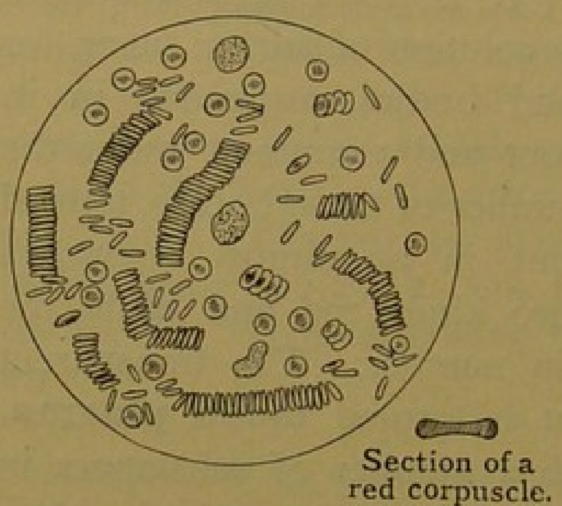



FIG. 58.—Blood as seen under the microscope, showing red corpuscles in rouleaux and singly; also three white ones.

solution of red substance termed **hæmoglobin.** Hæmoglobin is a complex nitrogenous compound, a proteid containing iron, and is of great importance, as it forms a loose combination with oxygen, and so acts as the oxygen carrier of the blood. It always contains some of this gas, but when combined with its fill of oxygen, so to speak, it is termed **oxy-hæmoglobin.** When deprived of this oxygen, it is termed **reduced hæmoglobin.** If water is added to blood the red corpuscles absorb some of the fluid and swell out into little globules; if a strong salt solution is added, water is drawn

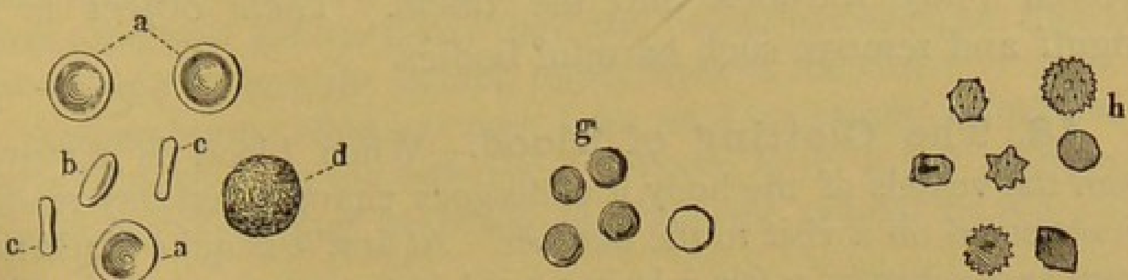


FIG. 59.—*a, b, c*, red corpuscles seen in different positions; *d*, a white corpuscle; *g*, red corpuscles made globular by water; *h*, red corpuscles acted on by salt solution.

from the corpuscles and they shrink. Red blood-corpuscles may be regarded as a kind of cell, but they are not true cells. as they contain no nucleus. (The shading in the thinner part of the red corpuscles in the figures must not be mistaken for a nucleus.) They perish after a few weeks, and are replaced by new ones, which are produced in the red marrow of certain flat bones and perhaps also in the spleen.

The colourless or white corpuscles, often also called **leucocytes**, are far less numerous than the red (1 white to 400 red), Three are indicated in Fig. 58. Most of them are a little

FIG. 60.—Human colourless blood-corpuscle, showing its successive changes of outline within ten minutes when kept moist on a warm stage. (Schofield.) (*From Gray's "Anatomy."*)

larger than the red ones. They also differ from the latter in shape and appearance, many being globular and crowded with tiny granules. Others have an irregular form, and may be seen slowly changing their shape, as they are capable of spontaneous movement and division like the amœba (par. 3). Water, or very dilute acetic acid, lessens the granular appearance and brings to view a central darker nucleus. The colourless corpuscles are therefore true cells consisting of nucleated protoplasm. They act like tiny living creatures, creep from place to place by putting out and drawing in processes, and even take up particles of foreign matter which they meet on the way. They also at times make their way out through the thin walls of the minute blood-vessels into the surrounding tissue, and this they do in quantity whenever an injurious foreign body intrudes into the tissue. Their object is to engulf and remove such harmful bodies.

**48. The Clotting of Blood.**—When blood is removed from the vessels of the body it undergoes changes, as may readily be observed on a visit to the butcher. At first it is quite liquid and flows easily, but in a few minutes it thickens or coagulates, and at the end of ten to twenty minutes forms one mass of jelly that will not flow. After an hour or so, some drops of a pale yellowish fluid ooze from the jelly, and this process goes on for two or three hours, until we have a pale yellow fluid, called **serum**, in which a dark

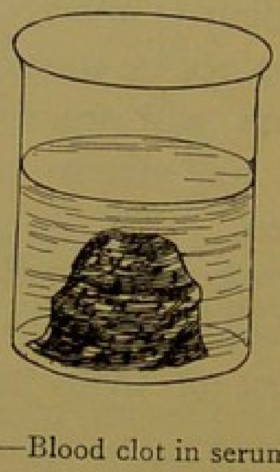


FIG. 61.—Blood clot in serum.

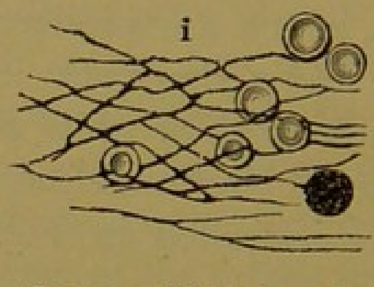



FIG. 62.—Fibrin threads entangling corpuscles (microscopic view).

jelly-like mass, called a **clot**, rests. This coagulation, or clotting of the blood, is due to the change of a proteid substance, called **fibrinogen**, in the plasma of living blood into a stringy solid, called **fibrin.** The threads of fibrin settling down in a meshwork contract and entangle the blood-corpuscles, so that a clot consists of fibrin and corpuscles. With a film of blood kept still under a microscope, the threads may be seen to make their appearance, as indicated in Fig. 62.

We now understand that living circulating blood consists of plasma and corpuscles, that the plasma consists of serum and a fibrin-forming substance called fibrinogen. There is no fibrin in living circulating blood, only a substance which gives rise to fibrin, owing to some kind of chemical change when blood is allowed to clot. The change of fibrinogen to fibrin is believed to be brought about by a peculiar substance, called **fibrin ferment**, that is derived from the white corpuscles. Coagulated blood consists of a clot in serum, the clot consisting of fibrin and corpuscles. If a vessel containing blood is surrounded by ice, coagulation goes on very slowly, and a clot is formed that is of light colour above. The clot is then said to have "a buffy coat." The explanation is that the red corpuscles sink a little faster than the colourless ones, so that the latter come to form the lighter, upper layer of the clot.

Remembering what has now been said about the formation of fibrin from plasma, the differences between fresh living blood and coagulated blood may be put in the following tabular form :—

| Fresh living blood consists of | | | Coagulate blood consists of | |
|---|---|---|---|---|
| Corpuscles | | ... ... ... ... | Corpuscles | Clot. |
| Plasma | Fibrinogen (in solution) | ... | Fibrin | |
| | Serum ... | ... ... ... ... | | ... Serum. |

A few words may now be added on the uses of coagulation. Blood does not coagulate in the living vessels while they remain uninjured, but it clots when it escapes, or when a vessel is injured internally. In a slight cut, for example, the outflowing blood soon forms a clot and so closes the wound. In the case of arteries, the contraction of the elastic walls at the cut ends also aids in closing the aperture. If, however, a large vessel be cut, the stream of blood is so great that it washes away what escapes before it can clot.

**49. The Blood Plasma.**—By taking special precautions the plasma of blood may be obtained separately. If a strong solution of Epsom salts be added to blood as soon as it is drawn, and this be kept about freezing-point for several days, the blood will not coagulate, but the corpuscles will settle to the bottom. Plasma can then be siphoned off. It consists of water, 90 per cent., and of solids in solution, 10 per cent. The solids are the proteids, serum-albumin, paraglobulin, and fibrinogen, with inorganic salts, of which sodium chloride is the chief, and a small quantity of fat. Serum differs from plasma only in being without the fibrinogen. Plasma obtained in the way indicated will, after adding water to dilute the salt in it, coagulate, and finally form a colourless clot, consisting of fibrin only. This shows that a clot can be formed without corpuscles. It will be remembered that the iron-containing proteid, hæmoglobin, is found in the red corpuscles only (par. 47).

Besides the substances just mentioned, blood contains certain gases, carbon dioxide or carbonic acid and oxygen being the chief. Every 100 volumes of blood can be made to yield about 60 volumes of gases when it is subjected to diminishing pressure under an air-pump. The carbonic acid (46 volumes per 100 volumes of blood in venous blood, and 40 volumes per 100 volumes of blood in arterial blood) exists mostly in loose combination with substances dissolved in the plasma, though a small quantity is also simply dissolved in the plasma. The oxygen (20 volumes per cent. in arterial blood, and 10 volumes per cent. in venous blood) exists for the most part in loose chemical combination with the hæmoglobin of the red corpuscles, only a little being in simple solution. A small amount of nitrogen (1 to 2 volumes per cent.) exists in simple solution both in arterial and venous blood.

We now understand that all the substances of which the different tissues of the body consist are contained in blood, and that it is indeed the real nutrient fluid of the body. We may say that every part of our bodies has been formed out of this liquid, but in order that it may be able to renew the used-up tissues in all parts it must be in continual movement. This movement leads us to the consideration of the heart and the vessels in which the blood circulates. After that we shall have to consider how the blood renews its supply of oxygen and nutrient matter and gets rid of the waste materials that it takes up.

**50. Experiments with Blood.**—Go to the butcher with two clean jars which have been rinsed out with salt solution to prevent the blood sticking to the sides. Obtain fresh blood in each. Allow one jar to stand without any disturbance. Stir the freshly drawn blood in the other for some time with a bundle of twigs or a piece of wire netting. On the twigs or wires will be found some stringy fibres. Wash the fibres well under the tap and you will obtain the white material called fibrin. Note the bright colour of the liquid from which the fibrin has been removed. This defibrinated blood does not coagulate, or clot, on standing. Bubble into it some carbon dioxide to drive out some of the oxygen and notice how the colour deepens. Now pass into it oxygen, or shake it up well in the air and note the effect. The bright scarlet colour returns as the red corpuscles take up their fill of oxygen. Hence we see that the colour of the blood depends on the amount of oxygen held by the hæmoglobin of the red corpuscles. The bright-red blood is known as **arterial blood,** the dark-red as **venous blood.** After an hour or so, examine the jar of blood that was left standing. It has coagulated or set into a jelly. Leave it still longer and you will see that a yellow fluid, the serum, oozes out, while the solid clot shrinks more and more, until after several hours, or a day, we have a clot at the bottom surrounded by yellow serum. Draw off some of the serum. Heat some of the serum in a test-tube and you will find that it solidifies like the white of egg does on heating. This is due to the albumen and globulin it contains, for it is a characteristic property of these proteids that they stiffen or solidify on being heated. Take out the clot and notice the bright-red colour outside. Break it open and notice its darker colour inside, where there was least oxygen. The part exposed to the air soon brightens in colour. (A large clot that has stood for some time will almost be black inside, for the air has not been able to get to this part, and the decomposition going on has reduced (taken away the oxygen from) the oxyhæmoglobin of the red corpuscles. After a time the dark surface exposed to the air becomes red.) Examine a tiny bit of clot under the microscope and notice the threads of fibrin and the corpuscles. No fibrin or corpuscles will be found in the serum if it is carefully obtained. Now obtain a minute drop of freshly drawn blood by pricking the finger with a clean needle, and examine it under the microscope. Observe the two kinds of corpuscles floating in the blood plasma. Only one or two white corpuscles, however, are likely to be found. Allow the slide to remain some minutes quite still, and then you will see that fine threads of fibrin have formed (Fig. 62).

# CHAPTER VII.

## *THE HEART AND THE CIRCULATION OF THE BLOOD.*

**51. Position, Shape, and Size of the Heart.**—The heart is a great muscular organ formed to receive a stream of blood on each side, and to force out again a stream on each side. It is situated in the thorax, behind the breast-bone and some of the costal cartilages, and between the lungs. It is of conical form, with the broad end or base upwards, while its pointed end or apex is directed downwards, forwards, and to the left, so as to terminate in the interval between the fifth and sixth ribs (Figs. 8 and 63). It is, therefore, somewhat obliquely placed, but very nearly in the middle of the thorax, not on the left side as is often supposed, owing to the beating of the lower part being more easily felt there. Great blood-vessels proceeding from the base of the heart help to suspend it and keep it in position. It measures about five inches in length, and three inches in breadth at the broadest part in an adult. The heart lies within a closed membranous bag formed of two layers, and called the **pericardium.** The inner layer of the pericardium has a smooth and shiny surface, and lies next to the heart. This inner layer is attached above to the roots of the large blood-vessels at the base of the heart, and it then turns and runs over its course to form another layer covering the first, thus forming a kind of double bag (Fig. 64). (An idea of a bag with two layers may be got by fastening up the mouth of a sock, and then pushing the foot inwards with the hand. Close the hand inside, and the fist will then be in a bag of two layers, and the wrist will represent the great vessels at the base of the heart.) In the narrow space between the two layers of the pericardium is a little pericardial fluid, which allows one layer to move on the other without friction. The pericardium is attached below to the diaphragm, while bands of fibrous tissue

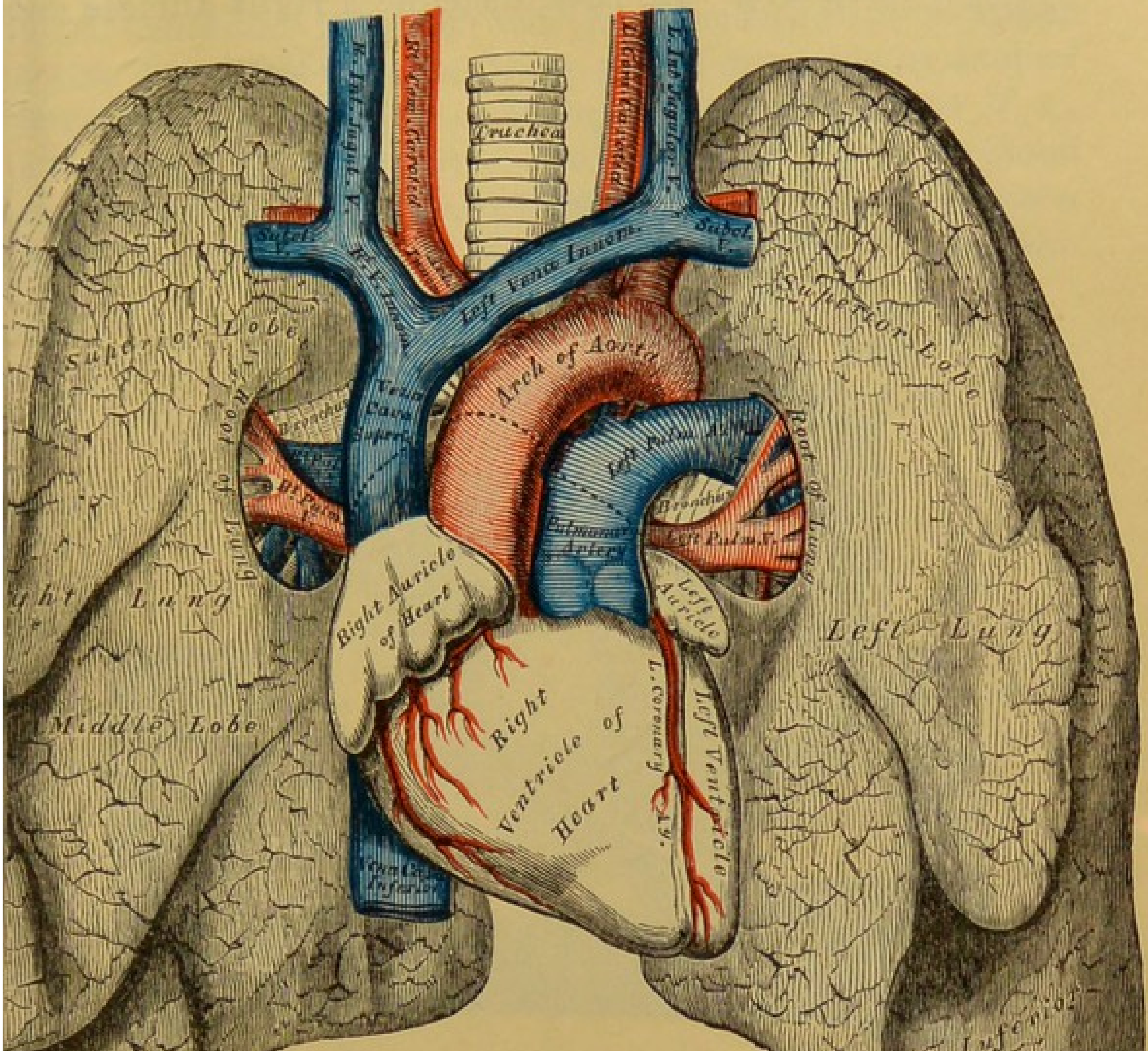



FIG. 63.—Front view of heart and lungs. (*From Gray's "Anatomy."*)
(Arterial blood red, venous blood blue.)

from the neck join it above. These attachments assist the great vessels in keeping the heart in place.

**52. Description of the Heart and its Action.**—Before giving a somewhat full description of the heart, the following short account of the organ will serve as a useful introduction. The heart may be regarded as a double organ, composed of a right and left part completely separated by a partition wall. Each side of the heart has two chambers. The upper one, called an **auricle,** communicates with a lower one, called a **ventricle.** We have, therefore, a **right auricle** and

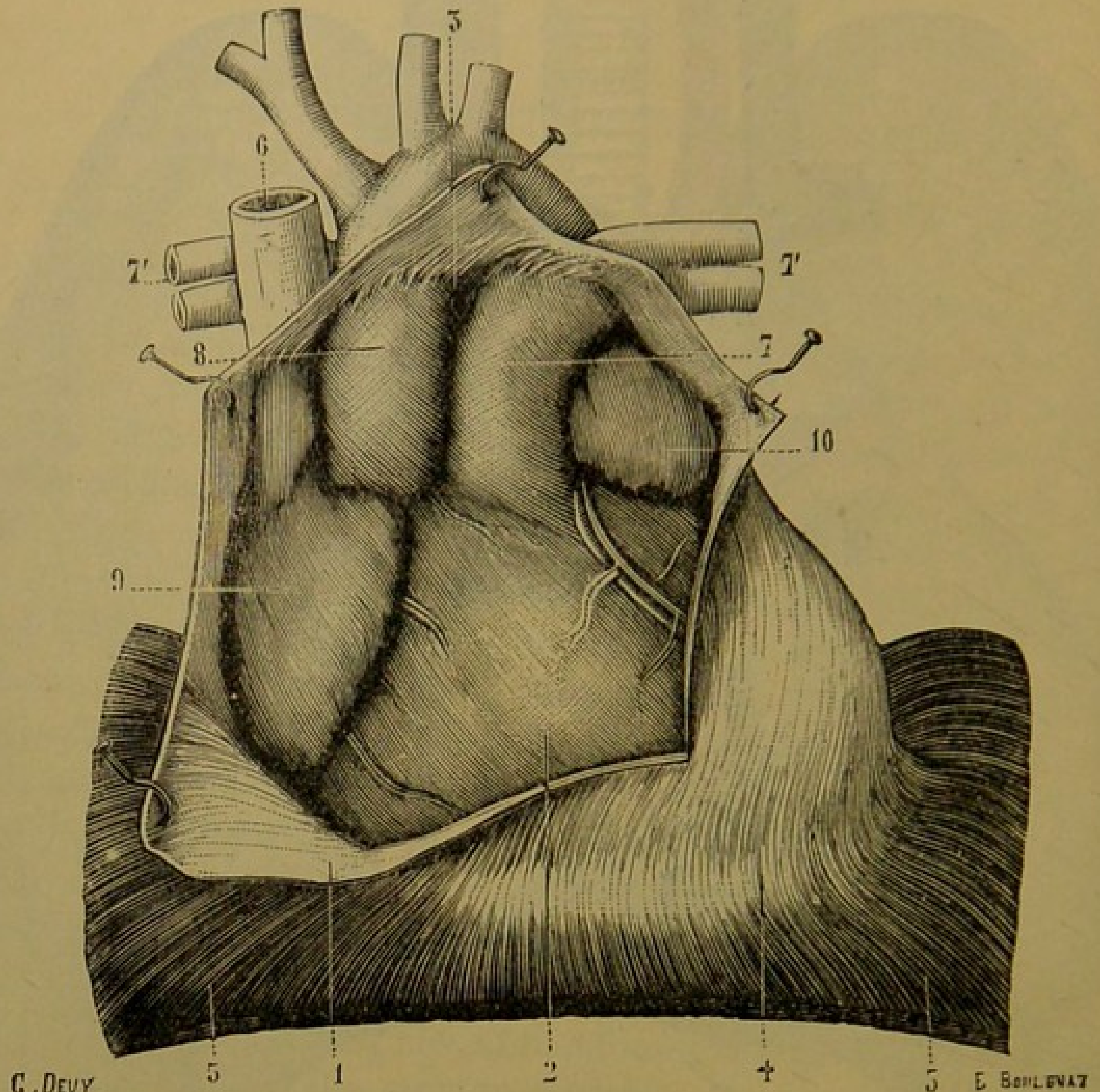



FIG. 64.—Front view of the heart in the pericardium. 1, The outer layer of the pericardium cut and hooked back to show, 2, the front face of the heart (right ventricle) still covered by the inner layer of the pericardium; 3, attachment of pericardium at the roots of the large blood-vessels; 4, attachment of pericardium to diaphragm; 5, diaphragm; 6, upper vena cava; 7, pulmonary artery; 7′, its branches; 8, aorta; 9, right auricle; 10, left auricle. (*From Testut's "Traité D'Anatomie."*)

a **right ventricle** on one side, and a **left auricle** and **left ventricle** on the other side. Flaps of membrane attached at their bases to the inner walls of each separated half between the auricles and the ventricles form valves which allow the blood to pass from auricle to ventricle, but not in the reverse direction. Tubes or vessels bring blood to the heart, and other vessels take it away from the heart. Vessels bringing blood to the heart are called **veins**, and vessels taking blood away from the heart are called **arteries.** Into the right auricle of the heart blood passes from the head, neck, and upper extremities by a large vein called the **superior** or **upper vena cava**, and from the lower part of the body by another large vein, the **inferior** or **lower vena cava** (upper V. C. and lower V. C. in Fig. 65). From the right auricle the blood is sent into the right ventricle through the opening between those chambers, this opening being guarded by a valve with

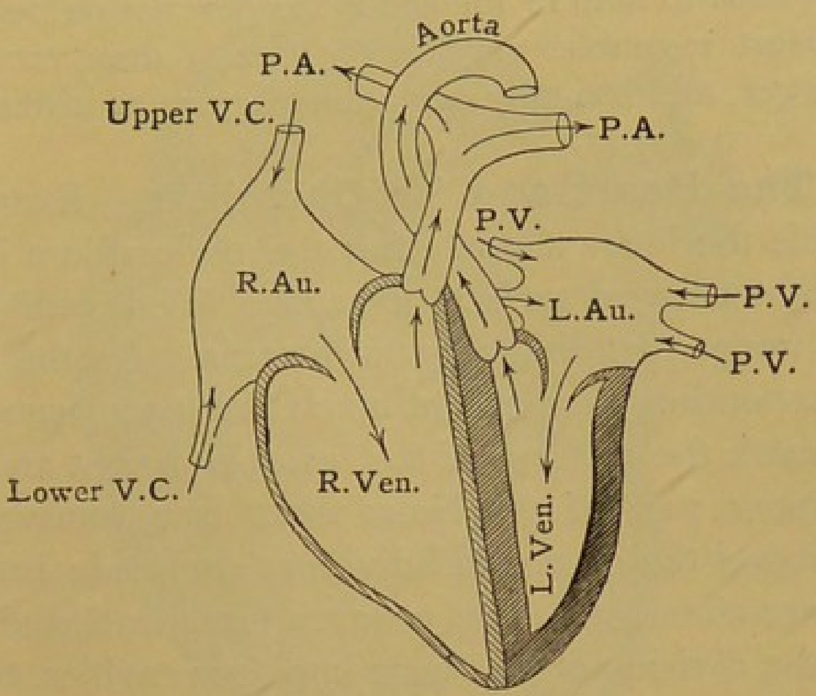



FIG. 65.—Diagrammatic section of the heart, to show its chambers and the direction blood-flow on each side. P.A., pulmonary arteries; P.V., pulmonary veins.

three flaps, called the **tricuspid valve.** From the right ventricle the blood is forced by the contraction of the ventricle into a great artery called the **pulmonary artery**, for the flaps of membrane between auricle and ventricle are raised during ventricular contraction until they meet and close the passage back into the auricle. The pulmonary artery divides into two branches, one for each lung (P. A. in the figure). The blood is returned from the lungs by four pulmonary veins (P.V.) into the left auricle. From the left auricle the blood passes into the left ventricle through an opening between two flaps of membrane, called the **mitral valve.** From the left ventricle the blood is forced by contraction into the great artery called the aorta, the mitral valve closing to prevent it going back into the auricle. At the beginning of the great pulmonary artery, and at the beginning of the aorta, are three watch-pocket folds of membrane, named **semilunar valves.** They allow blood to pass out from the ventricles, but can close to prevent it coming back.

The reader should obtain from the butcher a sheep's heart with the "bag" left on, and the great vessels cut at some distance from it. After examining and removing the pericardium, the heart should be used to help in following the description below; for the sheep's heart resembles very closely that of man, except that it is a little larger, and has only two pulmonary veins instead of four.

**53. The Heart and its Chambers.**—Examined from the outside the heart shows, after the pericardium is removed, on its front convex surface, a groove filled with fat running from the upper part obliquely downwards. On the flatter back is a corresponding groove, but much less conspicuous. These grooves mark the division of the heart into right and left sides. In the upper part of the heart there is a transverse groove running round the organ and dividing each side into an upper and a lower chamber. The grooves just mentioned, therefore, indicate the division of the heart into four cavities, two on each side. In these grooves, embedded in the fatty tissue, lie the chief blood-vessels of the heart itself, together with its lymphatics and nerves. Looked at in its natural position, the front convex surface of the heart is made up chiefly of the right ventricle, and the posterior flatter surface is mainly occupied by the left ventricle. The right side can be further distinguished from the left by the thinner walls of its ventricle, which may be picked up with the fingers, while the walls of the left ventricle are too thick and firm to be pinched up. At the broad base of the heart, which is uppermost, vessels will be noted, the one with the largest and stoutest walls being the aorta. At the base of the heart on each side a thin collapsed wall may be picked up with the fingers. These thin walls are the walls of the auricles. To each auricle is attached an ear-like, muscular, crinkled piece, called, from its fancied resemblance to a dog's ear, the **auricular appendix** of the auricle. It is really the wall of a pouch of the auricle. The interior of the heart is divided by a fixed longitudinal muscular partition, or septums into two chief cavities, a right and left cavity. Each of these right and left halves is again subdivided by a transverse constriction into an upper chamber, called an **auricle**, and a

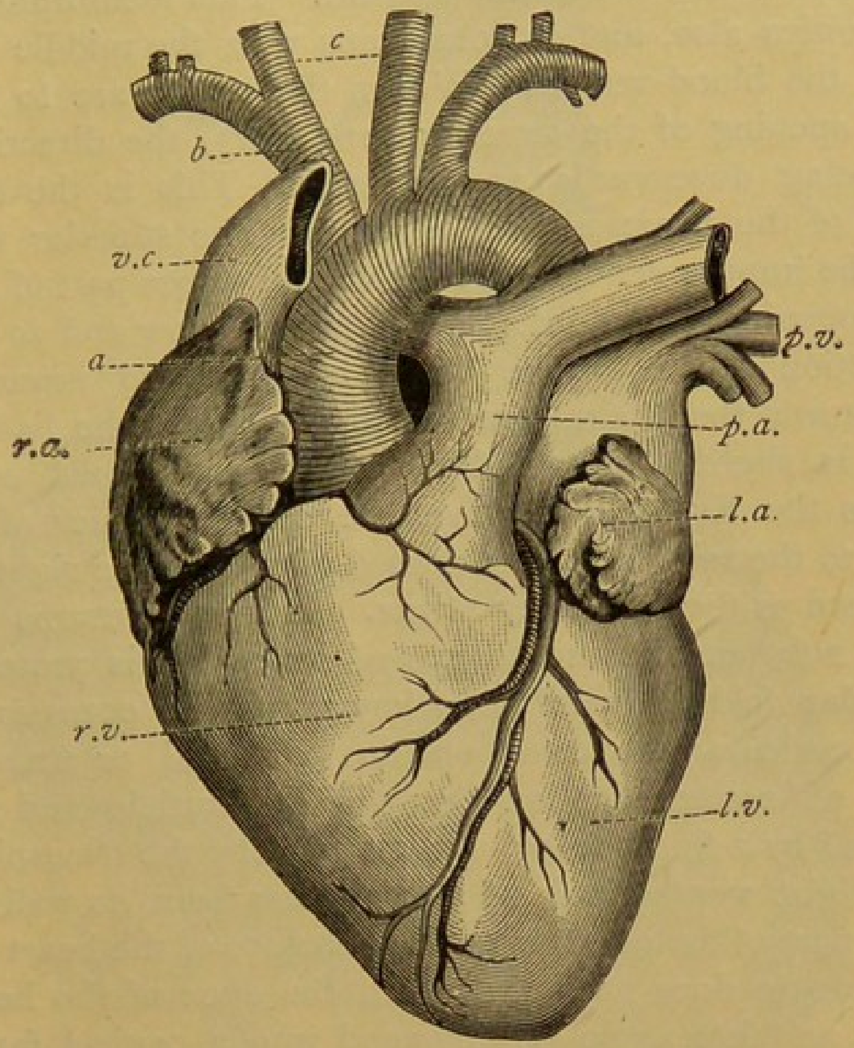



FIG. 66.—The heart seen from before. *r.a.*, right auricle; *r.v.*, right ventricle; *l.a.*, left auricle; *l.v.*, left ventricle; *v.c.*, upper vena cava (the lower vena cava passing up behind is not shown); *a*, aorta, with *b*, *c*, branches passing to head and arms; *p.a.*, pulmonary artery; *p.v.*, pulmonary veins. On the front surface, in a grove, are seen the coronary artery and vein. (Compare with Fig. 63).

lower one, called a **ventricle.** There is free communication between auricle and ventricle of each side of the heart, the auriculo-ventricular opening, however, being so guarded by membranous flaps as to allow the blood to pass from auricle to ventricle, but not in the opposite direction. There is no direct communication between the left and right sides or halves of the heart. The two auricles are the receptive cavities, and the two ventricles the propulsive cavities of the heart.

**The right auricle** occupies the right and front of the heart. Its walls are thin, and appear of a quadrilateral form, prolonged at the upper left corner into a tongue-shaped portion, called the **right auricular appendix**, which overlaps the root of the aorta. On opening the cavity, its interior is seen to be lined by a delicate smooth membrane, the **endocardium.** This membrane lines the other cavities also, and is continuous with the middle and inner coats of the blood-vessels. Within the cavity are to be seen—(1) The opening of the superior vena cava, the direction of the orifice being downwards and forwards. This is the only large aperture of the heart without a valve. The superior vena cava returns the impure venous blood from the upper part of the body. (2) The opening of the inferior vena cava below and to the right, the direction of the orifice being upwards and inwards. This vessel returns the blood from the lower part of the body, and its opening is slightly protected by a crescent-shaped membrane, known as the Eustachian valve, the convex border of which is attached to the vein. (3) The dilated portion of the right coronary vein, known as the **coronary sinus.** This vein returns the blood from the substance of the heart, and its orifice is protected by a semicircular fold of membrane, known as the **coronary valve.** (4) The auriculo-ventricular opening, an oval or funnel-shaped aperture of communication between the auricle and ventricle, surrounded by a fibrous ring, and guarded by the tricuspid valve.

**The right ventricle** is of a triangular form, its walls forming the chief part of the anterior or front surface of the heart (Fig. 63). Its lower angle does not quite reach the apex of the heart, while its upper and left angle is prolonged into a conical form to the beginning of the pulmonary artery. When opened, the septum of the heart is seen to bulge into this ventricle (Fig. 67), and its inner surface is marked by muscular bundles, some of which, named **papillary muscles**, are attached at their bases to the ventricular wall, and at the other end are prolonged into small **tendinous chords (chordæ tendineæ)**, which are joined to the edges of the segments of the auriculo-ventricular valve. This valve on the right side consists of three triangular flaps, and is therefore termed **tricuspid.** The flaps are composed mainly of fibrous tissue covered by endocardium, are attached by their bases to the inner wall between the two chambers, while their free margins hang down into the ventricle when the heart is empty. During the systole or contraction of the ventricle, the segments of the valve are driven up towards the auricle so as to meet, and thus prevent the blood returning into that cavity. The tendinous

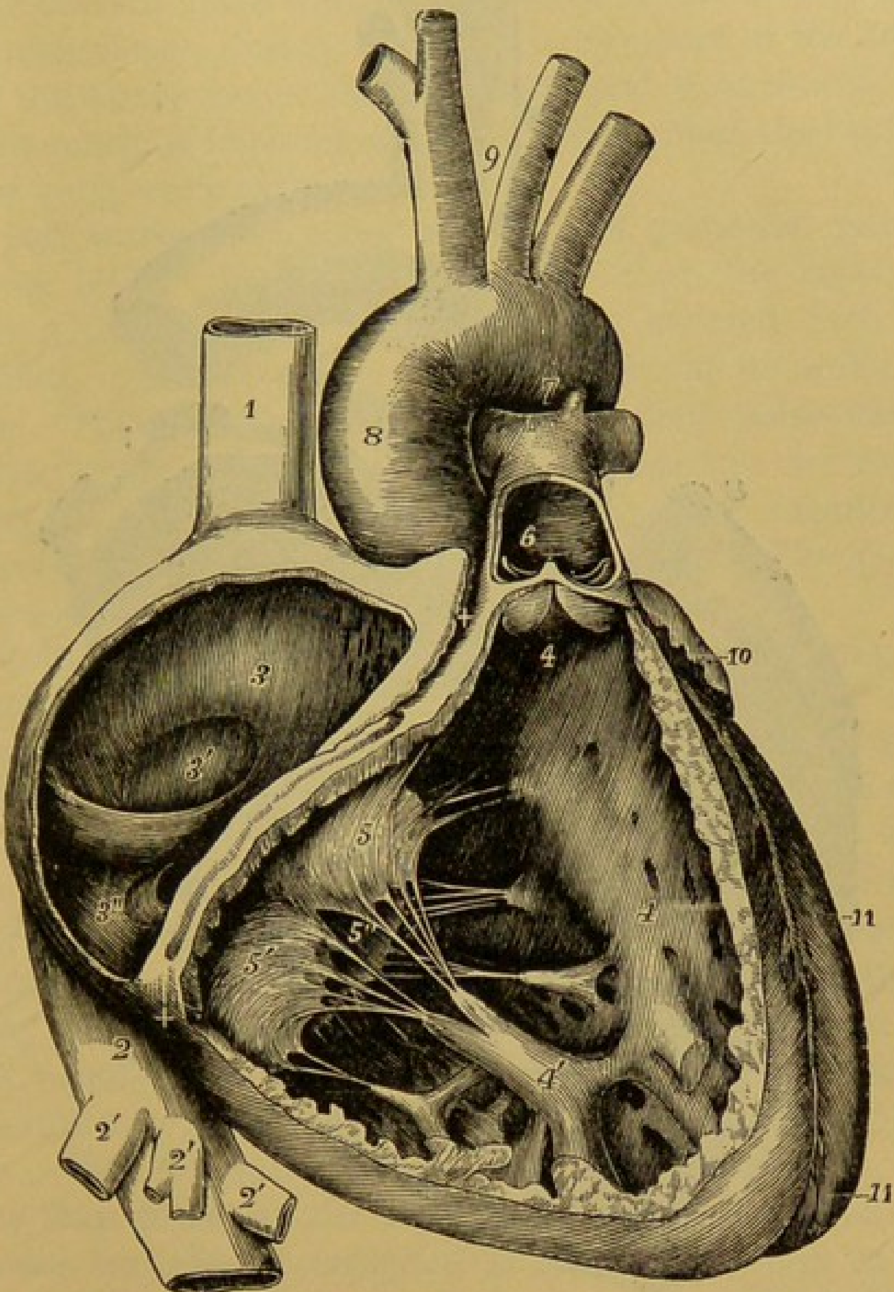



FIG. 67.—Interior of right auricle and ventricle, their front walls being removed. 1, superior vena cava; 2, inferior vena cava; 2′, hepatic veins; 3, right auricle; 4 and 4 on the septum or division between right and left side of the heart; 4′, a papillary muscle; 5, 5′, 5″, segments of the tricuspid valve attached by chordæ tendineæ to papillary muscle; 6, in pulmonary artery just above semi-lunar valves; 8 and 7, on aorta; 9, placed between the innominate and left common carotid artery; 10, appendix of left auricle; 11, 11, front edge of outer wall of left ventricle. (*From Quain's "Anatomy."*)

chords, or **chordæ tendineæ**, attached to the free margins of the flaps, through the contraction of the **papillary muscles**, to which these chords are attached below, keep the valve from yielding too much towards the auricle. Three **semi-lunar valves** guard the orifice of the pulmonary artery, which takes its rise at the upper and left angle of the right ventricle. These valves consist of three

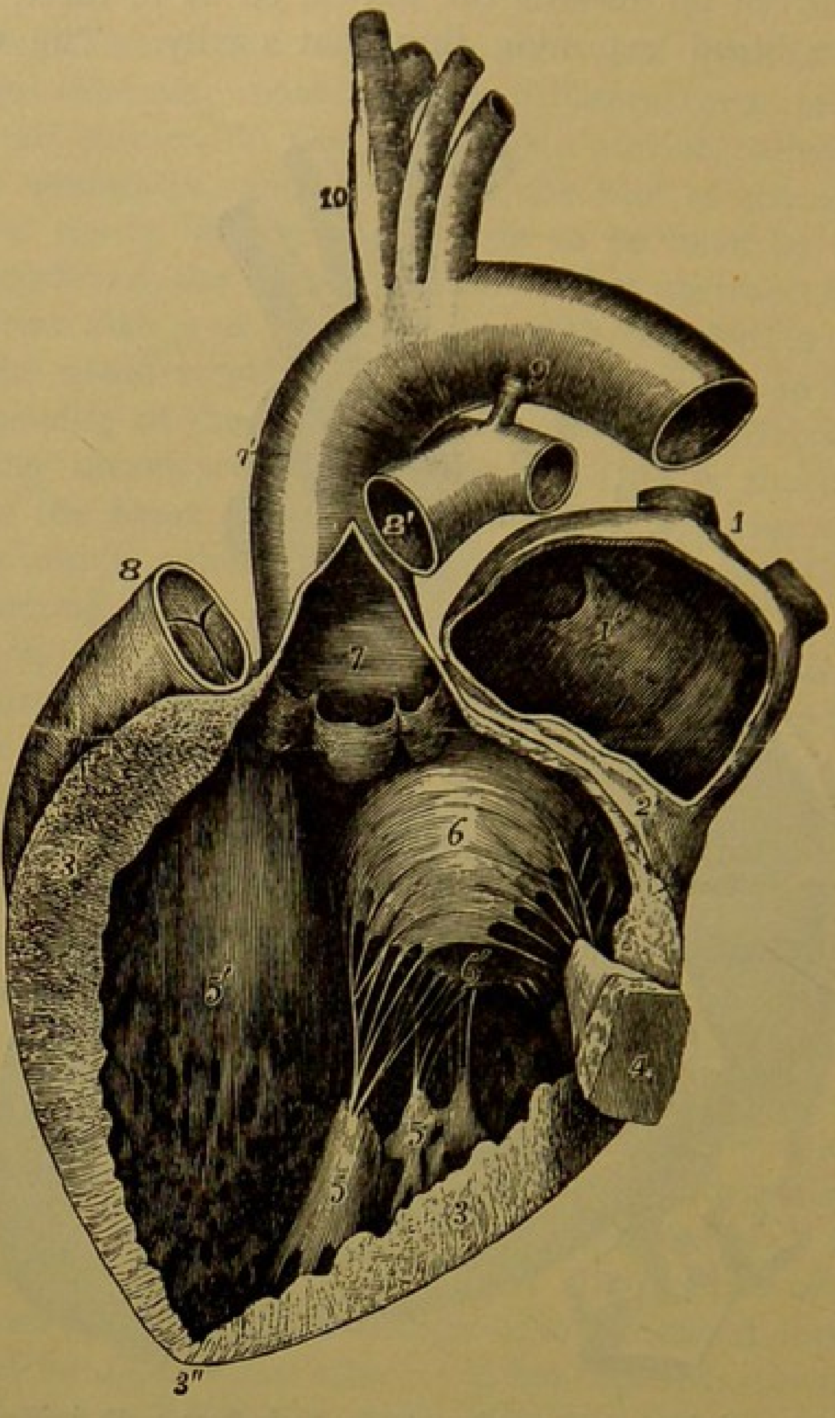



FIG. 68.—The left auricle and ventricle opened and a part of the wall removed so as to show their interior. (Allen Thomson). ½. The commencement of the pulmonary artery has been cut away, so as to show the aorta; the opening into the left ventricle has been carried a short distance into the aorta; and part of the auricle with its appendix has been removed. 1, right pulmonary veins cut short; 1', placed within the cavity of the auricle; 2, a narrow portion of the wall of the auricle and ventricle preserved around the auriculo-ventricular orifice; 3, 3', cut surface of the wall of the ventricle; 4, a small part of the wall of the left ventricle which has been preserved with the left papillary muscle attached to it; 5, 5, right papillary muscles; 5', the left side of the septum of the ventricles; 6, the anterior or aortic segment, and 6', the posterior or parietal segment of the mitral valve; 7, placed in the interior of the aorta near its commencement and above its valves; 7', the exterior of the great aortic sinus; 8, the upper part of the root of the pulmonary artery and its valves; 8', the separated portion of the pulmonary trunk; 10, the arteries arising from the aortic arch. (*From Quain's "Anatomy."*)

semicircular folds, formed of fibrous tissue, covered by membrane. They are attached by their convex margin to the wall of the artery at its junction with the ventricle, while their straight border is free and directed upwards. During the contraction of the ventricle the valves are pressed back towards the walls of the artery, but when the ventricle relaxes, during diastole, the pressure of the column of blood in the artery forces them inwards and downwards, so as to bring their margins together and close the opening, thus preventing any blood going back into the heart.

**The left auricle** occupies the left and posterior part of the base of the heart. It is slightly smaller than the right, but its walls are a little thicker. Its interior is covered with smooth endocardium. Behind are seen four orifices in its walls, two on each side. These are the openings of the four pulmonary veins, which bring the blood that has been oxygenated in the lungs into this cavity, those from the left lung entering close together, sometimes indeed terminating by a common opening. The pulmonary veins have no valves.

**The left ventricle** is the thickest part of the heart, and its walls form the apex projecting beyond the right ventricle. It forms a small part of the left side of the front of the heart, but a considerable part of its posterior surface. On opening it, its walls are seen to be about three times thicker than those of the right ventricle. They are thickest at the broadest part of the ventricle. Its lining membrane is continuous with that of the auricle, and its inner surface shows **papillary muscles** and **chordæ tendineæ.** The fleshy columns are smaller but more numerous than those of the right ventricle, and those forming the papillary muscles are collected into two groups, which are larger than those of the right ventricle. The tendinous cords are thicker, stronger, but less numerous than those on the right side of the heart, and they act in the same way, being attached at their upper end to the free margins of the two flaps of the **mitral** or **bicuspid** valve, which guards the auriculo-ventricular opening on this side. This valve, as its name implies, consists of only two segments, but they are thicker and stronger than those of the tricuspid. They are continuous at their bases, and are attached to the walls of the heart in the same way as those on the opposite side. The larger segment is to the front. Close to the auriculo-ventricular orifice of the left side is the opening leading into the **aorta**, the artery which distributes the pure blood to all parts of the body. The beginning of the aorta is provided with three semilunar valves, which are formed and act like those of the pulmonary artery. In two of the recesses of the aorta, just above two of the valves, may be seen the beginning of the two **coronary arteries** which supply blood to the substance of the walls of the heart. These two coronary arteries, after much branching, form capillaries, from which the coronary veins arise.

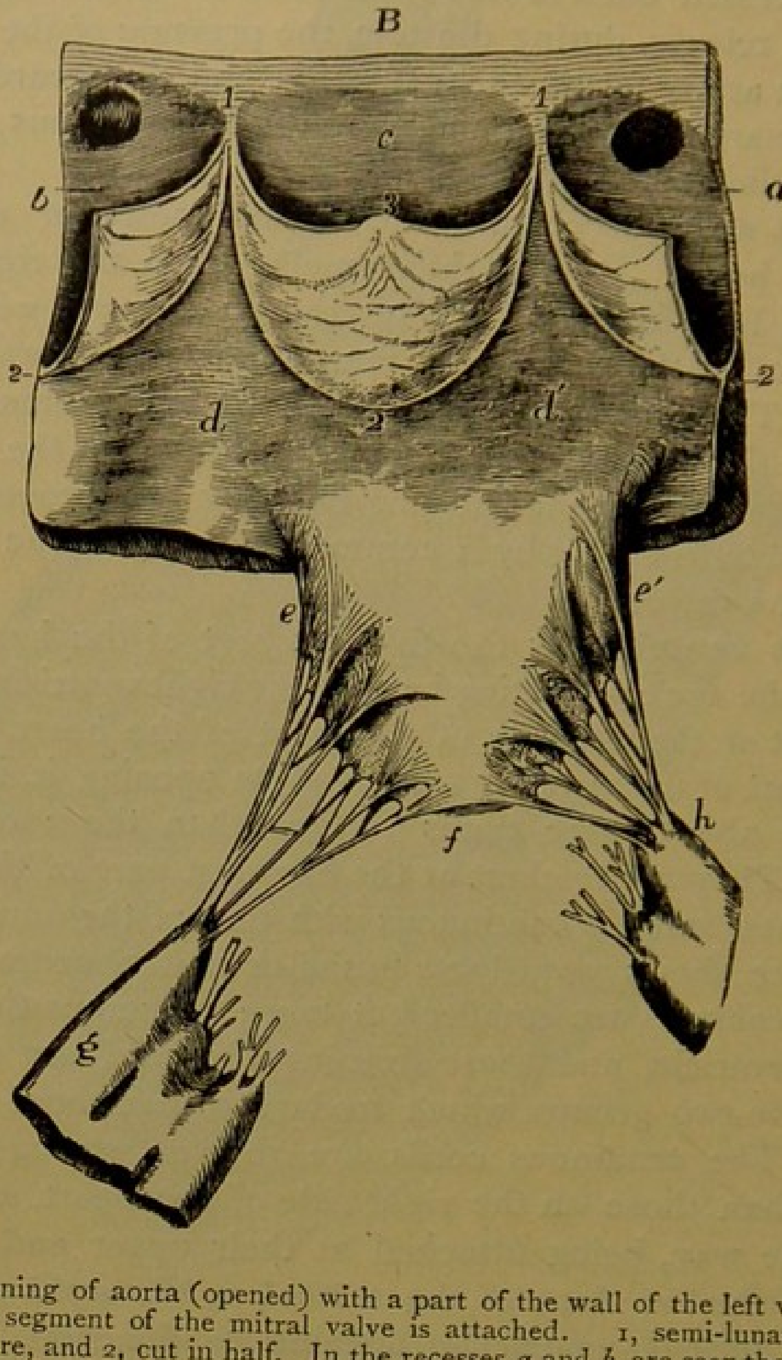



FIG. 69.—Beginning of aorta (opened) with a part of the wall of the left ventricle below to which a segment of the mitral valve is attached. 1, semi-lunar valve of the aorta is entire, and 2, cut in half. In the recesses *a* and *b*, are seen the beginnings of the coronary arteries ; *d*, *d′*, on inner wall of ventricle ; *e*, *e*, *f*, segment of mitral valve ; *g*, *h*, papillary muscles with chordæ tendineæ attached to the valve and other chordæ tendineæ belonging to other portion of valve cut. (*From Quain's "Anatomy."*)

The coronary veins for the most part unite to form one large coronary vein, that empties itself into the right auricle, its opening being guarded by a small valve. The **coronary circulation** just described shows the shortest way by which blood can pass from the left side to the right side of the heart.

**54. Working of the Heart.**—The human heart of an adult beats at the rate of about seventy times per minute, a beat being the contraction of the walls of the auricles and of the ventricles. This contraction of the muscular fibres of the heart shortens and thickens the walls and diminishes the cavities enclosed. The action of the heart is marked by an alternate contraction and relaxation of its muscular walls, the total movement being called a "cardiac revolution," or "cardiac cycle." Each cardiac cycle consists of three acts—(1) a short contraction of the auricles; (2) a longer contraction of the ventricles as soon as the auricular contraction is over; (3) a pause in action nearly equal in time to that occupied by the two contractions, until the auricles again contract. The contraction of any part is called its **systole** (Gk. *systello*, to contract); its relaxation its **diastole** (Gk. *diastello*, to dilate). Both auricles contract together, and both ventricles contract together, so that similar events are going on at the same time on each side of the heart. The exact time occupied by each phase of a cardiac cycle has been found approximately by registering graphically the motions of the auricles and ventricles directly communicated to light levers brought into contact with their surfaces. Taking the heart-beat at seventy times per minute, each cycle would occupy about $\frac{8}{10}$ of a second, made up as follows:—

Auricular systole = $\frac{1}{10}$ of a second.
Ventricular systole = $\frac{3}{10}$ "
General pause in action = $\frac{4}{10}$ "

The auricular systole on each side of the heart begins with contraction of the muscular fibres surrounding the great veins, and passes through the auricles as a peristaltic wave, thus sending the blood into the dilating ventricles. Regurgitation, or flowing back from the auricles into the great veins, is prevented by contraction at the mouths of these veins, and on the right side by the coronary valve in front of 3″ in Fig. 67. The so-called Eustachian valve (below 3′ in Fig. 67) is imperfect, and of little use in the adult. The systole of the ventricles immediately follows that of the auricles, and, as a result of this contraction, the blood gets behind the tricuspid and mitral valves, and brings the flaps together so as to close the passage back into the auricle. The tendinous chords, from the muscles attached to the valves, keep the flaps from being forced into the auricles. During contraction the ventricles change from a rounded to a more conical form, their walls become tense and hard, the apex of the heart is slightly tilted upwards, and the heart itself twists somewhat on its long axis from left to right. The ventricular cavity is thus greatly diminished, and the pressure within the ventricles being now greater than that in the arteries, the semi-lunar valves at the entrance of the great arteries are forced open, and pressed towards but not close to the arterial walls, and the blood enters these vessels.

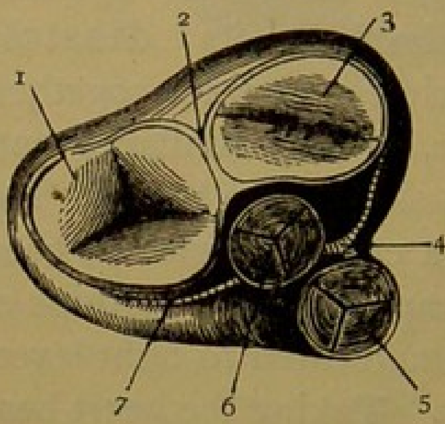



FIG. 70.—Representation of the valves of the heart in position as seen from above and in front. 1, tricuspid valve; 2, septum or wall between the two sides of the heart; 3, mitral valve, 4, left coronary artery; 5, semi-lunar valves of pulmonary artery; 6, semi-lunar valves of aorta; 7, left coronary artery.

During this ventricular systole, an ear placed against the walls of the chest hears a dull sound, the "first sound" of the heart, and the eye may notice and the hand feel an impulse against the chest-wall in the fifth left intercostal space. As soon as the ventricular contraction ceases, ventricular diastole begins, and proceeds during the greater part of the auricular diastole, which began at the close of the auricular contraction. At the beginning of the ventricular diastole the semi-lunar valves fill with blood and close, thus preventing any back flow into the ventricles, owing to the pressure in the ventricle ceasing and the elastic reaction of the walls of the pulmonary arteries and of the aorta. A second sharp sound is heard at the end of the contraction of the ventricles, and the heart returns to its oblique position, the auriculo-ventricular valves open, and blood begins to pass from the auricles into the ventricles. After a general pause, or passive interval, equal in time to the two systoles, during which the auricles are filling with blood, the cycle of events is completed and auricular contraction again begins. The force of contraction of the thin-walled auricles is small compared with that of the ventricles, as they have only to force the blood into the ventricles, and the force of contraction of the left ventricle is greater than that of the right ventricle, because the right ventricle has only to send the blood through the lungs, while the left ventricle is required to send the blood through the capillaries in all parts of the body. This accounts for its thicker walls of muscular tissue.

**55. Impulse and Sounds of the Heart.**—As already remarked, the heart during action communicates a stroke or beat to the chest-wall, and this cardiac impulse, as it is called, can be both seen and felt in the left side. This impulse has been found to occur at the same time as the contraction of the ventricles. It is usually best felt at a point in the fifth left intercostal space, mid-way between the left edge of the sternum and a vertical line drawn through the left nipple. It is caused by the sudden pressure of the lower front part of the ventricle near the apex against the chest-wall during ventricular contraction. It is common to call this impulse the "apex beat" of the heart. Besides the sensation which can be perceived by the eye and felt by the hand, if we place the ear against a person's chest over the region of the heart where the cardiac impulse is felt, two distinct sounds can be heard, a muffled dull sound, known as the "first sound," followed almost immediately by a shorter and sharper sound, known as the "second sound" of the heart. Their character is imitated by pronouncing the syllables **lubb-dup.** The first sound is found to begin with the ventricular systole, and to continue during the greater part of the contraction. But, though it occurs at the same time as the impulse of the heart, it is not caused by the heart's impulse, as it can be heard quite clearly when the chest-wall is removed. It is most probably a composite sound due to two chief causes—(1) the vibration of the tricuspid and mitral valves, when they are suddenly put into tension at the beginning of the ventricular systole; (2) the sound produced by the contraction of the muscular fibres forming the walls of the ventricles. Injury or disease of the auriculo-ventricular valves alters the character of the first sound (this is often observed in the case of the mitral valve). The second sound is undoubtedly caused by the vibration set up in the semi-lunar valves of the aorta and pulmonary artery, when they become tense at their sudden closure on the completion of the ventricular systole, for curved needles have been introduced into the aorta and pulmonary artery, so as to hook back one or more of the semi-lunar valves, and the second sound has then ceased.

**56. Summary of Events occurring during a Cardiac Revolution.**—The average frequency of the heart-beats is seventy-two per minute, which allows about $\frac{8}{10}$ second for each cardiac revolution. The events occurring during such a period or cycle dividing it into three parts to correspond with auricular systole, ventricular systole, and the time of rest may be thus tabulated—

| *First Period* $\frac{1}{10}$ *sec.* | *Second Period* $\frac{3}{10}$ *sec.* | *Third Period* $\frac{4}{10}$ *sec.* |
|---|---|---|
| 1. Auricular systole. | 1. Ventricular systole. | 1. General diastole of heart, blood flowing into both auricles and ventricles. |
| 2. Completion of the filling of the ventricles. | 2. Closure of the mitral and tricuspid valves. | 2. Semi-lunar valves of aorta and pulmonary valves closed. |
| | 3. Opening of the semi-lunar valves of aorta and pulmonary artery. | 3. Second or short sharp sound heard at the beginning of this period only. |
| | 4. Propulsion of blood into the aorta and pulmonary artery. | |
| | 5. Impulse of the heart against the chest-wall. | |
| | 6. Gradual filling of the auricles with blood. | |
| | 7. First or long dull sound heard during greater part of this period. | |
| | 8. Short silence following first sound. | |

**57. Circulation of the Blood.**—Having learnt the structure and action of the heart, and the names of the great blood-vessels connected with it, the reader is ready to learn something about the course of the blood in its circulation or round as it passes from its starting-point in the heart and comes back again. We will first describe the circulation in a brief way, and then in fuller detail.

The reader will remember that the right and left sides of the heart are quite distinct from one another, the chambers on each side being separated from those on the other by a septum, or partition, of muscular tissue. He will also shortly learn that there are two distinct objects to serve by the circulation of the blood—(1) the supplying of oxygen and removal of carbon dioxide from the blood; (2) the nutrition of the tissues and the removal of waste by the blood. These two purposes are effected by two systems of circulation, called the **pulmonary** system (Lat. *pulmo*, the lung) and the **systemic** system. In the pulmonary system the blood is driven by the contraction of the right ventricle into the pulmonary artery. This soon branches into two, one to each lung. Each branch divides into smaller arteries in the lungs, and then into minute capillaries.

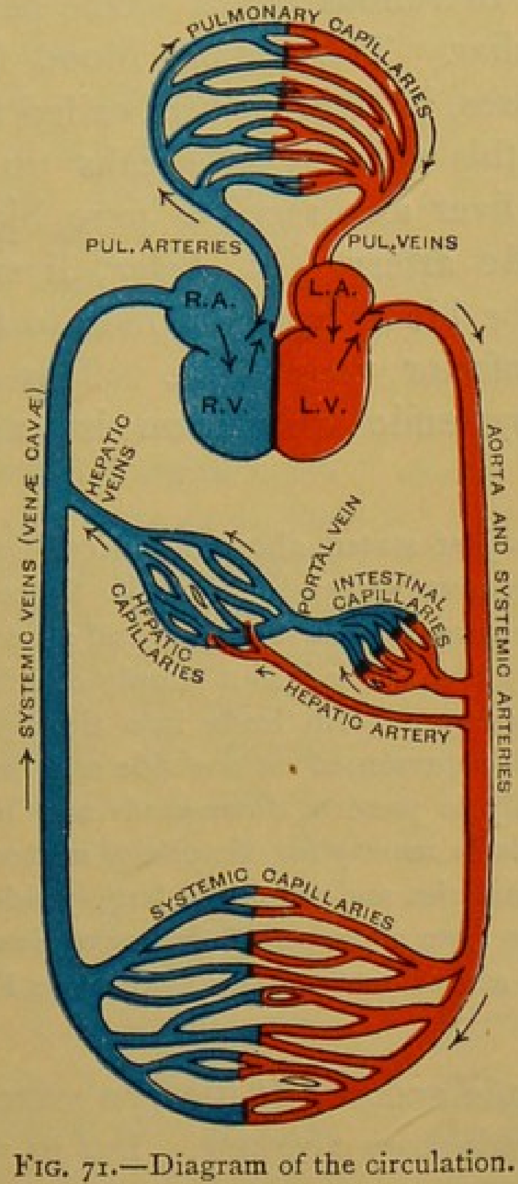



FIG. 71.—Diagram of the circulation.

In the pulmonary capillaries the blood is purified, and the capillaries uniting into veins bring the purified blood to the left auricle. In the systemic or general circulation the blood that has passed from the left auricle into the left ventricle is driven by the contraction of this ventricle into the great systemic artery, called the aorta. The aorta gives off branches to all parts and organs of the body, and at last breaks up into capillaries.

These capillaries of the general system unite into two great veins, one in the upper part and one in the lower (**upper vena cava** and **lower vena cava**), and bring the blood back to the right auricle of the heart. In its passage through the systemic capillaries, the blood gives up to the tissues oxygen and materials for their growth, and receives the waste products of the tissues, thus becoming changed from pure arterial to impure or venous blood. One part of this systemic circulation is peculiar. The impure blood from the stomach and intestines passes, by a great vein called the **portal vein**, to the liver, and this vein again breaks up in the liver into capillaries. The liver also receives pure blood by an artery called the **hepatic** artery (Gk. *hepar*, liver). The hepatic veins convey all the blood from the liver to the great systemic vein called the inferior vena cava. This peculiar part of the general or systemic circulation is called the **portal circulation.**

NOTE.—The facts just stated about the circulation are illustrated by Fig. 71, but the reader must remember that the figure is only a diagram, and not an actual representation of an object and its parts. To illustrate a thing diagrammatically is to show it in a simple or schematic way. Thus in this diagram only one great vein leads into the right auricle instead of two, the arteries are all represented on one side and the veins on the other, the aorta is shown only as passing downwards and branching into capillaries below. All this is merely for simplicity and convenience of representation. In reality, arteries and veins run largely side by side, a systemic vein (vena cava) comes from above, and the aorta gives off branches above for the head and neck as well as the parts below (see Fig. 67 and the fuller diagram, Fig. 83).

The above simple account of the two systems of circulation is useful as an introductory account. But in reality there is but one great system when we consider the round from any one chamber of the heart back to the same chamber. Let us follow the blood in this complete round, starting at the left ventricle.

By the contraction of the left ventricle the pure blood in this chamber is pumped past the semi-lunar valves into the main artery of the body—the **aorta.** Just after leaving the left ventricle the aorta arches backwards to the left, runs down near the spine through the thorax, and, piercing the diaphragm, passes into the abdomen. From the arch of the aorta three large branches are given off (Figs. 67 and 72). The first of these branches, on the right side (the **innominate** artery), soon divides into two, one of which, the **right carotid artery,** runs upward through the neck to supply the right side of the head, while the other branch, called the **right subclavian artery,** passes under the collar-bone into the upper arm, dividing at the elbow into **radial** and **ulnar** arteries. (The pulse is usually taken by feeling the radial artery at the wrist.) From the left side of the arch of the aorta there arises directly the **left carotid artery** for the left side of the head and neck, and the **left subclavian** artery for the left arm and hand. The carotid arteries on each side divide in the neck into an external carotid and an internal carotid, the latter supplying the brain and the former the part of the head outside the cranium. During its passage through the chest the aorta gives off branches (bronchial arteries) to supply pure blood to the tissues making up the lungs as well as branches to the gullet and to the muscles of the thorax.

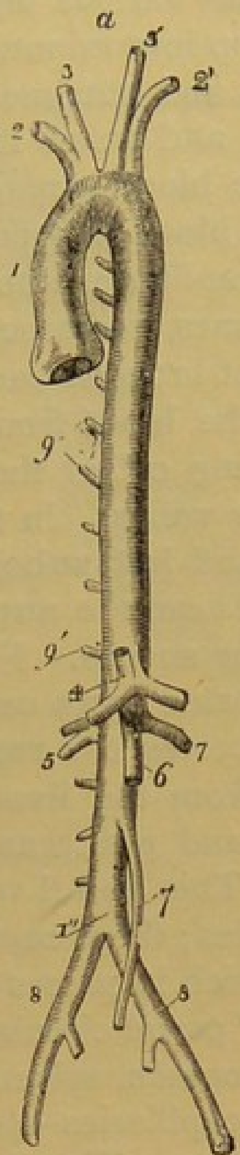
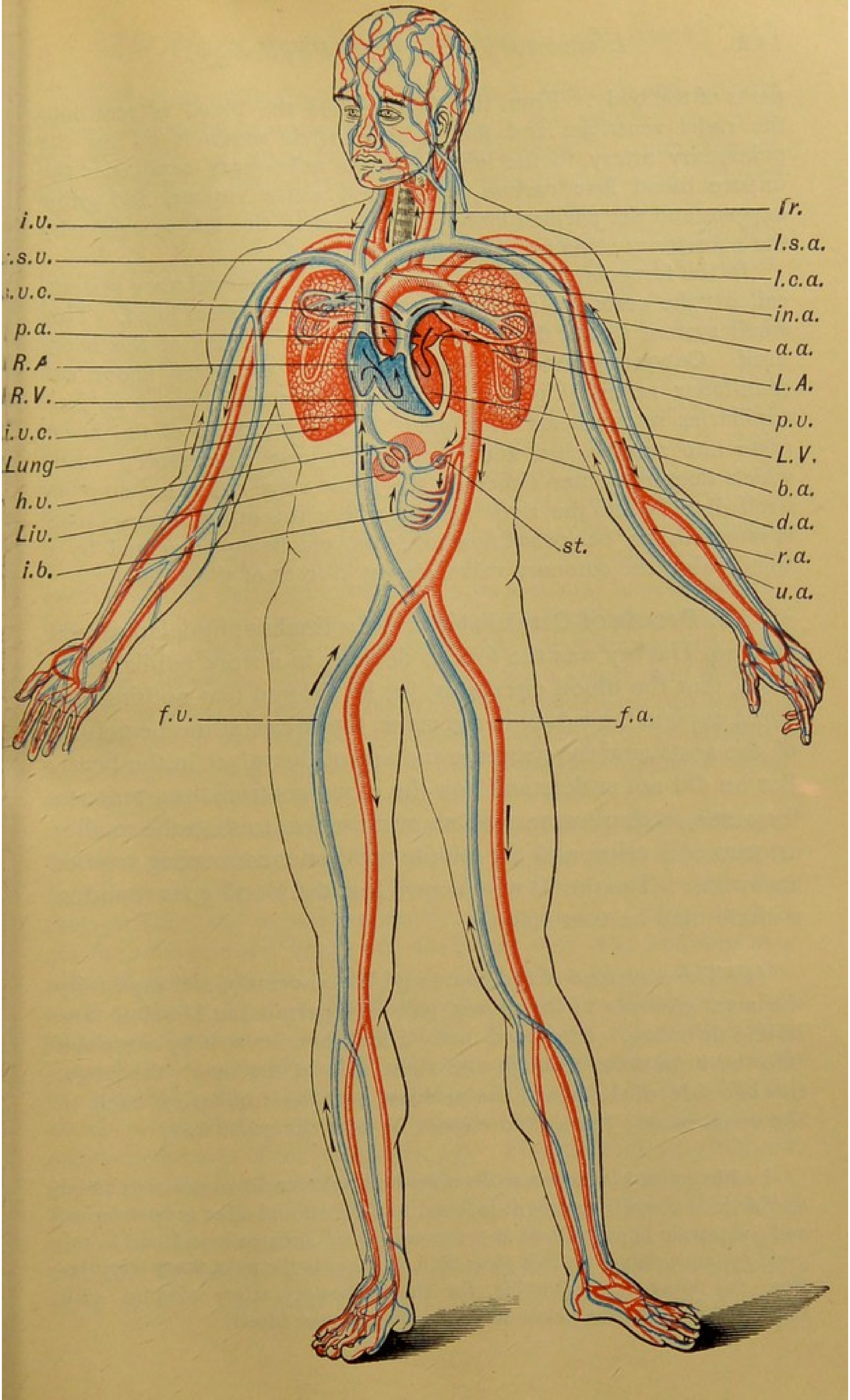


FIG. 72.—The aorta and its chief branches. 1, first portion of aorta ascending from left ventricle; 2, right subclavian artery, and 3, right common carotid artery formed from the innominate artery that comes from the aorta; 2′, on left side, left subclavian artery; 3′, on left side, left carotid artery; 4, cœliac axis dividing into branches for stomach, liver, and spleen; 5, renal arteries; 6, 7, arteries to intestines; 8, 8, common iliac arteries dividing into external iliac arteries and internal iliac arteries. (*From Paul's "Domestic Economy."*)

As the aorta passes down through the abdomen it gives off several large branches. One branch (the **cœliac axis**) is very short, for it soon divides into three—the **gastric artery** for the stomach, the **splenic** artery for the spleen, and the **hepatic artery** for the liver. Two branches, called **mesenteric arteries,** supply blood to the mesentery and intestines, and two **renal arteries** pass to the kidneys. In the lower and hinder part of the abdomen the aorta divides into two great trunks—the common **iliac arteries.** These again bifurate, and one branch on each side passes on into the thigh as a great **femoral artery,** while another branch, the internal iliac, supplies the viscera of the pelvis. From the femoral arteries the various parts of the leg receive their supply by smaller branches.

In the various organs and parts the smaller arterial branches break up into minute capillaries. Through the thin capillary walls oxygen and nutriment passes out in blood plasma to the various tissues, and waste matter, especially carbon dioxide, is taken up into the blood stream, the blood thus changing from pure scarlet arterial blood to impure dark venous blood (Fig. 74). By the union of the capillaries into small veins, and the union of small veins into larger ones, the impure blood from the countless systemic capillaries is at last brought back to the right side of the heart. Thus veins return the blood from the head and neck, two large ones on each side being called the **external jugular veins** and the **internal jugular veins.** In the hand and arms the veins unite to form the **right** and **left subclavian veins.** These large veins, and others, unite to form the **superior vena cava,** which pours its blood into the right auricle. From the feet and legs the veins unite to form the **inferior vena cava,** and on its way up the abdomen this large vein receives the **renal veins** from the kidneys, and the **hepatic veins** from the liver. The veins from the intestines, stomach, spleen, and pancreas unite to form a large vein called the **portal vein.** This portal vein runs to the liver, and there breaks up into capillaries; these capillaries pass their blood into the hepatic veins, from which it passes into the inferior vena cava. The peculiarity of this "portal circulation" is that the blood supplied to the intestines, stomach, spleen, and pancreas is made to pass through two sets of capillaries—one set in the organs themselves, and one set in the liver. The liver, in fact, contains about one-fourth of all the blood in the body, for it receives by the portal vein the blood ladened with the products of digestion from the organs just named, and pure blood by the hepatic artery, both streams mingling, and, after passing through the hepatic capillaries, reaching the inferior vena cava by the hepatic veins. The inferior vena cava passes up through the diaphragm, and empties its blood into the right auricle. This last cavity thus receives the impure blood from all

FIG. 73.—General view of the circulation of the blood. *Tr.*, trachea; *l.s.a.*, left subclavian artery; *l.c.a.*, left common carotid artery dividing above into internal and external carotid; *in.a.*, innominate artery; *a.a.*, arch of aorta; L.A., left auricle; *p.v.*, pulmonary vein; L.V., left ventricle; *b.a.*, brachial artery; *d.a.*, descending aorta; *r.a.*, radial artery; *u.a.*, ulnar artery; *st.*, stomach, etc.; *f.a.*, femoral artery; *f.v.*, femoral vein; *i.b.*, intestinal blood-vessels; *Liv.*, liver; *h.v.*, hepatic vein; *i.v.c.*, inferior vena cava; R.V., right ventricle; R.A., right auricle; *p.a.*, pulmonary artery; *s.v c.*, superior vena cava; *r.s.v.*, right subclavian vein; *j.v.*, jugular vein.



i.v.
.s.v.
.v.c.
p.a.
R.A
R.V.
i.v.c.
Lung
h.v.
Liv.
i.b.
fr.
l.s.a.
l.c.a.
in.a.
a.a.
L.A.
p.v.
L.V.
b.a.
d.a.
st.
r.a.
u.a.
f.v.
f.a.

parts of the body. From the right auricle the blood is sent into the right ventricle, and the right ventricle sends it on by the pulmonary artery to the lungs. In the pulmonary capillaries the impure blood lose carbon dioxide and water vapour, and gains oxygen, and the purified blood is returned to the left ventricle by the pulmonary veins from which we started.[1]

In the foregoing account a small part of the circulatory system, called "the coronary circulation," has not been mentioned. This small system serves the muscular and other tissues of the heart itself. **Coronary arteries** spring from the aorta just above the semi-lunar valves (Fig. 69), before it arches and breaks up into capillaries in the heart substance. The capillaries of the heart unite into small veins, and these finally form a **coronary vein**, which does not enter either of the great venæ cavæ, but empties itself directly into the right auricle, where the other impure blood is received, any backward flow into this vein being prevented by a small valve, the coronary valve, shown in front of 3″ in Fig. 67.

**58. Proofs of Circulation.**—An English physician named William Harvey was the first to declare, in a work published in 1628, that the blood circulates, for he showed that nothing else could explain the valves in the veins, the valves at the beginning of the aorta, and the structure and use of the valves in the heart. But he did not understand how the blood got from the arteries to the veins, as there were then no microscopes to show the smaller arteries and veins, and the minute capillaries connecting arteries and veins. The proofs now known that the blood goes round in a circle may be thus stated—

(1) The structure of the heart and blood-vessels, and especially the arrangements of the valves, will only permit the blood to flow in one direction. In a dead body a fluid can be sent by a syringe into the vena cava, through the right side of the heart, the lungs, the left side of the heart, the arteries, and the capillaries, back to the venæ cavæ; but a fluid cannot be sent the other way.

[1] Although it is common to describe the bright scarlet oxygenated blood as "arterial blood" because it is found in the aorta and other great arteries, and the purple impure blood as "venous blood" because it is found in the great systemic veins, yet it is clear that, as regards the **pulmonary circulation**, the terms are unsuitable, for the pulmonary artery contains dark impure blood, and the pulmonary veins bright pure blood.

(2) If an artery be tied in a living body it swells up and pulsates on the side of the ligature nearest the heart, and becomes empty on the other side. If an artery be cut, pressure must be applied to the cut end nearest the heart in order to stop the bleeding. Hence the blood must be flowing in arteries towards the capillaries.

(3) In the living body, if a vein be tied it swells up on the side furthest from the heart and empties on the side nearest the heart. If the vein be cut pressure must be applied to the side remote from the heart to arrest the bleeding. Hence blood must be flowing in veins from the capillaries.

(4) In some animals parts of the body are so transparent that the blood can be seen flowing from small arteries into capillaries, and then on into small veins. Such a part is the web of a *frog's foot.* Some of the vessels in it can be seen by the naked eye. On placing a frog in a bag, and laying it on a thin board, the web between two toes may be fastened out over a hole in the board without hurting the animal. On examining this web under the microscope the blood, with the corpuscles in it, may be seen running from a small artery through the network of capillaries in the thin connective tissue between the skin on each side of the web (Fig. 75). The red corpuscles, which are oval and much larger than those in man, rush along the small arteries in the blood stream two or three abreast, but in the smallest capillaries they have to be squeezed and elongated to get through. A few colourless corpuscles about the same size as those in man may also be noted.

**59. Dissection of a Sheep's Heart and Observation of the Heart-beat in the Frog.**—Order from a butcher a sheep's heart with the lungs, telling him to leave on the heart-bag (pericardium) and as much of the vessels as he can. You will then get the windpipe and lungs and the heart in its bag attached to a piece of the diaphragm. Cut open the pericardium, and note the small quantity of pericardial fluid and the mode in which one layer of the pericardium is attached to the heart and the roots of the great blood-vessels (Fig. 64). Remove the pericardium, and find the rounded front of the heart and the flatter posterior side. Decide which is the right side and which the left from the shape and relative thickness of the walls (par. 53). Find the clear longitudinal groove on the front surface, and also the transverse grooves. At the base of the heart find the thin-walled auricles with the crinkled muscular appendix of each. At the back of the heart, on the right side, find the inferior and superior venæ cavæ in connection with the right auricle. Cut away the upper vena cava close to the auricle, and push the pencil, or a finger, into the right auricle and down into the ventricle. Cut away the upper part of the auricle, and then pour water through the opening down into the ventricle. Now press gently the wall of this ventricle, and note the rise of the flaps of the tricuspid valve. On cutting into the right ventricle the flaps of the tricuspid valve may be seen to arise from the sides and to have cords (the chordæ tendineæ) below which pass to fleshy columns in the wall of the ventricle that form the papillary muscles. In the left upper corner of the right ventricle may be found the beginning of a stout tube that rises in front from this ventricle. This stout tube is the pulmonary artery, and it will be found to divide above, one branch going to each lung. After cutting away part of the walls of the right ventricle open the lower end of the pulmonary artery, and find the semi-lunal valves at its beginning, like watch-pockets of thin membrane, lying against the inner wall. Raise them from the wall with the point of a pencil.

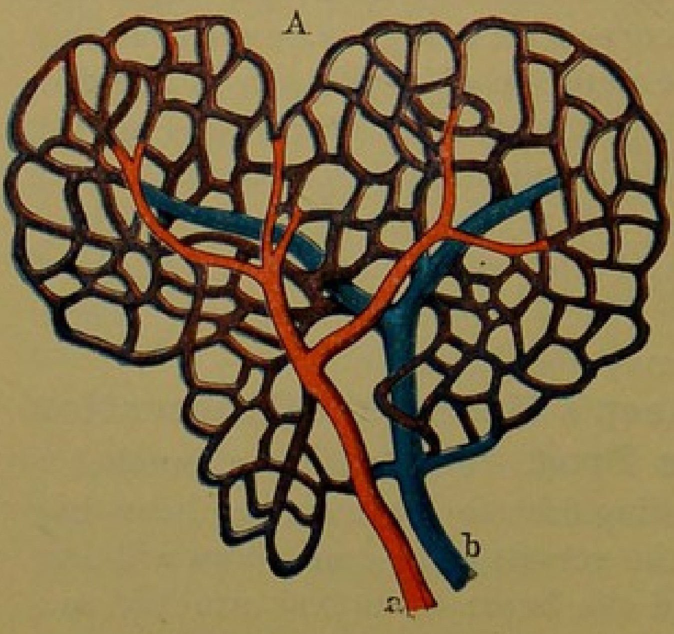



FIG. 74.—Magnified view of the capillary network surrounding a mass of fat cells. The small entering artery, *a*, is red; the capillaries, A, violet; and the small vein coming away, *b*, blue. Illustrates the change of arterial blood to venous blood.

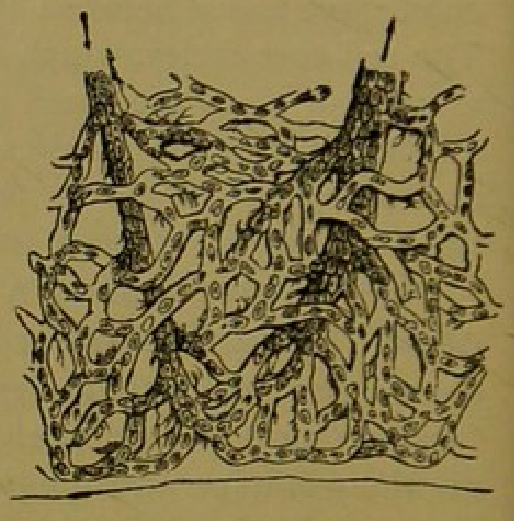


FIG. 75.—Capillary blood-vessels in the web of a frog's foot, as seen with the microscope. (After Allen Thomson.) The arrows indicate the course of the blood, and the oval corpuscles of frog's blood are seen within the capillaries. (*From Quain's "Anatomy."*)

Rising from the left ventricle, behind the origin of the pulmonary artery, there will be found the aorta—the stoutest of the tubes connected with the heart. With a little care, too, thin-walled vessels may be found connected with the left auricle. These are the pulmonary veins. (In the human heart there are four pulmonary veins.)

Now cut off the aorta a little above the top of the left ventricle. Look down and note the three semi-lunar valves similar to those found at the root of the pulmonary artery. Pour water down the aorta, and notice how these three valves fill, swell out, and meet in the middle, thus preventing water from going down into the ventricle. A fluid can flow out of the ventricle along the aorta, but not from the aorta into the ventricle. The left ventricle may now be opened by cutting round the apex and side at a little distance from the longitudinal groove. Examine its thick walls, the mitral valve, the tendinous chords, and the papillary muscles.

The beat of the heart can be observed in the exposed heart of a frog that has been killed by destroying its brain or cutting off its head, for in cold-blooded animals the heart lives and continues to beat after such a violent death. Kill a frog by cutting off its head, and then cut away the front wall of the chest. Open the pericardium, and observe the beat of the heart. The two auricles, contract and become paler, and then the ventricle (a frog has only one ventricle). The ends of the great veins form a kind of chamber called the sinus venosus, and this also may be observed to contract before the auricles. A frog's heart may be removed and put on a plate to observe the contraction, as it even then goes on contracting for some time.

# CHAPTER VIII.

## *STRUCTURE AND PROPERTIES OF THE BLOOD-VESSELS—BLOOD PRESSURE—THE PULSE—THE NERVOUS CONTROL OF THE CIRCULATION.*

**60. The Structure of the Arteries.**—The wall of a large artery can be separated into three coats—(1) a thin internal lining of endothelium, consisting of flat nucleated epithelial cells, united together at their edges, and having a little delicate elastic tissue outside; (*b*) a middle muscular coat, consisting of yellow elastic and white fibrous tissue, among which are many spindle-shaped muscle cells, forming plain or non-striated muscular fibres arranged round the arteries; (*c*) a tough outer coat of white fibrous connective tissue. The large arteries, like the aorta and its branches, contain a large proportion of elastic tissue, so that they stretch when pulled and increase in bore when distended. When empty they keep their tubular form. The smaller arteries are distinguished from the larger arteries by the increased proportion of non-striated muscle fibres.

**61. The Structure of Capillaries.**—In the smallest arteries the middle and outer coat gradually disappear, until in the capillaries, the average diameter of which is only about $\frac{1}{3000}$ of an inch, there is left only the inner lining of endothelial cells to form their exceedingly thin walls. These vessels are thus well adapted to allow of the passage of fluid or the diffusion of gases through the thin membrane forming their walls. In the systemic capillaries fluid passes out to nourish the surrounding tissue, and the red corpuscles give up most of their oxygen to the tissues. Carbon dioxide and other products of oxidation, on the other hand, pass from the tissue through the capillary walls into the blood.

**62. Structure of Veins.**—As the capillaries pass into veins, the same three coats as are found in arteries begin to appear, but even in the large veins the walls are not so thick as those of the arteries, because their walls contain a much less

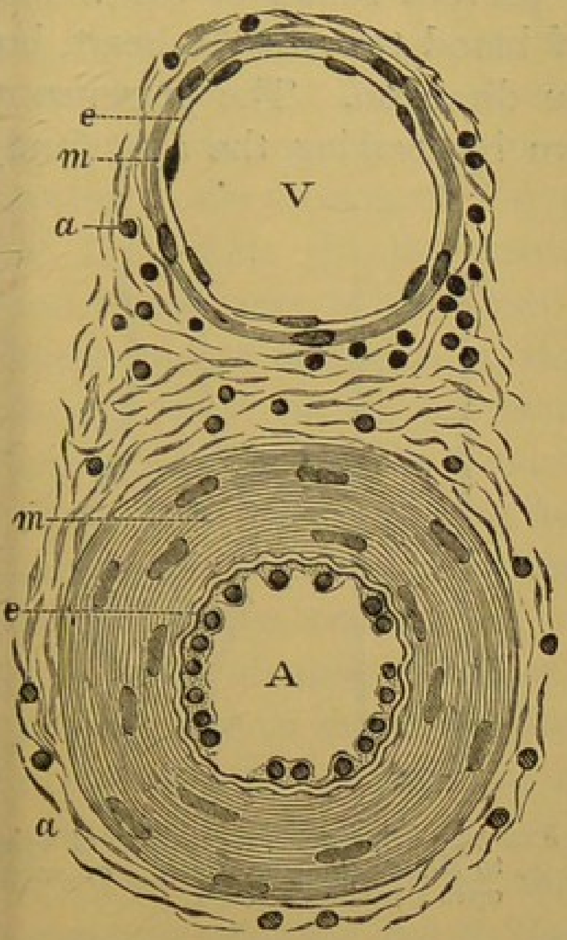



FIG. 76.—Section of small artery and accompanying vein (magnified). A, artery; V, vein; *e*, endothelial cells forming inner coat; *m*, muscular coat; *a*, connective tissue showing nuclei of connective tissue corpuscles. (*From Gray's "Anatomy."*)

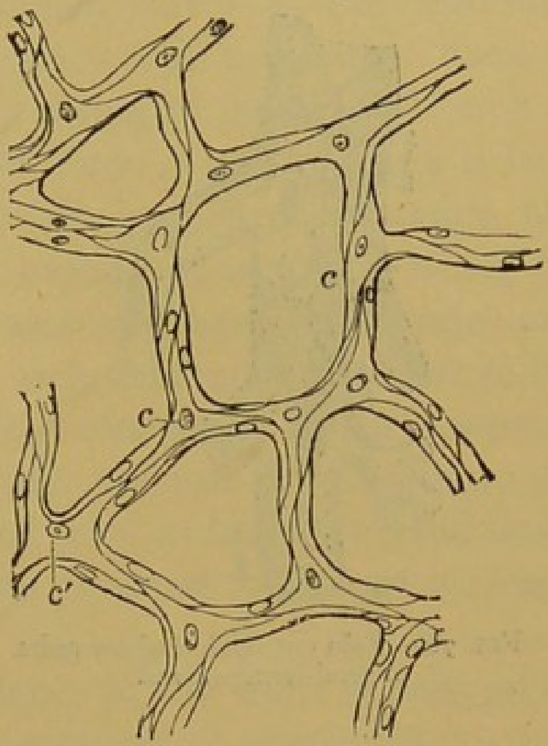



FIG. 77.—Capillary vessels (highly magnified), showing walls consisting of a single layer of nucleated epithelial cells, *c*, *c*, *c*¹, meeting-points of adjoining vessels. (*From Quain's "Anatomy."*)

proportion of elastic and muscular tissue than those of arteries, though their outer coat of fibrous tissue renders them strong and tough. When an artery is cut across it remains open and keeps its form as a tube owing to the amount of elastic tissue in its thick walls; but when a vein is cut its thin walls, with little elastic tissue, collapse or fall together. In this way the larger arteries and veins can be distinguished in a dead body or a piece of meat.

Most veins further differ from arteries in being supplied abundantly with valves along their course, while no artery possesses valves (except the pulmonary artery and aorta, which have valves at their origin close to the heart). The valves of veins are semi-lunar, or half-moon shaped folds of the lining membrane, and are usually arranged in pairs, so that the free margins can come together and prevent reflux of the blood. They thus allow the passage of blood towards the heart, but prevent its flow in the opposite direction. The presence of these valves may be readily shown by stroking the arm firmly

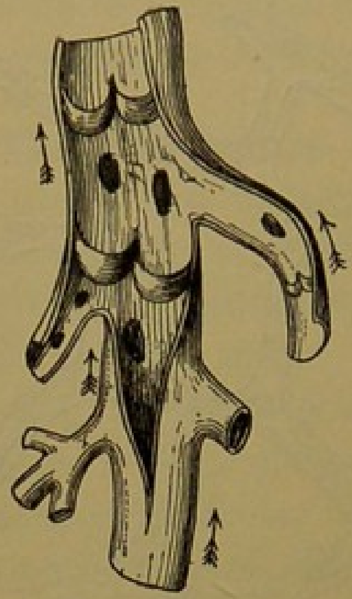


FIG. 78.—Vein cut open to show pairs of semi-lunar valves.

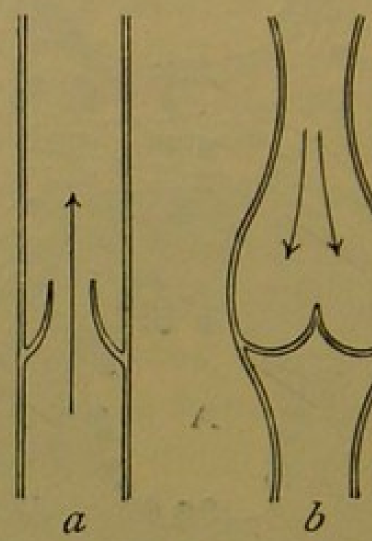



FIG. 79.—Diagrammatic section of veins to show action of valves. *a*, valves open; *b*, valves closed.

towards the hand, when little swellings or knots will rise up and be visible where the valves in the veins under the skin are stopping the blood from being pushed back.

Valves are most numerous in the veins of the limbs, neck, and near the surface generally. They are absent in the venæ cavæ, portal vein, and pulmonary veins.

**63. Blood Pressure.**—We have learnt that the aorta and the chief arteries have so much elastic tissue in their walls that they are really elastic tubes, and this elasticity of the arteries plays an important part in the circulation. During life the arteries are always so full of blood that their walls are on the stretch, for the blood is pressing against their walls with considerable force. This pressure of the blood on the arterial walls is called the **blood pressure.** It is shown when any large artery is cut, for the blood spurts out to some distance. It is also shown by placing a vertical tube in any large artery, when the blood is forced some distance up the tube—about five feet in the case of one of the large arteries near the heart. Conversely, the artery is pressing upon the contained blood with just the same force, as the reaction of an elastic substance is equal to the straining force. This equal pressure of the arteries on the blood in them squeezes the blood onwards towards the capillaries, for it cannot go back into the heart owing to the closing of the semi-lunar valves at the beginning of the aorta. In the small arteries and capillaries there is much resistance to the blood flow owing to the great friction in these minute passages, so that the force of the pressure is here largely used up in overcoming this capillary resistance, just enough remaining to send the blood on, into, and along the veins. The pressure also decreases in the smaller arteries and capillaries, as the total sectional area is greater than that of the larger arteries, or, in other words, because the blood is moving in a wider channel. Hence blood pressure is greatest in the arteries, less in the capillaries, and least in the veins; and fluids always flow from a place of higher pressure to a place of lower pressure.

The onward flow of the blood in the veins is assisted by muscular exercise and by the movements of respiration. When the thorax enlarges in inspiration, the diminished pressure there produced serves to draw the blood, as it were, from the veins into the right ventricle, and the descent of the diaphragm squeezing the organs of the abdomen has the same effect.

**64. The Pulse.**—At each contraction of the ventricle a fresh quantity of blood is forced into the already distended aorta, and this suddenly stretches it still more. This extra expansion of the wall of the aorta at every heart-beat passes quickly as a wave along the aorta, and then along all the arteries, and this wave of expansion is known as **the pulse.** The pulse or wave of expansion is thus due to the sudden forcing of blood into the stretched aorta. Part of the force of the contraction of the ventricle sends the blood into the aorta, and part goes to increase the expansion of the walls of the arteries, and at the same time the pressure of the blood. The blood pressure of the arteries thus rises and falls with the heart-beat, so that a vertical tube showing this pressure would exhibit regular risings and fallings in the column of liquid, the mean height being between highest and lowest positions. This increased expansion or blood pressure is used in squeezing on the blood during the ventricular diastole. It will thus be seen that it is the heart that keeps up the force exerted by the stretched arteries to squeeze on the blood in them. During the contraction the force is stored up, as it were, in the stretched artery, and while the ventricle is dilating this force is spent in keeping up the flow. The pulse travels over the walls of the arteries at a rate of about thirty feet per second, reaching the wrist from the aorta in about one-tenth of a second. It can be distinctly felt in any part where an artery passes over some hard structure, *e.g.* in the radial artery at the wrist, or in the temporal artery at the temple. The progress of the pulse wave must not be confounded with the flow of the blood, which is much slower, a little above a foot a second. The pulse wave may be compared to the wave produced by a rapid wind on the surface of a slowly moving stream.

There is no pulse in the capillaries nor in the veins, for the jerky flow in the arteries is converted by the elasticity of their walls, by the friction that the blood in its progress has to overcome, and by the greater total sectional area of the capillaries, into *a slower and steady continuous flow* in the capillaries and veins. A cut artery not only spurts out the blood, but spurts it out in jerks owing to the pulse wave, while the blood flows from a vein in a steady stream. The whole of the blood of the body passes through the heart, the arteries, the lungs, and capillaries nearly three times every minute—once in twenty-three and a half seconds.

**65. Regulation of the Frequency and Force of the Heart-beats.**—If the heart be quickly removed from the body of a sheep or other mammal that has been killed, it goes on beating for a few minutes, and in the case of a cold-blooded animal for some hours. This shows that the peculiar muscular tissue of the heart possesses the property of contracting and relaxing without nervous impulses from the central nervous system.

In the living body, however, this power of automatic movement is modified and regulated by nervous impulses sent out from the brain and spinal cord. This regulating influence of the nervous system on the heart is of two kinds—Firstly, an influence checking or stopping its beating altogether; secondly, an influence quickening or strengthening its beats. From a part of the brain called the medulla or spinal bulb, several pairs of nerves are given off on each side (par. 147). One pair, called the **vagus** or **pneumogastric nerve**, sends branches to the heart, and the influence of the vagus nerve on the heart is a restraining or checking influence. This influence is generally in action, keeping the beat at a moderate rate. When a more active blood supply from the heart is needed, as in vigorous exercise, these restraining influences of the vagus nerve diminish. Fright or shock, or some other strong emotion, or a blow on the stomach, may cause the vagus to send such strong restraining influences that the heart stops beating, and the want of a fresh supply of blood in the head may then cause a person to faint, the loss of consciousness being due to the want of pure blood in the brain. Nerves also pass to the heart from the spinal cord that increase the frequency or force of the beat, or both, when stimulated. Strong emotion may produce the rapid beating called **palpitation,** by acting through the accelerating heart nerves from the spinal cord, though such increase may also arise from the removal of the restraining influence of the vagus.

**66. The Nervous Control and Regulation of the Blood-vessels.**—The changes in frequency and force of the contraction of the ventricles of the heart affect the blood supply of the whole body. But it often happens that some limb or other organ is in vigorous action, and it then requires more blood than the other organs. When moving the arms actively they want an increased blood supply; when calculating difficult problems the brain wants more blood, and after a good meal the stomach requires an increased supply to carry on the work of digestion. This variation of blood supply to separate organs and tissues is brought about by changes in the calibre or width of the small arteries. It will be remembered that the arteries have a middle coat of plain muscular fibres running round them, and that these fibres become relatively more abundant in the smaller arteries. To these muscular fibres nerves are supplied, just as motor nerves pass to the striated skeletal muscles. The nerve fibres passing to the muscular tissue of arteries regulate their calibre, and are called **vaso-motor nerves** (Lat. *vas*, a vessel).

The vaso-motor nerves spring from the spinal cord, and from here they make connections with a group of cells in that part of the brain called the medulla, or bulb. From this group of cells in the medulla, called the **vaso-motor centre,** nervous impulses are constantly passing to the small arteries and keeping them in a state of moderate contraction, known as **arterial tone.** This state of tonic contraction of the arteries is the usual one, but influences may pass to the vaso-motor centre in the medulla that lead to the lessening of the tonic contraction of the arteries going to some limb or organ. These vessels then dilate, and an increased blood supply is furnished to them. On the other hand, certain influences may stimulate the action of the vaso-motor centre, and cause stronger influences to pass along the vaso-motor nerves leading to the constriction of the arteries and a lessened supply of blood. The circulation of venous blood stimulates the vaso-motor centre, and as the blood always becomes venous at death, the stimulation of the centre at this time contracts the arteries and drives the blood into the capillaries and veins as the heart ceases to beat. Hence "the emptiness of the arteries after death."

**Blushing** is an instance of vaso-motor action where some emotion so acts on the vaso-motor centre that the nervous impulses, which pass by the vaso-motor nerves to the arteries of the neck and face, and which keep these vessels in a state of tonic or moderate contraction, become relaxed or withdrawn, and then the capillaries of these parts become flushed with blood.

**Pallor,** due to fright, is also at times an instance of vaso-motor action, due to an increase in the impulses that contract the smaller arteries, so that the blood supply to the face is diminished. But sudden pallor may also, as stated in the previous paragraph, be due to a checking and weakening of the action of the heart, and it is then often accompanied by fainting.

**67. Experiments illustrating Features of the Circulation.**—Many of the important facts of the circulation and blood pressure can be illustrated by a common enema syringe and a supply of rubber tubing. With these an artificial model or schema of the circulation may be constructed. One form of such a model is illustrated in Fig. 80. The heart is represented by an elastic enema syringe, H, in which there is a valve (the auriculo-ventricular valve) ; the arteries by a piece of elastic tubing leading from it, A ; the capillaries by a reservoir, C, containing several passages ; and the veins by another elastic tube leading from the capillaries back to the heart, V. In the tube representing the arteries there is inserted a manometer or pressure-gauge, M. Another manometer, P, is attached to the veins. The letter L represents a clip or clamp which can be screwed up so as to compress A. The valve in H prevents back flow.

The apparatus being quite full of water, the mercury will stand at the same level in each of the two manometers, since the pressure on the surfaces of the two limbs is the same, viz. the outside atmospheric pressure conveyed directly to $m'$ and $p'$, and through the water to $m$ and $p$.

Now squeeze the syringe with the hand to imitate the left ventricular beat that sends the blood into the aorta and its branches. If the connecting pieces are freely open, it will be noticed that after each stroke the increased pressure in A forces the mercury down in the near limb $m$ of the manometer M and up in the far limb $m'$. The mercury, however, soon falls again, and very shortly afterwards the manometer attached to V shows a similar rise and fall ; for the fluid pumped into A easily passes on to V. With each successive pump of the syringe the same rise and fall, owing to the same increase and decrease of pressure, takes place in each manometer.

Now screw up the clamp so as to narrow the tube A and to introduce a considerable resistance to the onward flow into C.

This represents "the peripheral resistance" offered by the contractile action of the small arteries, and the friction in the capillaries. It will now be noticed that with each squeeze of the syringe the mercury rises higher and higher in the outward limb of M, showing increase of pressure in A, until it attains a certain height, where it remains, merely oscillating a little above and below at each squeeze of H (each heart-beat, as it were). But the venous manometer shows scarcely any rise of pressure, and but slight oscillation of the mercury in each limb. (The amount of pressure is shown by the difference of the level in the two limbs of the manometer.) For each squeeze of the syringe, or stroke of the pump as it may

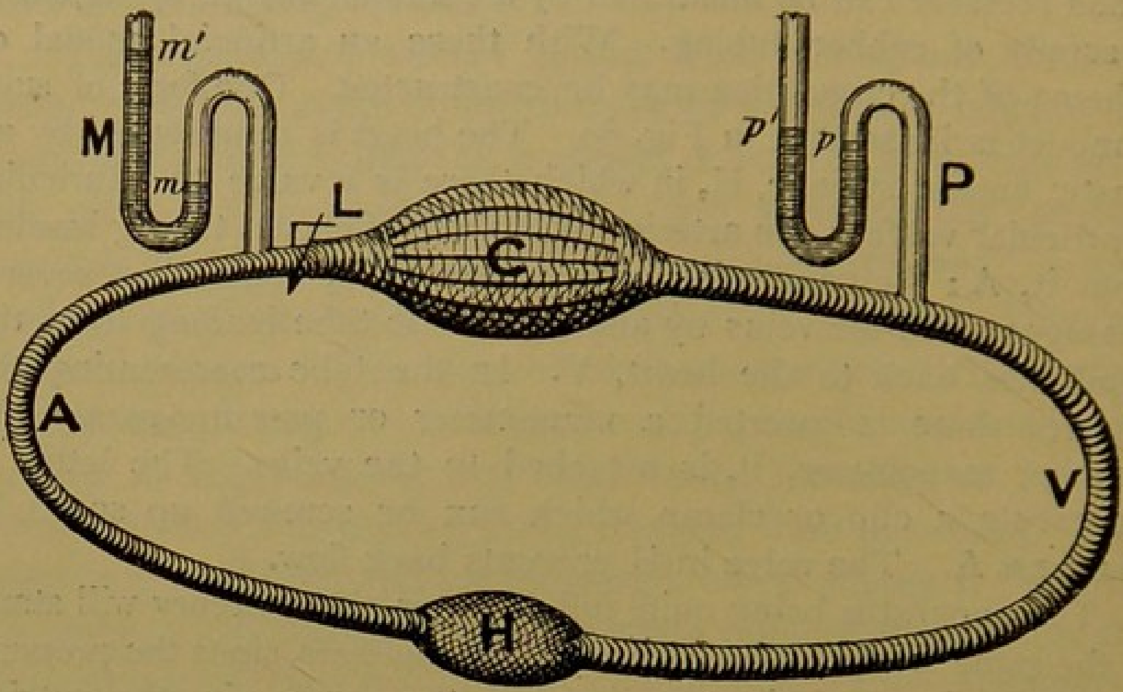



FIG. 80.—Apparatus to illustrate circulation and blood pressure. (*From Thornton's "Human Physiology."*)

be called, forces a certain amount of fluid into the arterial tube and into C, but owing to the peripheral resistance this cannot pass on into the capillary lake all at once, so that part of the force of the pump is spent in sending the fluid onwards and part in distending the walls of the elastic arterial tube and increasing the pressure in it. The elastic reaction of the distended tube tends to force the fluid onwards also, and to overcome the peripheral resistance, where the more distended the tube becomes the stronger is this elastic reaction. With a certain rapidity of stroke the elastic reaction of the tube and the intermittent flow in A becomes a continuous flow in V, and the pressure becomes so great that the fluid forced out of the arterial tube during the interval between each stroke is exactly equal to that sent in at each stroke. Thus the fluid passes continuously into the venous tube V, and flows on steadily at a low pressure, a large part of the arterial pressure having been used up in overcoming peripheral resistance at L and C.

If, while working the syringe, a small hole be made in the tube A, the water will spurt out in jerks to some distance, but with a certain speed of working from a hole in V there would only be a gentle, steady flow. Further, with each squeeze of the syringe a pulse wave may be felt in A, but none in V, when the resistances at L and C are in action.

# CHAPTER IX.

## *THE LYMPHATIC SYSTEM.*

**68. Lymph.**—The blood circulates in a system of tubes, and the smallest of these, called capillaries, are so numerous that they form a close network in muscle and other tissues. The capillaries have exceedingly thin walls, as the walls are formed of a single layer of flattened cells united together at the edges. Through these thin walls part of the blood plasma passes by **diffusion**, and thus brings nutritive material to the cells and fibres of tissues. The fluid containing nutrient material that oozes out of these capillaries and bathes the living tissues is called **lymph.** It is therefore important to note that there is no actual contact between blood and tissues, for the blood is confined to the capillary vessels, but there is diffusion of nutrient liquid from the blood to the lymph, and from this the cells and fibres of the tissue draw their nourishment. The lymph thus plays the part of middleman or intermediary between blood and tissue. The cells and fibres of the tissue are bathed in lymph, and from the lymph they take up nutriment, while into it they excrete their waste products.

Lymph is a colourless fluid containing in solution, like blood plasma, proteids, carbohydrates, and salts, though the proteids are somewhat less and the water more in quantity. It also contains some white corpuscles that have passed out of the blood capillaries, but few or no red ones. It will also coagulate and clot like blood plasma.

Besides the passing in of nutrient material from lymph to the cells of the surrounding tissue, there is also a passage in the opposite direction of waste material from the tissue cells to the lymph. In addition to this nutrient material supplied to the tissues by the lymph and originally obtained by the blood from the food, there passes from the capillaries into the lymph, and then to the tissue, the gas oxygen by which the tissue is enabled to oxidize the nutrient matter, and thus set free the store of energy it contains. In the opposite direction, *i.e.* from the tissue to the lymph, and then into the blood of the capillaries, there passes the gas carbon dioxide, one of the products of the oxidation mentioned. The carbon dioxide thus taken up is carried away by the blood stream to the lungs, where it is given up and a new supply of oxygen obtained, as will be explained in the next chapter.

A large part of the lymph that passes out of the blood capillaries returns again after undergoing the changes mentioned into the capillaries, but there remains a certain quantity in the tissues that does not find its way into the capillaries, though it eventually gets into the main blood stream in a roundabout way, now to be explained.

**69. Lymphatic or Absorbent Vessels.**—The excess of lymph from the blood that does not return into the blood capillaries, with some of the white corpuscles that have escaped into the tissues, lies in minute spaces between the cells of tissues, and these spaces are drained by minute tubes, which *begin* in the tissue and are called *lymphatic capillaries*. These unite to form larger lymphatic vessels, and by these lymphatic vessels the lymph is carried away from every tissue and organ of the body, to be at last sent into the stream of venous blood a little before this blood enters the heart. The lymphatic vessels run in general in a superficial set and a deep set. Some idea of their distribution and connections may be obtained from Fig. 81. In their course lymphatic vessels pass through enlargements, called *lymphatic glands*. These will presently be described.

The lymphatic vessels formed by the union of lymph capillaries have the general structure of veins, but their walls are thinner, so that they are difficult to see when empty. When full and distended they show a beaded appearance, owing to the numerous semi-lunar valves. As the free edges of all the valves are turned towards the heart, the motion of the fluid must always be in that direction, and there can be no reflux. The causes of the onward flow are the pressure behind and

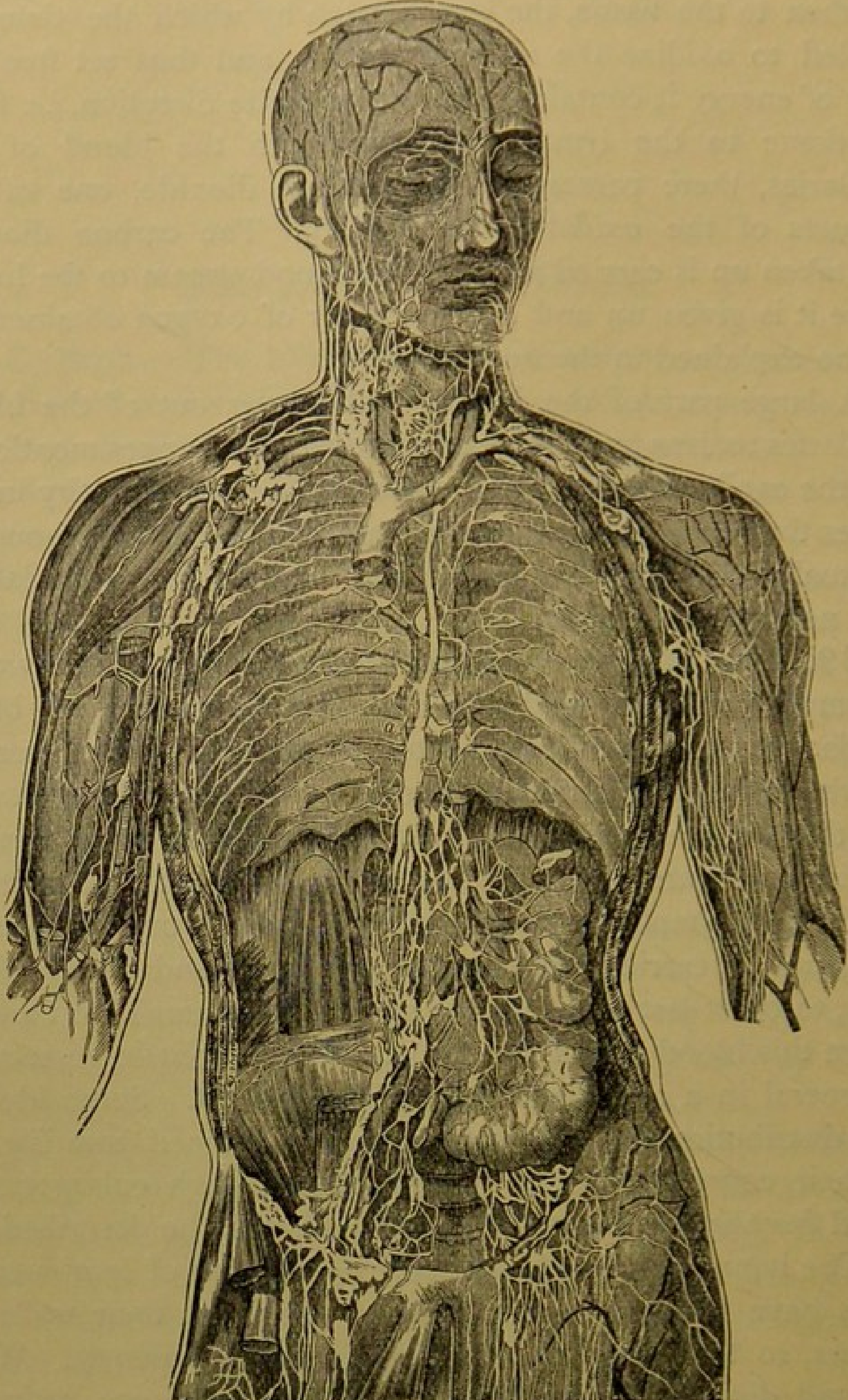


Fig. 81.—Diagram of lymphatic system, showing vessels and glands (white). *a*, thoracic duct entering on the left into the blood stream at the junction of two veins at root of neck; *v* left innominate vein; *i*, a portion of intestine with lacteals passing from it.

the smaller pressure at the point of discharge. The various muscular movements that squeeze the tissues also aid in forcing on the lymph in the direction allowed by the valves. The lymphatic vessels of the small intestines have the special name of *lacteals* (Lat. *lac*, *lactis*, milk), because besides absorbing tissue lymph they absorb from the intestines the emulsified fat of the food, and thus after meals become filled with a white milky looking fluid called *chyle*. More will be said about the lacteals in the chapter on digestion.

**70. The Thoracic Duct.**—All the lymphatic vessels from the lower limbs, the lower part of the trunk, the intestines, and the left side of the body discharge into a large trunk vessel that is known as the **thoracic duct**, although a part of it is in the abdomen. It is a tube about one-third of an inch in diameter, and extends in front of the spine from opposite the second lumbar vertebra to the root of the neck, passing on its way upwards through the diaphragm. At its lower end, where the lacteals (the lymphatics of the intestines) and many other lymphatics from the legs and abdominal viscera enter, there is a long dilatation called the **receptaculum chyli.** At its upper end it turns sharply to the left and opens into the subclavian vein just at its junction with the external jugular vein. The vein formed by the union of these two veins enters the superior vena cava (par. 57). Valves are found at various parts in the thoracic duct, and a pair of semilunar valves at the entrance allows the lymph and chyle contents to pass into the blood-vessel, and guards against any reflux.

The lymphatics from the right upper limb, the right side of the head and neck, and the right lung enter a small **right lymphatic duct** that enters the venous system at a corresponding place to the entrance of the thoracic duct on the left side. Hence we now understand that there is a constant stream of lymph passing from the tissues to the lymphatic ducts, and that the fluid passes from these ducts into the blood stream of the subclavian veins at the root of the neck.

**71. Lymphatic Glands.**—Both the lacteals from the intestines and the other lymphatics that take up lymph in the other parts of the body pass on their way to the thoracic duct through small structures termed lymphatic glands. Through these glands therefore, the lymph and chyle must pass in their outward course to the blood stream. These bodies vary in size from a hemp-seed to a large hazel-nut, and occur both singly and clustered together.

They are abundant under the armpit, in the fold of the groin at the top of the leg, at the front and sides of the neck, root of lungs, and in the mesentery by which the intestines are suspended to the abdominal wall. Lymphatic vessels pass into these glands on one side and leave them on the other, the glands being also supplied with blood-vessels. The gland is enclosed in a capsule or covering, and within shows a mass of fine connective tissue, into the meshes of which the entering lymphatics pour their fluid. Numerous small colourless corpuscles or lymph cells are found in the loose tissue within a gland. These are really young colourless corpuscles, for in a lymphatic gland the white corpuscles undergo division and multiply in number. The lymph and chyle brought to a gland percolate through the meshes of the gland tissue, and in their passage carry away many new colourless corpuscles, so that the lymph leaving these glands contains more colourless corpuscles than that entering them. One function of the lymphatic glands is, in fact, to keep up the supply of these corpuscles in the blood, and to make up for those that break up. The spleen is another organ furnishing these corpuscles. Lymph glands serve also to arrest foreign bodies (bacteria, dust particles, etc.) brought by white corpuscles, and the actively multiplying cells in them often destroy such bodies and keep them from getting into the blood stream.

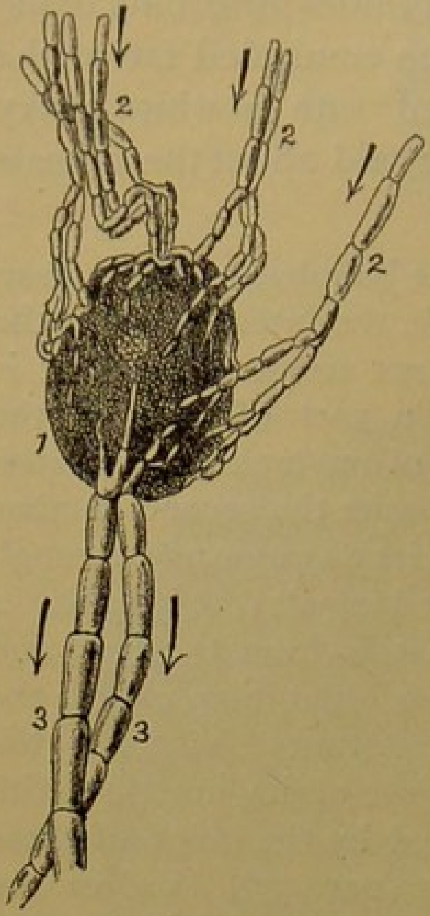



FIG. 82.—A lymphatic gland (1) is shown with (2) afferent vessels, and (3) efferent vessels. The numerous valves cause the beaded appearance of the lymphatic vessels.

**72. Summary of the Vascular System.**—A short review of the whole vascular system will now be useful—the term "vascular system" including all the vessels which convey the circulating fluids, *i.e.* the blood, lymph, and chyle. The diagrammatic figure accompanying this will assist in this review, for this diagram has more detail than Fig. 71. The venous blood is collected from the capillaries of the head and neck *f* by the upper vena cava *h*, and from the capillaries of the extremities and trunk *g* by the lower vena cava *l*, and by these two great veins poured into the right auricle of the heart, *m*; from the right auricle it flows into the right ventricle, *n*, which propels it into the lungs, *k*. Here the venous blood gives up carbon dioxide, and receives oxygen, becoming converted into arterial blood. Arrows indicate the air entering and leaving the windpipe. From the capillaries of the lungs *p* the purified blood passes by four pulmonary veins, represented by *q*, into the left auricle *a*, and from this into the left ventricle *b*. The left ventricle then propels the blood into the aorta *c*. This great artery gives off branches above, *d*, to the head and neck, and below to the stomach and intestines (represented by *r*), to the liver *s*, and to the smaller arteries and capillaries of the other parts of the body *g*. From all these systemic capillaries the blood again returns through the venous system. The blood from the stomach and intestines *r* does not pass at once into the general system, but enters by a distinct vein, called the **portal vein**, *u*, into the liver *s*, through which it passes, and in which it unites with the pure blood of the hepatic artery *t*, before it enters the hepatic veins *v*, to join the inferior vena cava. This part of the circulation is called the **portal circulation**.

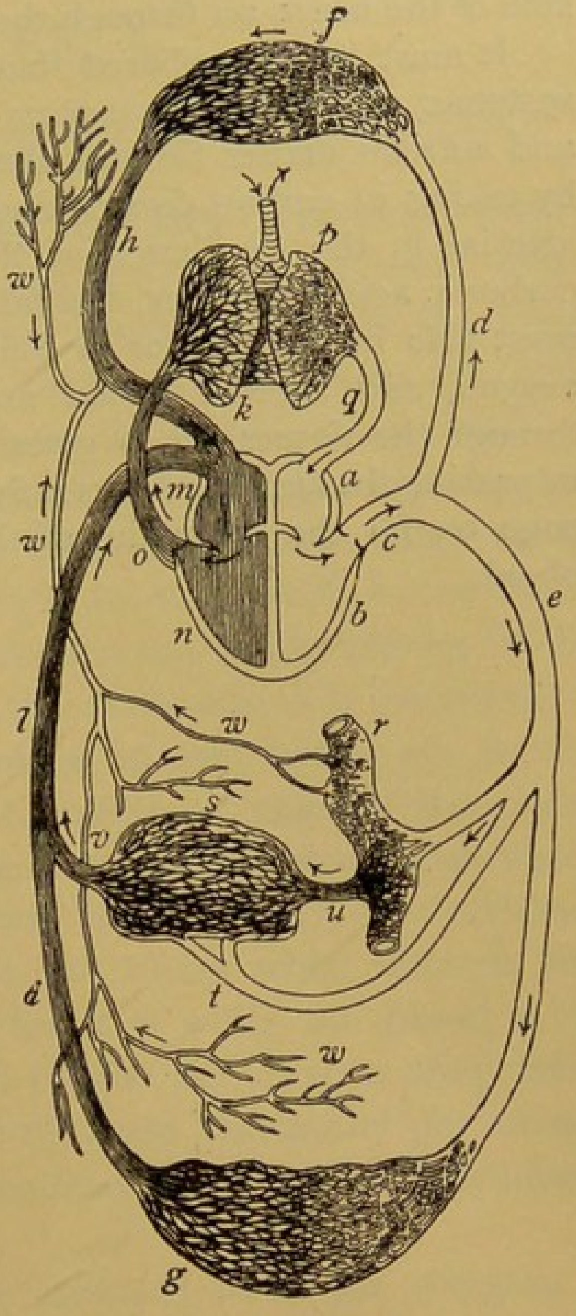



FIG. 83.—Diagram of the vascular system—pure blood in the unshaded vessels, impure blood in the shaded vessels. For explanation of letters, *see* Text.

The diagram also represents the lymphatic or absorbent system of vessels. Lymphatic vessels, represented by *w*, *w*, *w*, arise in all the tissues and in all the organs, and convey away lymph. Most of these vessels unite to form a large trunk, the thoracic duct, the vessel formed by the union of *w*, *w*, *w*, and this trunk pours the lymph into the venous blood stream before it enters the heart (compare Fig. 81). The lymphatic vessels from the intestines, the middle *w* (*r* represents the intestines), are called lacteals, because they convey with the lymph a milk fluid during digestion, called **chyle.**

Careful study of Fig. 83 will be well repaid. Describe the circulation, beginning with the pure blood in the left auricle *a*, and following its course through a part of the body to the right side of the heart, on through the lungs to the starting-point again.

It must be remembered that the blood becomes venous in the systemic capillaries of all parts by giving up some of its oxygen and nutrient matter through the exuded lymph to the tissues, and by taking in carbon dioxide and other waste matter. It becomes arterial in the capillaries of the lungs where it gives up some carbonic acid and water, and takes in oxygen again. The student must also be careful not to think that venous blood contains no oxygen, and arterial blood no carbonic acid; for, in passing through the tissues, blood gives up only a part of its oxygen, and in passing through the lungs only a part of its carbonic acid. See page 90 for the quantities of the two gases in the two kinds of blood.

## CHAPTER X.

### *THE ORGANS AND PROCESSES OF RESPIRATION.*

**73. The Need of Oxygen in the Tissues.**—Every muscular contraction, every activity of a gland, and even every feeling and thought carried out by nervous action in the brain involves and is accompanied by chemical changes in the cells of these tissues. The chief chemical change is a kind of oxidation, so that in this change the oxygen brought by the red corpuscles of the blood is constantly being taken up in all parts of the body and made to unite with some other element or some compound. As a result of the activity of the cells of the various tissues of the body, there is produced a number of substances that cannot be of any further use in the body. These substances may therefore, as regards the body, be called waste products. The most abundant of these waste products is the gas called carbon dioxide ($CO_2$), or carbonic acid gas. This gas passes into the blood when it is in the general or systemic capillaries, for it is while the blood is in these capillaries that the tissues obtain the oxygen they need and pass in the carbon dioxide they are constantly producing, thus bringing about the changes from arterial to venous blood (par. 50).

As there is in the body a constant need for oxygen, a constant supply must be kept up; and as the waste product, carbon dioxide, is constantly being produced, a constant removal of this substance must take place. **Respiration** or breathing is the process by which the supply of oxygen is renewed and the removal of carbon dioxide effected. The organs of respiration are the lungs, and it is in the capillaries of the lungs, as we have already learnt, that the change from venous to arterial blood takes place. This change is due to the fact that the venous blood brought from the right side of the heart to the lung capillaries gives up carbonic acid to the air in the lungs and takes in oxygen; for, as we shall shortly see, the air in the lungs is separated from the blood in the lung capillaries by two exceedingly thin membranes only, and through these membranes gases can readily pass. The air in the lungs in this way loses oxygen to the blood and gains carbon dioxide from it, and as the air in the lungs is frequently renewed from the outside, the supply of oxygen and removal of carbon dioxide goes on continuously. Increased exertion, as in vigorous exercise, increases the oxidation processes in the tissues, especially in the muscles, but increased rapidity of breathing keeps up the needful supply and removal.

**74. The Air.**—The atmosphere or air consists of a mixture of several gases, each of which, besides having certain general properties belonging to all gases, has its own distinctive qualities (par. 6).

One general property of all gases is the power of mixing with other gases naturally. This property is called **diffusion.** If a bottle of ammonia gas is opened in a room, then although the air of the room is still, the ammonia will soon be recognizable by its smell in all parts, for its molecules spread and wander through the gases of the air in all directions. Gases also diffuse easily through porous partitions of all kinds, as through an unglazed piece of earthenware or through a bladder. If a bladder be filled with carbon dioxide gas and hung up in a jar of oxygen, it will be found after a short time that the gases in all parts inside and outside of the bladder contain the two gases in equal proportion, although the carbon dioxide is heavier than the oxygen. If defibrinated blood be made dark and venous by carbon dioxide and hung in a bladder in a jar of oxygen, diffusion takes place and the blood will change after a time to bright red, owing to the diffusion of oxygen into the bladder.

Another property of gases, which however varies in degree very much, is the power of dissolving in liquids. Carbon dioxide, for example, is more soluble in water than oxygen, and oxygen is more soluble than nitrogen. Ordinary spring water always contains some of these gases in solution. Fishes live by taking in the dissolved oxygen as the water passes over their gills.

The air, also, like other fluids, has the property of transmitting pressure in all directions. At the surface of the earth the pressure of the atmosphere is nearly 15 lbs. per square inch. This pressure is exerted on every square inch of the body. We are not conscious of it, as we are constituted to live under this pressure. A boy's leather "sucker" illustrates this pressure. He presses a circular piece of wet leather against a flat stone so as to squeeze out all air beneath. There being now no pressure beneath, but a pressure above, the sucker is kept on the stone by atmospheric pressure, and the two can be lifted together, provided the weight of the stone is less than the pressure of the air on the sucker. On letting in the air beneath, the pressure below counteracts that above, and the sucker is no longer kept on the stone when the string is pulled.

The atmosphere, or air, is a mixture of gases. The percentage composition, by volume, of inspired air and expired air are shown in the following table:—

| | Inspired air. | Expired air. |
|---|---|---|
| Nitrogen ... | 79 ... | 79 |
| Oxygen ... | 20·9 ... | 16 |
| Carbon dioxide ... | ·04 ... | 4·3 |
| Water vapour ... | variable amounts ... | saturated |

The gas argon (·8 per cent.) is reckoned in with nitrogen. It was only discovered in 1894, since, like nitrogen, it is a very inert gas, and takes no part in the changes that go on in respired air or in the other chemical actions in which atmospheric air is concerned. The changes to note in expired air are—(1) a loss of nearly 5 per cent. of oxygen; (2) an increase of about 4 per cent. of carbon dioxide; (3) an increase of water vapour, as expired air is always saturated. There is also in cold and temperate climates an increase of temperature, for the expired air has always a temperature near that of the body (98·6° F. or 37° C.), whatever be the temperature of the air inspired. Expired air also contains a minute quantity of organic impurities.

The presence of an increased quantity of carbon dioxide in expired air may be shown by breathing through a glass tube into lime-water. The lime-water quickly becomes milky, owing to the union of the carbon dioxide with the lime to form small particles of chalk or calcium carbonate. Pure atmospheric air does not do this when forced into lime-water until a large quantity has been sent through it. That expired air contains much water vapour may readily be seen by breathing on a cold glass, when the moisture is condensed into small particles of water vapour. The same condensation becomes visible on a frosty day as the warm air leaves the nose or mouth.

As just stated, the loss of oxygen is about 5 per cent., and the gain of carbon dioxide about 4 per cent. Now, the union of oxygen with carbon to form carbon dioxide does not cause a change in the volume of the gas, the volume of carbon dioxide produced being always equal, when measured at the same temperature and pressure, to the oxygen consumed. This deficiency, therefore, in the volume of carbon dioxide given off proves that not quite all the oxygen is used to unite with carbon. A small quantity is used in the body to oxidize hydrogen and form water, and a small amount is used in forming the waste product called urea.

An average man in the course of a day takes in nearly $1\frac{3}{4}$ lb. of oxygen, and gives out nearly 2 lbs. of carbon dioxide and $\frac{3}{4}$ lb. of water, the expired air being raised to the heat of the body. The body, therefore, through the lungs, loses both matter and heat energy.

**75. The Upper Air Passages.**—The organs of respiration are the trachea or windpipe, the bronchi or branches into which the lower end of the trachea divides, and the two lungs to which the bronchi conduct the air. On its way to the lungs the air passes either through the mouth or nose into the pharynx before it can enter the larynx at the top of the trachea.

An opening between the lips leads into a cavity called the mouth. The sides of the mouth are formed by the cheeks, the floor by the tongue and teeth of the lower jaw, and the roof by the teeth of the upper jaw and palate. The arch of the palate is hard in front, being formed of a plate of bone covered by mucous membrane. The hinder part of the palate consists of a thin sheet of muscle running backwards and downwards and covered above and below by mucous membrane

Its hinder part has a central conical prolongation called the **uvula.**

The opening at the back of the mouth leading into the pharynx is called the **fauces** (in popular language the throat). This opening is bounded above by the soft palate. From the under surface of the soft palate arise two folds of mucous membrane, containing muscles which pass downwards and slightly forwards to the base of the tongue on each side, so as to form the lateral boundaries of the fauces. These two ridges or folds are known as the **anterior pillars of the fauces.**

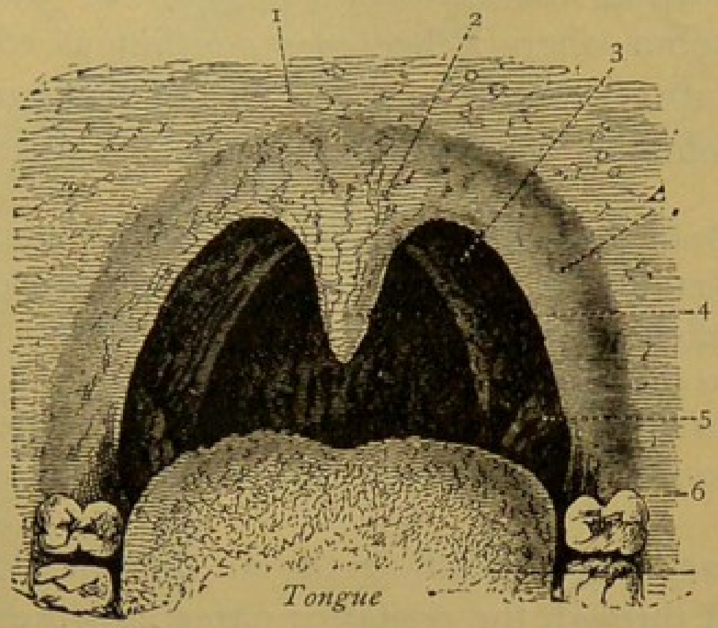



FIG. 84.—View of back of mouth, showing the fauces leading into the pharynx. 1, hard palate; 2, soft; 3, pillars of fauces; 4, uvula; 5, tonsil; 6, third molar tooth.

Behind each of these ridges is another ridge, springing from the hinder edge of the soft palate and passing downwards and backwards, to end in the side wall of the pharynx. These are the **posterior pillars of the fauces.** Between the anterior and posterior pillars of the fauces on each side is an oval mass of lymphoid tissue called the **tonsil.** Small openings on the surfaces of the tonsils lead into crypts or follicles, in which active multiplication of lymph corpuscles occurs. Many of these lymph cells pass out and mingle with the saliva as salivary corpuscles.

The outer nostrils or **anterior nares** lead into a cavity above the roof of the mouth on each side, the two cavities being separated by a central partition running backwards.

Projecting from the central partition on each side are three scroll-like bones, termed the turbinal bones. Above, each cavity is bounded by bones at the base of the skull. Behind, each cavity leads into the upper part of the pharynx above the soft palate, the two openings being called the **posterior nares.** The soft palate can be raised so as to close the entrance of the posterior nares in the pharynx.

The **pharynx** is the funnel-shaped cavity, widest above, at the back of the nasal passages and the mouth. It is about four inches long, and extends from the under surface of the sphenoid bone at the base of the skull to about the fifth cervical vertebra, where it becomes continuous with the gullet, or œsophagus. It consist of sheets of striated muscle lined by mucous membrane. The pharynx has seven openings—

(*a*) Two from the nasal passages—the **posterior nares.**

(*b*) Two leading to the tympanic cavities behind the drum of each ear—the openings of the **Eustachian tubes.**

(*c*) One to the mouth—the **fauces.**

(*d*) One to the larynx, leading to a chink—the **glottis.**

(*e*) One to the œsophagus, or gullet, behind the larynx.

In ordinary quiet breathing the air passes along the nasal passages and through the posterior nares into the pharynx, and in so doing becomes warmed as well as freed from dust particles by hairs that line the anterior nasal passages. Air may also enter the pharynx through the mouth. In both cases, the air, after reaching the pharynx, passes through a triangular opening into the larynx at the upper end of the trachea.

**76. The Larynx, Trachea, Bronchi, and Bronchial Tubes.**—We have already learnt that two tubes go down from the pharynx into the trunk—the posterior one, the œsophagus or gullet, to the stomach, and the anterior one, the trachea or wind-pipe, to the lungs. At the top of the trachea, and continuous with it, is the larynx—a kind of triangular box, the walls of which are formed of cartilages and muscles. The most prominent cartilage, the thyroid cartilage, meets in an angle at the front and forms the prominence called Adam's apple. The larynx thus lies at the lower and front part of the pharynx. The opening into the larynx is guarded by a leaf-like lid—the **epiglottis**, which is attached below to one of the cartilages of the larynx, but is free above. In ordinary

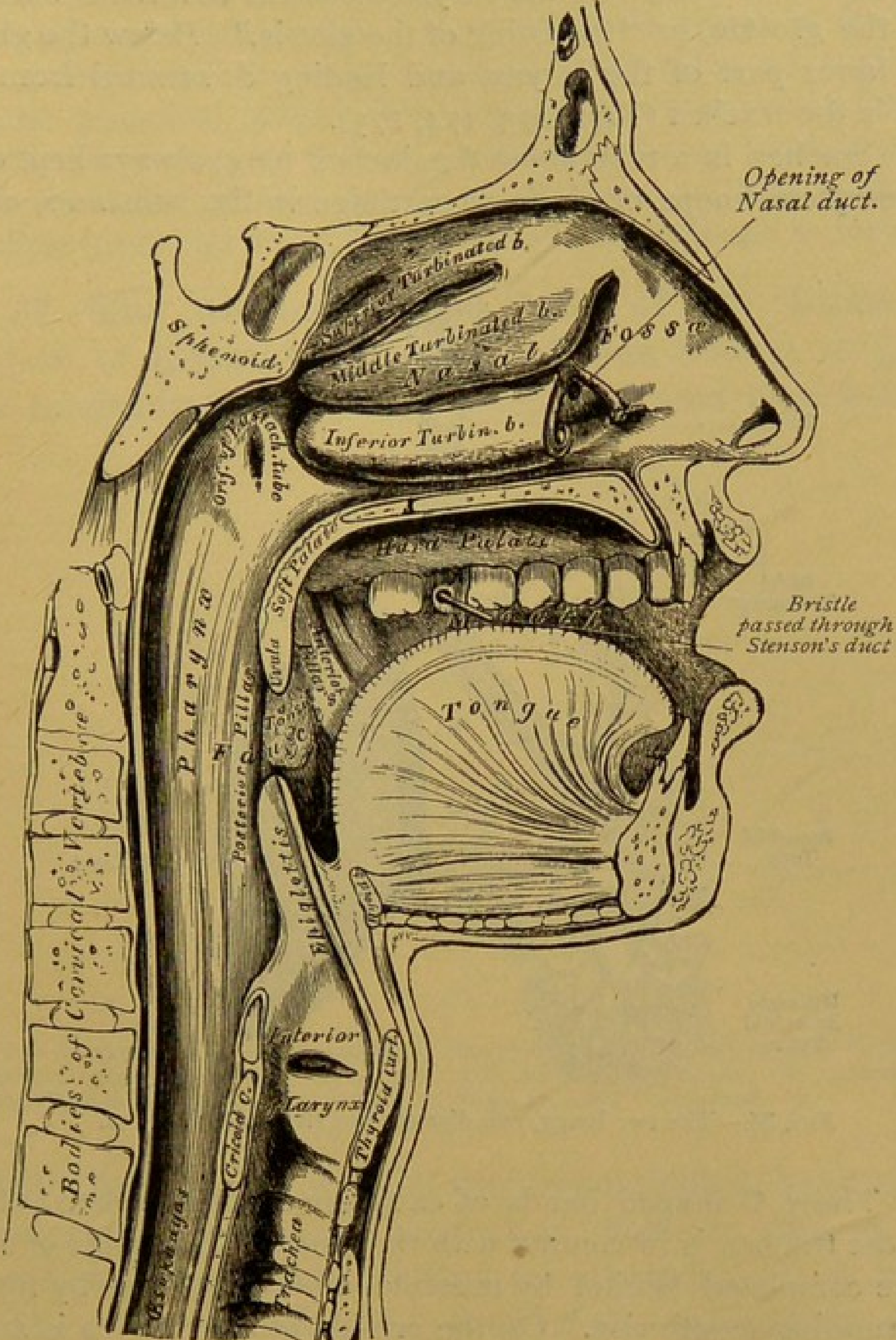



FIG. 85.—The mouth, nose, windpipe, and gullet seen in section.
(*From Gray's "Anatomy."*)

breathing the epiglottis stands upright, leaving the entrance to the larynx free, but during swallowing it is brought upwards and backwards, so as to close this entrance and prevent food and drink from passing into the larynx (Fig. 105). In the cavity of the larynx are two bands, or folds, of membrane that run from the back to the front. These bands are called the **vocal cords**, as the vibrations of their free edges set up by currents of air from the lungs produce the voice. The fissure in the larynx between the vocal cords is called the **glottis**, or "the chink of the glottis." Below the glottis is the lower part of the larynx, and leading downward from the larynx is the trachea (Figs. 173, 174, 175).

The trachea is a tube about five inches long, always kept open by incomplete hoops or rings of cartilage in the substance of the

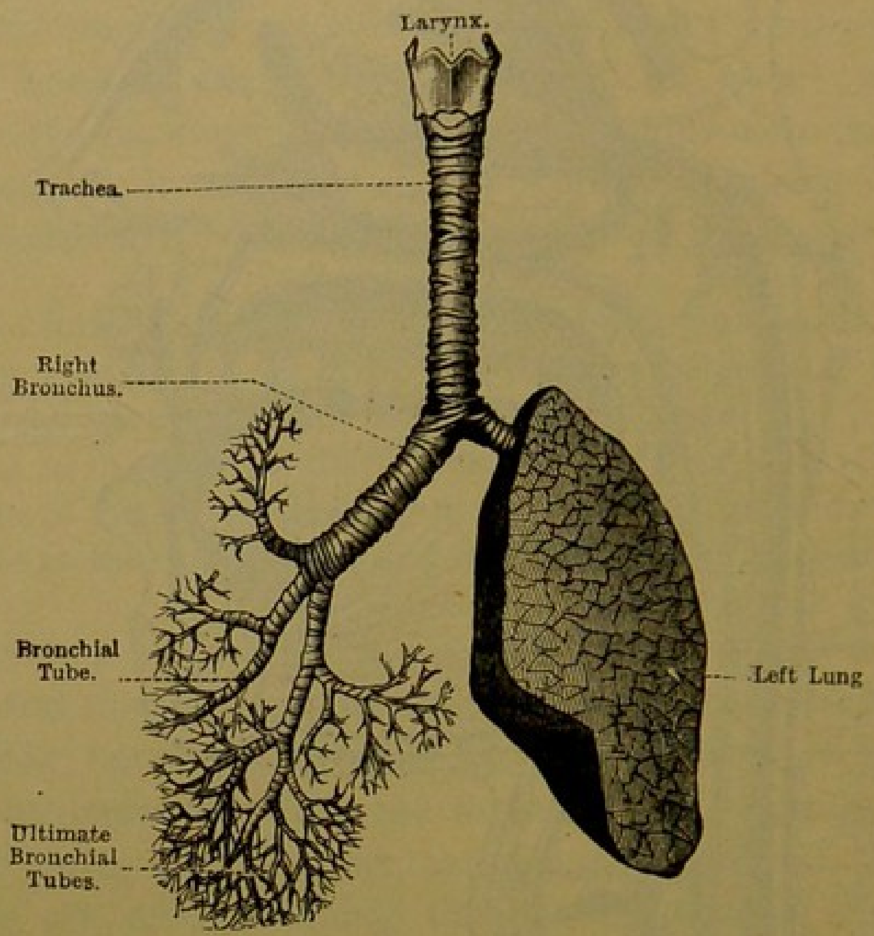



FIG. 86.—The two lungs, one dissected to show the air tubes.

walls. These C-shaped bands of cartilage are incomplete behind, where the trachea is in contact with the gullet. The rings of cartilage are completed behind by muscular tissue, and also by fibrous tissue running lengthwise. On the outside of the trachea is a coat of connective tissue, whilst internally is a thick mucous membrane. The epithelium of this mucous membrane consists of cells, the inner layer of which is columnar and provided with the fine hair-like processes called **cilia** (Fig. 4). The cilia during life are constantly in motion, alternately moving towards the throat with a rapid movement, and then slowly straightening again. In this way dust particles and mucus are driven upward until they can be coughed out. Among the ciliated cells are small glands and cells which secrete mucus to keep the mucous membrane moist. Ciliated epithelium also lines the larynx (except over the vocal cords) and parts of the nasal chambers. At its lower end the trachea divides into two branches —the right and left bronchi. Each bronchus enters at the root of a lung, and within the lung divides and subdivides into smaller and smaller bronchial tubes. The bronchi and bronchial tubes have a structure similar to that of the trachea, being lined by ciliated epithelium, and having bands of cartilage in their walls. The smallest bronchial tubes, however, have no cartilage in their walls.

**77. The Alveoli or Air Cells of the Lung.**—The smallest or **ultimate bronchial tubes**, from $\frac{1}{30}$ to $\frac{1}{50}$ of an inch in diameter, end in a cluster of dilated branches called

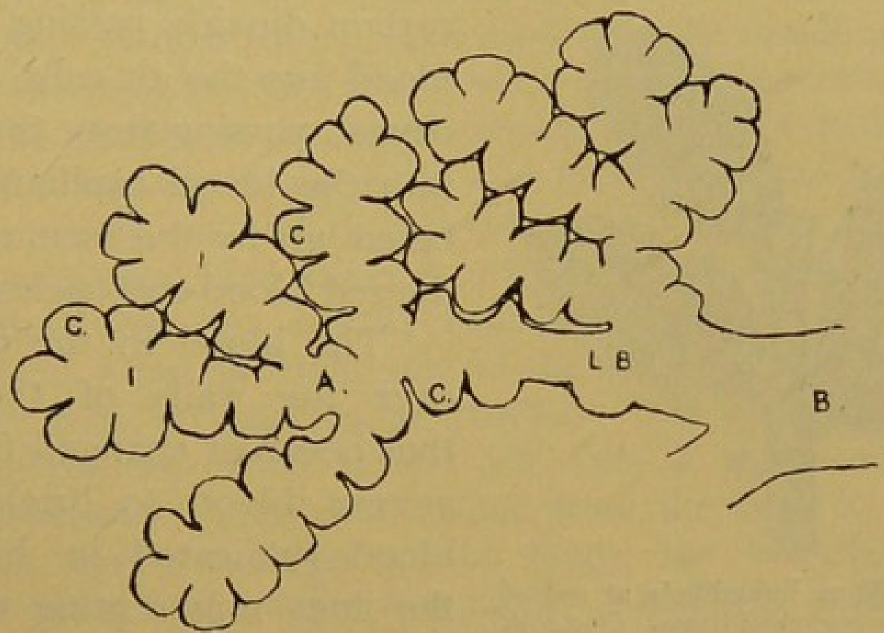



FIG. 87.—Diagrammatic representation of the ending of a bronchial tube in sacculated infundibula. B, terminal bronchus; LB, lobular bronchiole; A, atrium; I, infundibulum; C, air cells or alveoli. (*From Quain's "Anatomy."*)

**infundibula.** The walls of each infundibulum have pouches or recesses, about $\frac{1}{100}$ of an inch in diameter, each of which is called an air-cell, or **alveolus** (pl. **alveoli**). It is in these air-cells or alveoli lining the walls of the infundibula that an exchange of gases takes place between the air brought along the bronchial tubes, and the blood in the pulmonary capillaries that spread over the surface of the air cells. It will be easily understood that the arrangement of pouched infundibula at the end of the numerous small bronchial tubes leads to a vast number of air cells with a large extent of surface, a surface estimated to be one hundred square yards, or about fifty-five times as great as the outer surface of the body. To these air cells the air has access through the trachea and bronchial tubes, and on them the blood capillaries are spread out.

The walls of the air cells are very thin, consisting of a fine layer of elastic connective tissue, which is lined inside by a single layer of thin flattened cells. In this fine connective tissue lie very fine thin-walled blood capillaries, derived from branches of the pulmonary arteries that have run along near the bronchial tubes. The blood in the blood capillaries over the walls of the alveoli is thus separated from the air in the alveoli by two very fine membranes only. Through these membranes the gases *diffuse*, some carbon dioxide passing from the blood into the air cells, and some oxygen passing from the air cells into the blood capillaries, to be taken up by the hæmoglobin of the red blood-corpuscles.

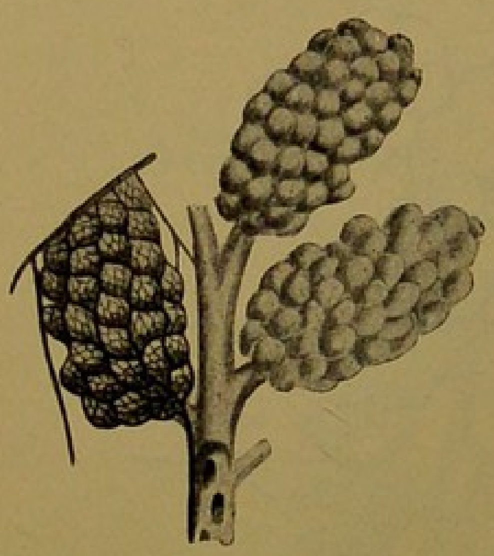


FIG. 88.—Three infundibula at end of minute bronchial tubes. One with blood capillaries passing over the alveoli. (Diagrammatic.)

The blood in the capillaries over the walls of the alveoli thus becomes changed from dark venous blood to bright arterial blood (indicated in Fig. 88 by the lines representing the capillaries becoming lighter). The capillaries unite into small veins, and these at last form the large pulmonary veins that take the purified blood to the left auricle of the heart.

**78. Position and Condition of the Lungs in the Thorax.**—The two lungs are the greyish, spongy, elastic organs which fill, during life, the whole cavity of the thorax on each side of the space occupied by the heart and great blood-vessels. (Refer to Figs. 8 and 63.) Each lung has a narrow rounded apex reaching into the neck above the first rib and clavicle, and a broad concave base adapted to the upper surface of the diaphragm. Behind, and at the sides, each lung runs to a thin edge to fit into the hinder narrowing recess between the chest wall and the arching diaphragm, and the basal margin of each lung extends lower down behind and at the sides than in front. The dorsal surface of the lungs fits into the concavity of the chest wall behind. The inner surface of each lung is concave, for the two lungs are separated from each other by a space in which lie the heart, great vessels, and trachea. The anterior border of each lung is thin and sharp, and in part overlaps the heart in the pericardium. The anterior border of the right lung is almost vertical, but that of the left lung has on its front lower border a deep notch, into which the heart projects (Fig. 63). When both lungs are well filled with air the heart is covered in front, except that portion lying in the notch of the left lung.

Each lung is divided into two great lobes by a fissure, and the upper lobe of the right lung is partially divided into two by a second fissure. The right lung is a little larger than the left; it is broader than the left owing to the inclination of the heart to the left side, but it is about an inch shorter than the left, as the diaphragm rises higher on the right side to accommodate the liver beneath.

Near the middle of the inner concave surface of each lung a number of tubes and vessels enter and leave the organ (bronchus, pulmonary artery, pulmonary veins, bronchial arteries and veins, nerves, lymphatics), and these structures are said to form the **root of the lung.** As already explained, the pulmonary artery carries blood from the right side of the heart to the capillaries of the air cells in order to be purified. The pulmonary veins return the purified blood to the left side of the heart. The **bronchial arteries** carry pure blood from the aorta to nourish the various tissues making up the lungs, the bronchial veins return this blood to the upper vena cava. Lymphatic vessels arise by minute channels in the walls of the air cells and smaller tubes, and these unite to form vessels that pass to lymphatic glands at the root of the lung, and then proceed to the thoracic duct.

It will now be understood that the substance of the lungs consists of bronchial tubes, with their terminal dilatations (infundibula and air cells), of numerous blood-vessels, lymphatics, and nerves, the whole being bound together by a connective tissue rich in elastic fibres. As the greater part of the bulk or volume of a lung is made up of the infundibula and alveoli filled with air, and as there is elastic tissue in the thin walls of the air cells, it is clear why the lungs are so light, and why they are so distensible. In fact, it must be borne in mind that the natural condition of the lungs in the thorax is a distended condition, for the thorax is an airtight cavity, the stout walls of which keep off the outside pressure of the atmosphere. But this atmospheric pressure can be exerted through the air in the tubes and alveoli, and it is sufficient to stretch each lung so that it completely fills its own side of the thorax. Thus the lungs are always as much distended as the size of the thorax will allow.

When an opening is made into the thorax, either by design or accident, the pressure of the atmosphere is then exerted on the outside of the lung also, and this outside pressure balances the inside

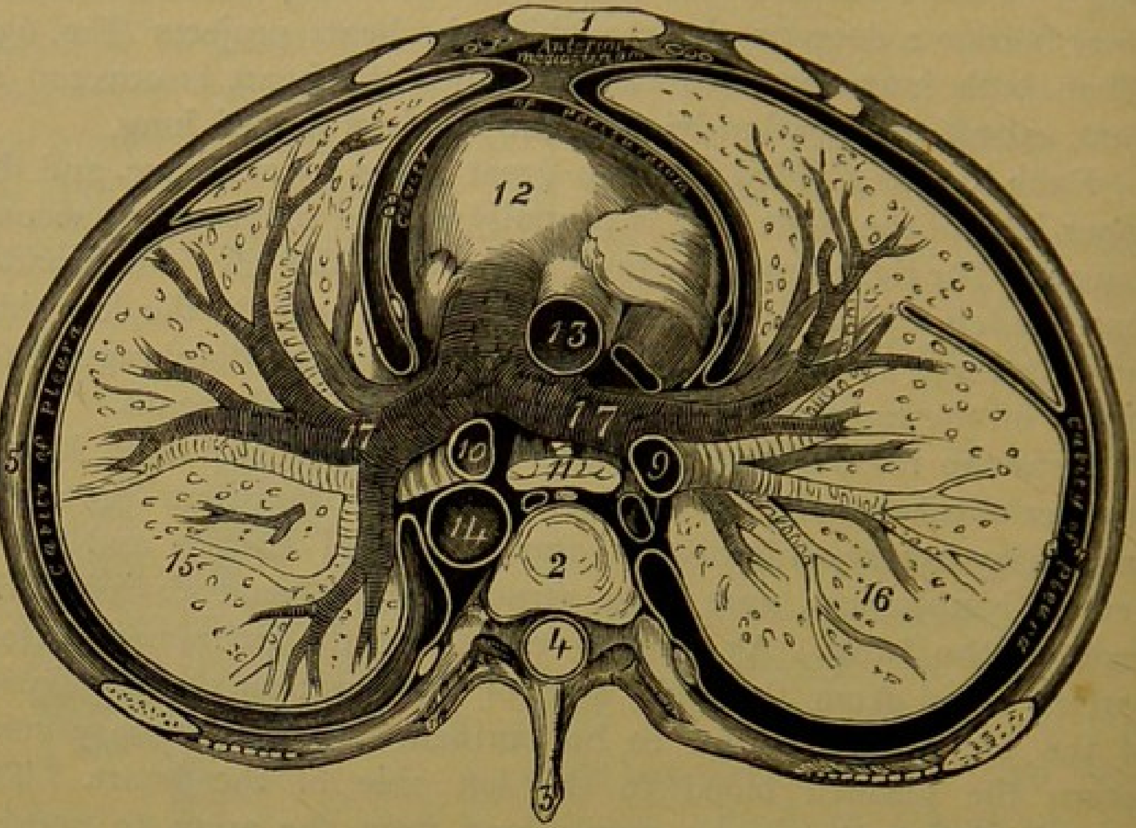



FIG. 89.—A transverse section through the thorax a little above the heart, showing the position of the thoracic viscera, the blood-vessels, and air-tubes passing into the lungs, the reflections of the pleura, etc. The space between the two layers of the pleura is exaggerated. 1, sternum; 2, body of dorsal vertebra; 3, spinous process of vertebra; 4, spinal canal; 5, rib; 6, inner layer of pleura; 7, outer layer of pleura; 8, pericardium; 9, right bronchus; 10, left bronchus; 11, œsophagus; 12, heart; 13, ascending aorta with superior vena cava to the right; 14, descending aorta; 15, section of left lung; 16, section of right lung; 17, pulmonary arteries passing to each lung. (*Reduced from Gray's "Anatomy."*)

pressure through the tubes and alveoli. There is, then, no force to keep the lung distended, and the recoil of the stretched elastic tissue causes it to collapse and shrink to nearly one-third the natural size on that side. In collapsing the lung separates the two layers of pleura from one another, and air passes into the cavity between them. If an opening be made into both sides of the chest both lungs collapse, breathing becomes impossible, and death ensues. Even in the shrunken condition, however, the tubes and cells do not close up entirely, so that a piece of sheep's lung, for example, still contains air after death, and will float on being thrown into water.

**79. The Pleura.**—Each lung is covered on its outer surface by a thin serous membrane called the **pleura**, which invests the organ as far as the root, and is then reflected upon the inner surface of the chest wall, the diaphragm, and the pericardium of the heart, as represented in Figs. 89 and 90. The part of the pleura attached to the lung is called the **visceral layer**, and the part attached to the thoracic wall and diaphragm the **parietal layer**. Each pleura thus forms a kind of closed sac or double bag, the two layers of each pleura being, however, much closer than represented in the diagram. The inner surfaces of the two layers are, in fact, close together, for, as just explained, the pressure of the atmosphere exerted through the air passages on the elastic lungs keeps them so distended that the visceral layer always rubs against the parietal layer. The inner surface of the two layers are smooth, and, being moistened by a little fluid, the surface of the lung to which the visceral layer is attached can glide on the layer covering the chest wall without any perceptible friction. In pleurisy the surface of the membrane becomes roughened and sticky owing to inflammation, and the movement of the lung is then accompanied by painful friction.

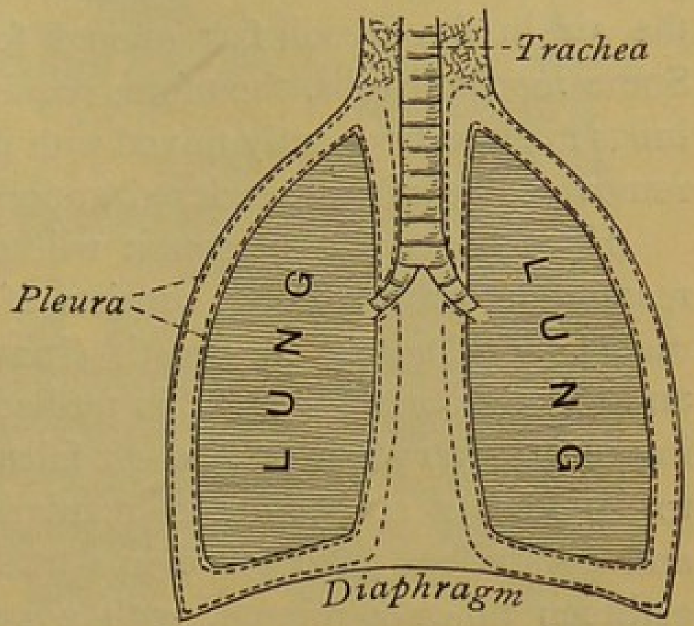



FIG. 90.—Diagrammatic vertical section of the thorax, to show the reflection of the pleura from the root of lungs. Dotted lines represent pleura, but there should be really no space between the two layers of each pleura. The central space is occupied by the heart.

**80. The Movements of Respiration.**—We have learnt that the lungs afford a large extent of surface, covered by a vascular network, through which the blood moves in tiny streamlets, and only separated by very thin membranes from the atmospheric air; and we know that by the action of the heart fresh blood is constantly being sent from its right side through the abundant vascular network of the lungs, and then on to the heart, the whole of the blood of the body passing through the lungs during twenty-seven heart-beats, or in about twenty-two seconds. We must now learn what the arrangements are for the regular and frequent changes of the air in the lungs. The need for such arrangements is seen when we consider that the air in the alveoli or air cells soon becomes laden with carbon dioxide and loses much of its oxygen, that it then becomes unfit to convert venous blood into arterial, and that the slow process of gaseous diffusion from the outside atmosphere would not renew the air in the alveoli fast enough for the needs of the body. Some mechanism is, therefore, required by which the air in the lungs may be frequently mixed with the air from outside, so as to remove some of that rendered impure, and to bring in fresh air.

If we observe a person it will be noticed that the act of respiration, or breathing, consists of a regular series of movements. On taking in breath (**inspiration**) the chest rises, and the abdomen, or belly, is pushed outwards. When breathing out (**expiration**) the chest falls, and the abdomen returns to its former size. These regularly alternating inspirations and expirations take place in a healthy adult about sixteen or eighteen times a minute, with a pause between each. With children **respiration**, as the double act is called, is more frequent, and it is more frequent during exercise, owing to the increased tissue activity and the increased supply of oxygen required for this.

Careful observation shows us that during the entrance of fresh air in inspiration the chest cavity is enlarged by the action of certain muscles, and that during expiration the chest cavity diminishes again, and so expels air from the lungs.

**81. Inspiration.**—The chief muscles that are concerned in ordinary inspiration are the diaphragm and the intercostal muscles. The contraction of the first increases the thoracic cavity vertically, that is, from above downwards; the action of the intercostal muscles elevates the ribs, and so makes the thorax wider from front to back and from side to side. Let us consider first the **structure and action of the diaphragm.** The diaphragm is the muscular partition dividing the great ventral cavity of the trunk into thorax and abdomen. This partition forms an arch convex to the thorax and concave to the abdomen. Above, there is attached to it the pleura and the pericardium, and below it is covered by the peritoneum. The central part of the diaphragm is formed of a sheet of tendon, from which broad sheets of voluntary muscle run outwards, to be attached in front to the sternum and to some of the costal cartilages, at

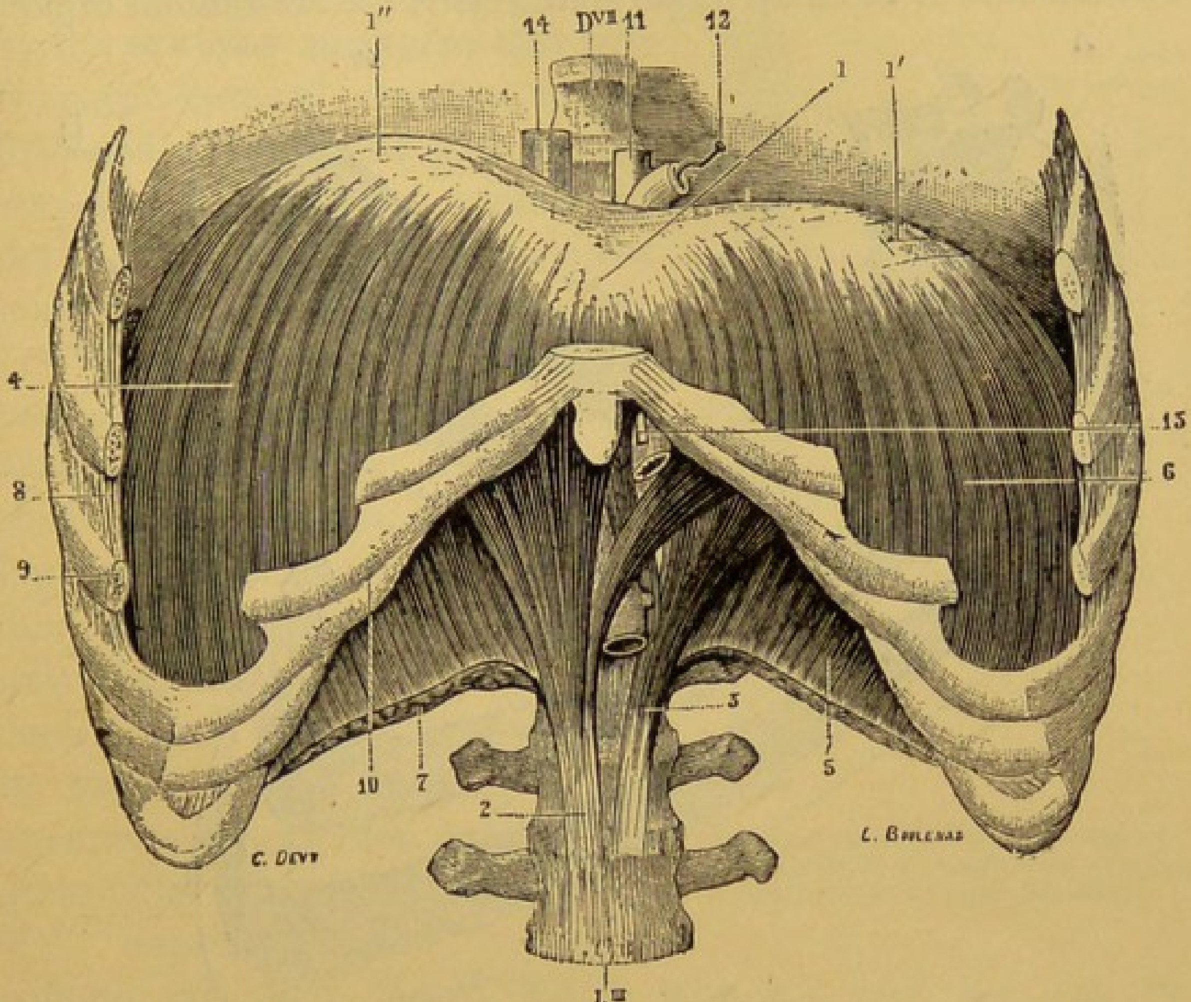



FIG. 91.—View of diaphragm, showing its convex upper face in front and concave under face behind. 1, 1′, and 1″, the tendinous centre; 2 and 3, pillars of the diaphragm; 4 and 6, muscular sheet passing to ribs in front; 5, hinder lower surface; 7, section of posterior muscle; 9, section of eighth rib; 10, costal cartilage; 11, descending aorta; 12, œsophagus drawn aside; 13, left vagus nerve; 14, lower vena cava; D VII, seventh dorsal vertebra; L III, third lumbar vertebra. (*From Testut's "Anatomie."*)

the sides to the ribs, and behind by two strong muscular bands, called the pillars of the diaphragm, to the bodies of the lumbar vertebræ. The whole organ thus completely separates the cavity of the trunk into two portions. Various tubes pass between thorax and abdomen, as shown in Fig. 91. When the muscular fibres of the diaphragm contract, their origin on the walls of the trunk remains fixed; but, since the fibres shorten, they pull on the central tendinous part, drawing this down a little, and at the same time making the side portions less convex by pulling them away from the lower part of the chest walls. The thorax thus becomes deeper *from top to bottom*, the increase taking place in its lowest and widest part, and the result of this being an enlargement of the chest cavity. The descent of the diaphragm compresses the abdominal organs

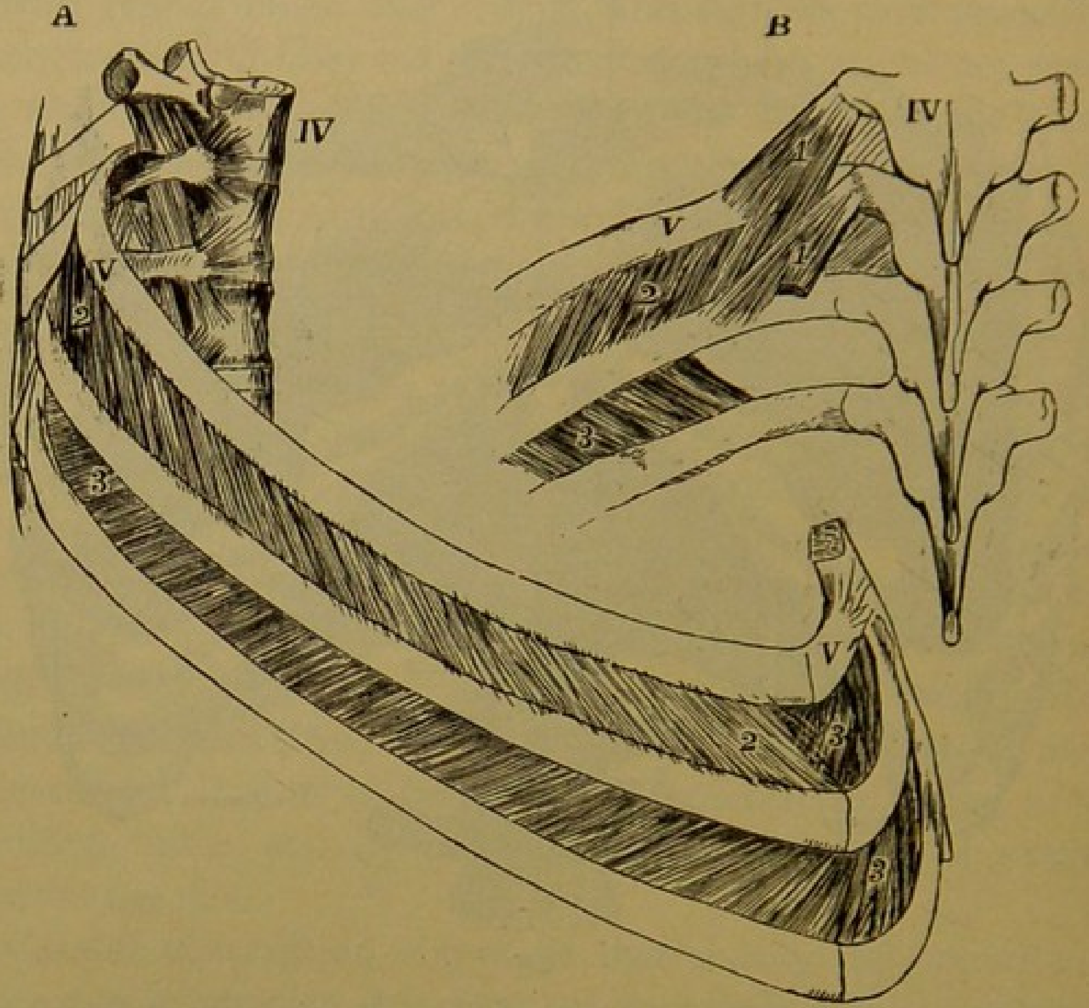



FIG. 92.—Intercostal muscles of the fifth and sixth spaces. (Allen Thomson, after Cloquet.) A, from the side; B, from behind; IV, fourth dorsal vertebra; V, V, fifth rib and cartilage; 1, 1, levatores costarum muscles, short and long; 2, 2, external intercostal muscle; 3, 3, internal intercostal layer, shown in the lower space by the removal of the external layer, and seen in A in the upper space, in front of the external layer—the deficiency of the internal layer towards the vertebral column is shown in B. (*From Quain's "Anatomy."*)

beneath, and so causes the walls of this cavity to swell out, as may readily be observed. The elevation of the ribs is brought about by muscles lying between them, called **intercostal muscles.** There are two layers of these muscles, one over the other, the outer layer being called the **external intercostal muscles,** and the inner layer the **internal intercostal muscles.** The ribs, it will be remembered, are articulated with the vertebræ behind, and, as they pass round from the spinal column to the sternum in front, they slope obliquely downwards, the slope being greatest in the lower ones that are attached to the sternum. The fibres of the external intercostal muscles pass from one rib to another, sloping downwards and forwards. During an inspiration the upper ribs are fixed, so that they cannot be pulled down, by the **scalene muscles** that pass from the cervical vertebræ to the first and second ribs, and the external intercostals then contracting draw up the lower ribs into a more horizontal position; and as the first ends of the ribs rise they twist the costal cartilages somewhat, and carry the sternum upwards and outwards, thus increasing the distance between the sternum and spinal column, and so enlarging the thorax *from front to back.* That this must be so can be shown by the simple piece of apparatus represented in the diagram (Fig. 93). The upright piece, VV, represents the vertebral column, the three pieces, RRR, represent two ribs, and the piece *st.* represents the sternum. The sloping position of RRR and *st.* represents the natural position of the ribs at rest in expiration, and the dotted lines represent the raised ribs, where the sternum is further away from the spinal column. The raising of the ribs is also assisted by muscles, called elevators of the ribs (**levatores costarum**), that pass from a fixed point on the spine downwards and forwards to the ribs.

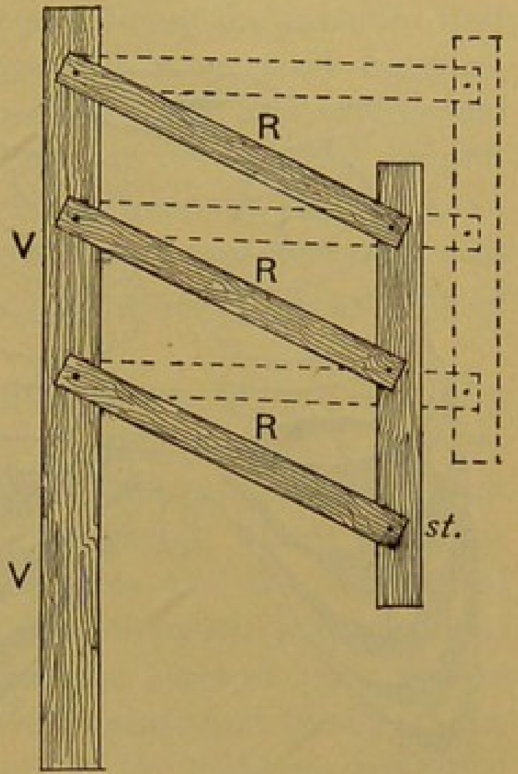



Fig. 93.—Apparatus to illustrate enlargement of chest from front to back when the ribs are raised.

The elevation of the ribs is also accompanied by an increase in the width of the chest *from side to side* as the arches of the lower ribs, especially the three ribs attached to the cartilage of the seventh rib, sag or sink somewhat in the middle, and the raising of the ribs thrusts this sagging part outwards (Fig. 96*a*).

We now understand that inspiration requires considerable muscular action, that is mainly produced by the contraction of the diaphragm and external intercostal muscles, and that this muscular action leads to an increase in the size of the chest in all directions. As a consequence of this increase in the volume of the thorax air rushes down the trachea and other passages to distend each lung so as to fill up the enlarged thoracic cavity, for, as we have seen, the size of the lungs depends on the size of the thorax, an increase of the thorax allowing them to be further distended by the pressure of the atmosphere.

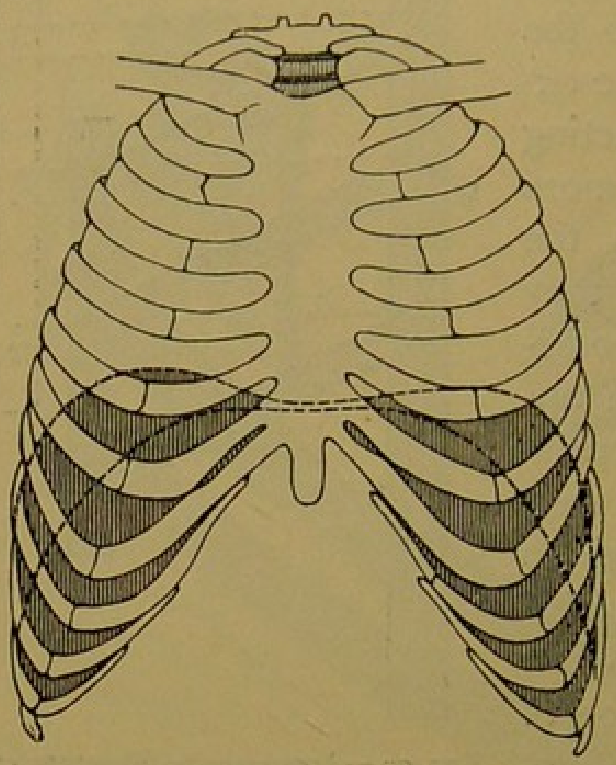


FIG. 94.—Diaphragm in thorax, showing medium height, with lower line indicating position when contracted in inspiration.

**82. Expiration.** — As soon as the muscles that cause the various movements in inspiration cease to contract and relax, the diaphragm is driven up into its arched position by the elastic recoil of the stretched abdominal wall, and the ribs and sternum fall to their natural unstrained position. The chest cavity is thus diminished in volume and air forced out. This expiration of air is assisted also by the elastic recoil of the lungs, for during inspiration they have been stretched, or distended, more than they are when the inspiratory muscles are relaxed. The chest cavity thus returns to its original size, and air is expired or sent out of the lungs in ordinary breathing by the cessation of the inspiratory muscular effort and the elastic recoil of the parts stretched in inspiration, aided by the elasticity of the lungs themselves.

We now understand that *inspiration* is brought about by muscular action which draws the thoracic walls apart in all directions. This enlargement of the thorax leads to the expansion of the lungs to fill the enlarging space, and air then rushes in to equalise the pressure within and without the chest. Quiet *expiration*, however, is not the result of a muscular act, but a passive return to the resting condition of the stretched thoracic walls and lungs, this return forcing air out of the lungs.

**83. Forced Respiration.**—The respiration (inspiration and expiration) just described is the ordinary quiet respiration. When a deep inspiration, or laboured inspiration, as it is called, takes place, several other muscles come into play besides those just mentioned, and assist in raising the sternum and ribs. Laboured expiration, unlike quiet expiration, becomes in part an active muscular act, the muscles taking part being the muscles that form the abdominal walls and the internal intercostal muscles. The contraction of the abdominal muscles press the abdominal organs, and these force up the diaphragm to an unusual height. The internal intercostal muscles, which lie beneath the external, and pass from a rib above obliquely downwards and forwards, pull down the lower ribs in forced expiration and diminish the cavity of the thorax from front to back.

**Coughing** is a peculiar expiratory movement. There is a deep inspiration followed by a closure of the glottis, and a sudden forcible expiration which bursts open the glottis and sends a blast of air through the mouth. It is usually brought about by some irritation of the respiratory mucous membrane, and is a **reflex act** (par. 154). **Sneezing** is another peculiar expiratory movement, almost the same as coughing, except that the blast of air is driven through the nose, for the descent of the soft palate and the approach of the anterior pillar of the fauces shut off the passage from the mouth. **Sighing** is a quick, deep inspiration followed by a slow, gentle expiration.

**84. Quantity of Air breathed.**—Inspiration plus expiration constitutes respiration, and the respiratory act takes place in an adult at rest sixteen or seventeen times a minute. The amount of air taken in at each inspiration, and then given out at the following expiration, is about 30 cubic inches (nearly a pint), and only about one-sixth of that which the lungs contain. By a strong expiration we can send out about 100 cubic inches more than in such an ordinary expiration. But there is then some air still left in the lungs which cannot be sent out by any effort. We can, in fact, distinguish four different quantities of air in the lungs—

(1) The quantity of air which remains in the lungs after the strongest expiration (about 100 cubic inches). This is called **residual air.**

(2) The quantity of air which can be forcibly expired after an *ordinary* expiration has taken place (about 100 cubic inches). This is called **supplemental air.**

(3) The quantity of air inspired and expired in ordinary quiet breathing (about 30 cubic inches). This is called the **tidal air.**

(4) The quantity of air that can be taken in, in addition to the tidal air, by the deepest inspiration (about 120 cubic inches). This is called **complemental air.**

The total quantity of air that can be expelled from the lungs after a forced inspiration by a forced expiration is spoken of as the "vital capacity" of the lungs. In the average man the vital capacity is about 250 cubic inches.

It is clear from what we have said that after an ordinary expiration there is about 200 cubic inches that remain stationary in

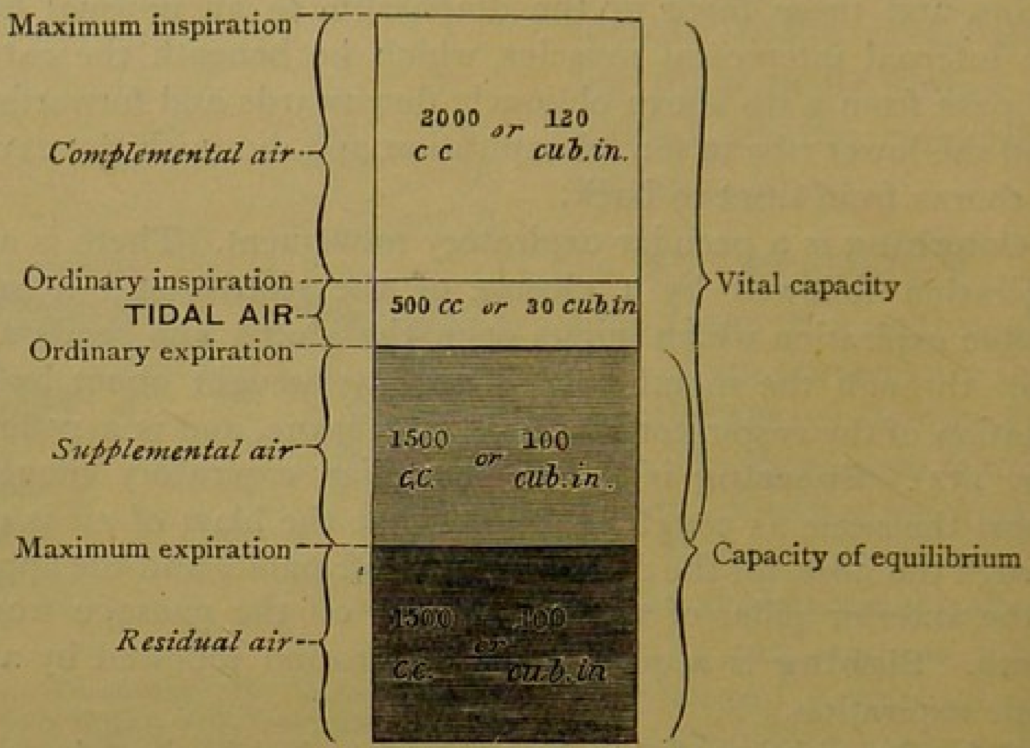



FIG. 95.—Amounts of air contained by the lungs in various phases of ordinary and of forced respiration. (*From Waller's "Human Physiology."*)

the lungs, for the tidal air is that which passes from the large bronchi, trachea, and upper air passages, and these will then be refilled from the atmosphere. But the oxygen in the entering tidal air passes quickly by diffusion into the smaller tubes and air cells, and from these cells diffuses into the blood, while the carbon dioxide diffuses from the blood into the stationary air, and from this into the outgoing tidal air. Thus an interchange of gases goes on, by diffusion, between the blood and the air in the alveoli of the lungs, and a further interchange by diffusion between the alveolar air and the tidal air.

**85. Nervous Regulation of Respiration.**—The respiratory movements are usually involuntary, and go on without our attention, though many voluntary muscles are concerned in them. Such muscles only contract when they receive nervous impulses along the motor nerves passing to them. The motor nerves concerned in ordinary inspiration are—(1) the two **phrenic nerves** from the spinal cord in the neck to the diaphragm; (2) the **intercostal nerves** from the spinal cord in the thoracic region to the intercostal muscles. If one phrenic nerve is cut, the diaphragm on that side is paralyzed, and if both phrenic nerves are cut, no movement of the diaphragm occurs on either side, as no motor impulses can reach it. Section of the intercostal nerves leads in a similar way to cessation of the action of the intercostal muscles. It thus appears that nervous impulses must be proceeding regularly without our being aware of them, from some part of the central nervous system to the muscles of inspiration. The part of the central nervous system from which these nervous impulses proceed is in that part of the brain called the medulla, or spinal bulb, and the part of the medulla from which the impulses start is called the *respiratory centre*. Its position has been found by experiment, and if this part is injured or removed, respiration ceases, and death soon follows.

To the respiratory centre sensory or afferent impulses must pass, which serve as the exciting cause of the motor impulses sent out. These sensory impulses in ordinary respiration probably pass along branches of a great nerve called the pneumogastric, or vagus. They are due to the state of distension of the air cells of the lungs, in which the fibres going to the lung have their finest terminations, so that respiration is normally a series of reflex actions.

Other afferent nerves besides the vagus may convey impulses to the respiratory centre that lead to changes in breathing. Anything irritating the trachea or larynx, both of which receive branches from the vagus, produces impulses that pass to the centre and cause it to send out strong motor impulses to the expiratory muscles, which lead to coughing. Excitation of the nasal branch of the fifth nerve in the nostril leads to sneezing. Sudden excitation of the sensory nerves of the skin, as on stepping into cold water or dashing water on the skin, leads to a gasp or sudden inspiration. Quickened respiration also follows running or any other violent exertion, for such action leads to a more rapid oxidation of muscular tissue, and the venous blood reaching the centre then stimulates it to greater activity in order to supply the greater demand for oxygen, and the need for increasing the excretion of the greater quantity of carbon dioxide produced. Increased action of the heart at the same time produces a more rapid circulation. Lastly, voluntary impulses from the brain may influence the respiratory centre. We can, when we will, either stop the respiration or breathe very rapidly, but only for a short time. After holding the breath for two minutes at the most, our will is no longer able to resist the body's need of oxygen. After breathing forty or fifty times a minute we soon find ourselves unable to continue this. The rate returns to the normal sixteen to eighteen times a minute, or one respiration for every four heart-beats, a relation of the two that always exists.

**86. Tissue Respiration.**—We have explained that respiration consists of an exchange by diffusion of gases between the blood in the pulmonary capillaries and the air in the alveoli of the lungs. It was at one time thought that oxidation of waste matter took place in the lungs themselves. When it was shown that the temperature of the lungs is not higher than that of other parts, and that oxygen and carbon dioxide exist in the blood itself, this idea had to be given up. It was then thought that oxidation took place in the blood; but carbon dioxide can be obtained from lymph and muscular tissue, and so this idea was proved erroneous. Numerous experiments show that the oxidation goes on in the tissues of all parts, and especially in that of the muscles. The exchange of gases between the blood and the tissues of all parts is spoken of as internal or tissue respiration. The whole of respiration is thus stated by Dr. Waller—"Oxygen, introduced into the lung by muscular movement, diffuses into the pulmonary blood and is conveyed to the systemic capillaries, whence it diffuses into the lymph and tissues; here it enters and forms part of some complex compound, which subsequently yields carbon dioxide as a disintegration product; carbon dioxide diffuses from the lymph to the blood, and is therein carried to the lung, whence it diffuses into the air."

**87. Practical Work in Connection with Respiration.**—Obtain from a butcher the lungs and windpipe of a sheep, telling him to leave the heart attached, as in removing the heart holes are often made in the lung. Notice the larynx at the top of the windpipe, with the lid-like epiglottis. Look down the larynx and notice the narrow chink called the glottis between two membranous bands, the vocal cords. Examine the trachea and notice that it is kept open by rings of cartilage, incomplete on one side, the back of the trachea, which adjoins the œsophagus. This will enable you to distinguish the back of the lungs from the front. Cut down the trachea and observe that the cartilages are flattened bands lying in the thickness of the wall and connected behind by muscular tissue. The internal surface of the trachea is a smooth mucous membrane. To see the cilia on the outside layer of cells of the mucous membrane requires a microscope.

Notice the smooth surface of one of the lungs and pick up the pleural membrane that adheres to it. A piece may be torn off and its thinness observed. Find the bronchus of this lung and trace out its subdivision into smaller and smaller bronchial tubes, cutting the tissues away.

Cut off the other lung at the beginning of the bronchus, and insert into this a piece of glass tubing, binding it firmly by means of a piece of tape. On blowing into the tube the lungs expand to twice the size, but on taking away the mouth from the tube, the lung collapses and the air blown in is driven out. The air blown in distended the walls of the air cells, and on taking away the mouth from the tube the reaction of the elastic tissue drove the air out again. Cut off a piece of a lung and observe the cut ends of the air tubes and blood-vessels. Throw the piece into water and it floats, because the shrunken lung still contains air. On another specimen the cut end of a whitish open tube, the pulmonary artery, may be found at the root of the lung. A collapsed vein may be found near it.

Count your own rate of breathing, or that of a friend, first, when at rest; secondly, after a short walk; thirdly, after a good run. What causes the increased rate of breathing? Does the heart-beat increase in proportion (par. 85)? What is the test for carbon dioxide? Lime-water. Obtain some lime-water in a beaker. Breathe into it through a straw or through a piece of glass tubing. Notice how the lime-water becomes milky. Explain the milkiness. Breathe on the surface of a clear cold mirror and notice the moisture deposited from the saturated air coming from the lungs.

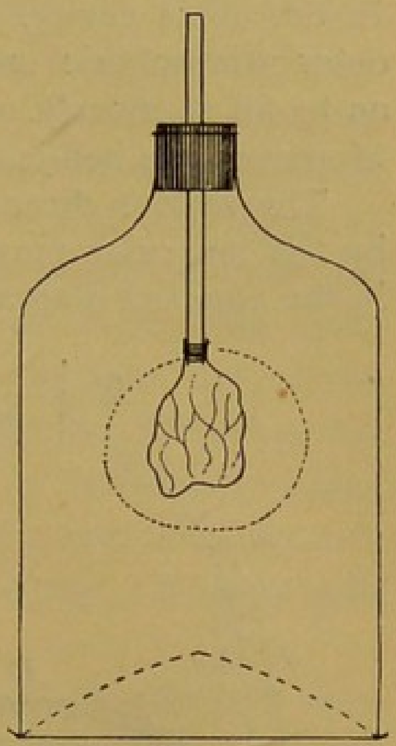


FIG. 96.—Apparatus to show how the descent of the diaphragm increases the inflation of the lungs.

To illustrate, though in an imperfect way, the effect on the lungs of increasing the capacity of the chest by the descent of the diaphragm, fit up the following piece of apparatus :—

Over the bottom of a bell-jar fix a piece of sheet rubber firmly. To one end of a glass tube fasten a toy balloon, after passing the glass tube through a rubber cork that fits the mouth of the jar. Before putting in the cork and tube, press up the sheet of rubber into the lower part of the jar, as indicated by the dotted line of the figure. Then put in the cork with tube and balloon attached. On letting down the sheet of rubber, air rushes down the tube and inflates the balloon to the extent indicated by its dotted line.

The bell-jar represents the chest cavity ; the sheet of rubber the diaphragm; the glass tube and elastic balloon the windpipe and one lung. At first, when the rubber is pushed up below, and the tube and cork then inserted, the atmospheric pressure outside the jar and inside are the same. Allowing the rubber to come down after putting in the tube and balloon represent the descent of the diaphragm, with the result of air going into the lung, for the descent of the sheet makes the pressure of air inside the jar less than outside, and this greater outside pressure forces air down into the balloon. In the chest cavity, however, there is no air at all, so that the outer atmospheric pressure always keeps the lungs distended so as to fill it entirely, except the space taken up by other organs. Moreover, the bell-jar allows no movements of its sides.

The various directions in which the chest cavity are enlarged by the muscular movements producing inspiration are indicated in the annexed diagram by the dotted outlines.

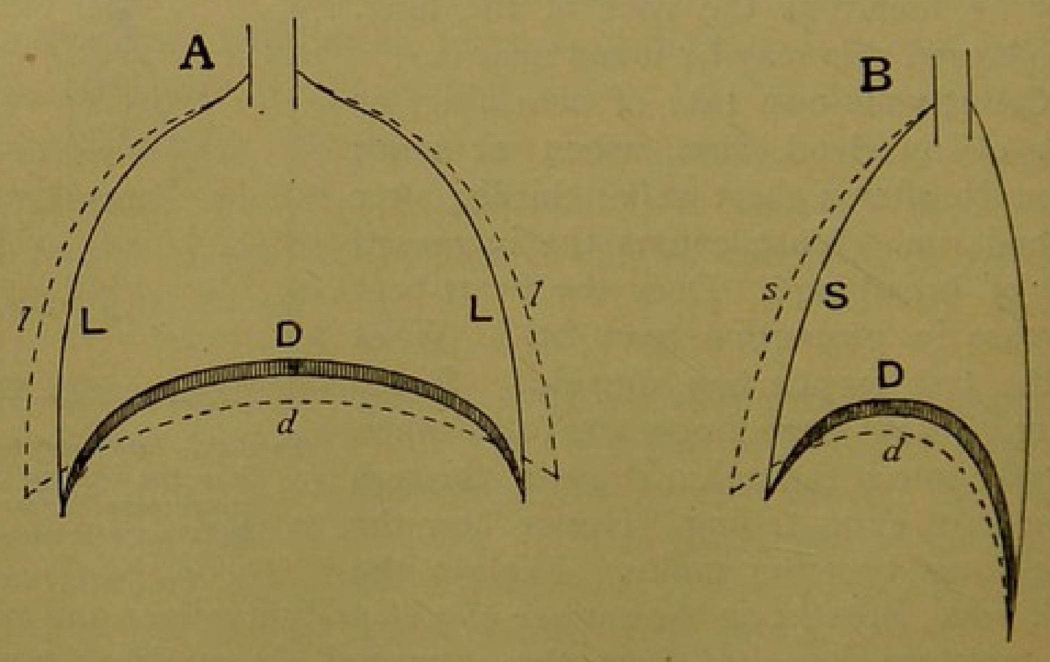



FIG. 96*a*.—Diagrams illustrating enlargement of thorax during inspiration. A, vertical section of thorax from side to side ; B, vertical section of thorax from front to back ; D, *d*, diaphragm ; L, *l*, lateral walls of chest ; S, *s*, sternum.

# CHAPTER XI.

## *FOOD.*

**88. Food and the Need of Food.**—We have already said that a living body may be regarded as a machine, the object of which is to generate heat, produce motion, and repair waste (par. 8). Now no machine can generate energy or power to do work of itself. In an ordinary locomotive engine the energy that warms and moves it comes from the stored-up or potential energy of the coal, for the burning of the coal sets free heat that forms and expands steam, and then puts rods and wheels in motion. What fuel and water are to the engine, bread and meat and other substances are to the body, and these substances are termed **foods.** When absorbed and taken up or assimilated in the body, their oxidation produces heat and the energy for muscular movement, and so carries on both the internal and external work of the body. But the food of the body is more than a fuel or energy producer; it furnishes the materials for the repair of the waste that is continually going on, and during certain periods of life it also increases the size of the bodily organs. The body is, to a large extent, a self-repairing and self-constructing machine.

A man or other animal placed on a delicate machine is soon found to undergo a loss of weight, for he is not only radiating heat into the surrounding air, but from his lungs there passes continually carbon dioxide and water vapour, and from his skin sweat is constantly given up. Careful observations and experiments show the total weight of the losses from an average body amounts to about 8 lbs. per day. These losses may thus be stated :—

| | Water. | Solids in solution. | Carbon dioxide gas. |
|---|---|---|---|
| From the lungs ... | 12 ozs. | — | 26 ozs. |
| From the skin ... | 24 ,, | $\frac{1}{4}$ oz. salts | Small quantity in solution |
| From the kidneys ... | 56 ,, | $1\frac{1}{4}$ oz. urea<br>1 oz. salts | Small quantity in solution. |

In this daily loss the chief elements are carbon, nitrogen, hydrogen, and oxygen. The carbon is lost for the most part in the carbon dioxide given off, and the nitrogen disappears in the urea dissolved in the urine. It is important to notice that the daily loss of carbon is about 8 ozs., and the daily loss of nitrogen about $\frac{1}{2}$ oz., the proportion being fifteen parts of carbon to one of nitrogen. In the above statement of losses we have not included the fæces discharged from the lower bowel (about 5 ozs. daily), for this has never formed a part of the substance of the body, but has merely passed through the alimentary canal. It is plain that if a man is to keep his weight and to continue warm and active new material must be taken into the body, both to rebuild the substance of the tissues used up and to restore, by slow oxidation, the warmth and other energy expended. In young and growing bodies food is also needed for growth.

The main functions of food then are—(1) to form the material of the body and to repair the waste of tissue that is constantly going on; (2) to yield heat to keep the body warm and to supply the energy for nervous and muscular work. Hence food may be defined as "**anything which, when taken into the body, is capable of repairing its waste or of furnishing it with material from which to produce heat, or nervous and muscular work.**" To understand how the loss of matter and energy is made good, we must consider the nature and composition of the various substances used as food.

**89. Classification of Food-stuffs.**—In the account of the composition of the body (par. 7), we learnt that its tissues are composed of a number of chemical organic compounds, termed **proteids**, **carbohydrates**, and **fats**, together with certain **mineral salts** and a large percentage of **water**. An animal cannot build up the complex compounds of its tissues from simple inorganic materials as a plant can. It must be supplied with articles of food that contain substances allied in composition to its own tissues, so that the chemical compounds by which the body is nourished are very similar to the compounds of which the body is composed. The changes which the substances taken as food must undergo before they can be absorbed into the blood and taken up by the tissues will be described in the next chapter.

The substances found by analysis as chemical compounds in articles of food like bread and meat are called **food-stuffs,** or **alimentary principles.** The following table furnishes a list of the different kinds of food-stuffs found in our articles of diet :—

| | |
|---|---|
| 1. Proteids<br>2. Carbohydrates<br>3. Fats | Organic. |
| 4. Mineral salts<br>5. Water | Inorganic. |

Proteids are also known as **nitrogenous food-stuffs**, as they are the only ones that contain nitrogen, while the carbohydrates and fats are **non-nitrogenous organic compounds.**

Oxygen may also be regarded as a kind of food—a gaseous food—taken in through the lungs and used in the tissues to produce heat, muscular movements, and other forms of energy required by the body. We have explained in the last chapter the oxygen requirements of the body. A short account of each of these great classes of food-stuffs will now be given.

**90. Proteids.**—A large number of complex compounds of carbon, hydrogen, oxygen, nitrogen, and sulphur form an important class of substances called **proteids.** They exist in soft solids, or in solution in many common bodies used in our daily diet. The different members of the group are closely related, and are all distinguished by certain chemical tests, though they differ in certain chemical and physical properties. The chief proteids, with the articles of food in which they are found, are—Albumin, found in white of egg, blood, and milk ; globulin, found in yolk of egg and blood ; glutin, found in flour and meal of various kinds ; myosin, found in lean meat; casein, found in milk and cheese; fibrin, found in clotted blood. Gelatin, obtained by boiling bones and tendons, is a substance resembling the above proteids in many particulars, but is less valuable as a nutriment. The albumins and globulins are distinguished from the other proteids by coagulating on heating. Proteids are the only class of food-stuffs containing nitrogen, and are, therefore, absolutely essential, for the body must have nitrogen to repair that lost in urea, and it is only from proteids that the body can obtain nitrogen. Proteids being thus required to build up muscle and other tissues are often called "tissue builders." But they can also be used as fuel, being oxidized to produce carbon dioxide, water, and urea, though the chief fuel ingredients of food are the carbohydrates and fat. They may also to some extent give rise to fat in the body. They are most abundant in the lean meat of all animals and in such vegetables as peas and beans. **Gelatin** is a nitrogenous compound closely allied to the proteids. It is obtained from white fibrous tissue on boiling. It is soluble in hot water, but sets in a jelly when the water cools. Gelatin can replace a certain quantity of proteid required, acting as what is called a "proteid-sparing food," but it cannot entirely take the place of proteids; for animals fed on gelatin in place of proteid undergo rapid waste. Certain bodies, called **extractives**, are sometimes put with the proteid foods, as they contain nitrogen. They are found in meat extracts and beef-tea along with other substances, but they seem only to serve as stimulants and appetizers.

**91. Carbohydrates.**—Carbohydrates are compounds of carbon, hydrogen, and oxygen, the two last elements being in the same proportion as in water. They include the starches, sugars, gums, and cellulose found in our foods. **Starch** is found in cereals, in potatoes, and in green fruit in small solid grains. It must be changed into a kind of sugar (glucose) by ferments in the digestive juices before it can be absorbed into the body. **Glycogen,** or animal starch, is found in the liver and muscles of animals. **Cellulose** is a substance allied to starch that forms the cell walls of plants and the envelope of starch grains. It is difficult to convert into glucose. Hence the need of boiling starch to burst the cellulose covering so that the digestive juices can act on the starch proper. There are several kinds of sugar useful in foods. **Dextrose,** or **grape sugar,** is found in many fruits, and occurs in minute quantity in the blood. **Levulose** closely resembles dextrose. It is found in honey. Neither is so sweet as cane sugar. **Cane sugar** is found in the sugar-cane, beetroot, and maple. When cane sugar is heated with dilute acids it is said to undergo inversion, for it takes up water, and is converted into **glucose**, or equal parts of dextrose and levulose. The same change is effected in cane sugar by the intestinal juice. **Maltose**, or malt sugar, is a kind of sugar produced during the germination of malt. It is also produced by the action of saliva and pancreatic juice on starch. **Lactose**, or milk sugar, is a variety of sugar occurring in milk. The carbohydrates of our food become oxidized to supply heat, and in the process are converted into carbon dioxide and water. When more is taken than can be so used the excess becomes changed into glycogen in the liver, and is then taken to various parts and converted into fatty tissue.

**92. Fats.**—Fats and oils are found in the tissues of some animals, in milk, and in certain seeds. There are different kinds of fats, butter being a mixture of three or four kinds. The oxidation of fats is one of the chief sources of heat to the body, a given weight of fat producing more heat energy than the same weight of any other food-stuff. If more fat is taken than is used in the body it is stored in the body to be used later. Chemically considered, fats are compounds of fatty acids and glycerin. A fat acted on by an alkaline base forms a soap and glycerin—a process called saponification. Fats undergo another change in the body—a physical change, in which the fat is broken up into minute globules—a process called **emulsification**. Milk is a natural emulsion—a fluid with minute globules of fat suspended in it.

**93. Salts.**—The various inorganic salts used in foods are much the same as those found in the body (par. 7). They are found in most articles of food. Common salt makes food more palatable, and aids in gastric digestion. The phosphates of lime and magnesium are needed for making bone.

**94. Water.**—The need for water is easy to understand when we remember that nearly two-thirds of the body weight consists of this compound, and that there is a loss of about 6 lbs. daily. Though a small proportion is produced by the oxidation of the hydrogen in certain tissue compounds, the greater portion must be derived from that which one drinks and the water in the various articles of food, for all the food-stuffs contain a considerable percentage of water. The water taken into the body serves as a tissue-builder, for the solution and conveyance of food to different parts, for the action of the ferments in the digestive juices, and for the solution and removal of such waste substances as the urea in the urine. It also serves for the regulation, by evaporation from the lungs and skin, of the body heat (par. 133).

## 95. Summary of Food-stuffs or Alimentary Principles and their Uses in the Body.

| | | |
|---|---|---|
| PROTEIDS ... ... *e.g.* the albumin of eggs, the casein of milk and cheese, the myosin of lean meat, the glutin of bread | form tissue | All may also serve as fuel and be oxidized, thus furnishing energy in the forms of heat and muscular work, but fat and carbohydrates are the main food-stuffs used as fuel. |
| FATS ... ... ... *e.g.* the fat of meat, the butter of milk, the oil of seeds | are stored as fat | |
| CARBOHYDRATES ... *e.g.* the starch of bread, sago, etc., the sugar of sugar-cane, beet-root, milk, fruits | are stored as fat | |
| MINERAL MATTERS *e.g.* sodium chloride (common salt), the phosphates of lime, soda, and potash | Share in forming bone and assist in digestion. | |
| WATER ... ... .. | Takes part in tissue formation ; assists in dissolving the food-stuffs and conveying them to different parts ; aids in the removal of waste ; aids in regulating the body heat. | |

**96. Composition of Common Articles of Food.**—The chemical compounds or food-stuffs enumerated above are not, except in the case of water, cane sugar, and sodium chloride used as articles of diet in a separate state. We do not have a meal composed of myosin, casein, starch, etc., our articles of food are meat, bread, milk, etc., which contain these chemical compounds in various proportions. To ascertain the amount of such articles of food required we must know the amount of these chemical food-stuffs in the articles of food and bear in mind the amount of daily loss from the body. The chemical analysis of articles of food furnishes us with the first kind of information ; observation and experiments have furnished the other information. The following table, from Waller's "Human Physiology," sets forth in an instructive way the relative amounts of food-stuffs, or proximate principles, contained in certain common articles of food, and also the percentage of the two elements, carbon and hydrogen, found in them.

Approximate Composition of some Common Articles of Diet.

(*Compiled chiefly from Parke's tables.*)

| Articles of food. | Alimentary principles or food-stuffs. | | | | Elements. | |
|---|---|---|---|---|---|---|
| | Water per 100. | Proteid per 100 | Fat per 100. | Carbo-hydrate per 100. | Carbon per 100. | Nitrogen per 100. |
| Milk ... ... ... ... | 86 | 4 | 4 | 4 | 7 | 0·6 |
| Butter ... ... ... | 7 | 1 | 92 | — | 70 | 0·15 |
| Eggs ... ... ... ... | 75 | 14 | 10 | — | 15 | 2 |
| Beefsteak ... ... ... | 70 | 22 | 5 | — | 15 | 3·3 |
| Bread ... ... ... | 40 | 8 | 1·5 | 50 | 28 | 1·25 |
| Potatoes ... ... ... | 75 | 2 | — | 21 | 10 | 0·3 |
| Oatmeal ... ... ... | 15 | 12 | 5 | 65 | 40 | 2 |
| Dried peas ... ... ... | 15 | 22 | 2 | 60 | 40 | 3·3 |
| Rice ... ... ... ... | 10 | 5 | 1 | 83 | 40 | 0·75 |
| Cocoa powder ... ... | 10 | 15 | 50 | 25 | 55 | 2·2 |
| Cheese ... ... ... | 40 | 35 | 25 | — | 35 | 5·2 |
| Beer ... ... ... ... | 89 | 1 | — | 10 | 5 | 0·15 |

The above table furnishes a kind of key to the nutritive value of the articles mentioned, an article being of high nutritive value when it contains a large relative proportion of the food-stuffs, provided the food-stuffs are present in an easily digestible form.

We see from this table, *e.g.* that milk contains all classes of food-stuffs, and that the nitrogen and carbon are nearly in the desirable proportion of 1 of nitrogen to 15 of carbon by weight. Hence milk is regarded as a perfect food. The proteid in milk is in the form of casein, the fat exists in small globules which rise to the surface on standing and form cream, the carbohydrate is lactose or milk sugar, and the salts are chiefly phosphates and chlorides of potassium and calcium. Cheese is an important product of milk, in which the element nitrogen exists in proportion to the carbon in far greater quantity than in milk, as its chief constituent is the curded casein.

Eggs approach the character of a perfect food, but the carbon element is deficient. The whole of the fat is contained in the yolk.

Of the nitrogenous articles of diet, meat is the chief, and of these beef contains the greatest proportion of proteid (myosin and globulin). Lean beef contains over 20 per cent. of proteid material, mutton 18 per cent., and pork 11 per cent. Meat also contains fatty matters (as lecithin), extractives (as kreatin and sarcolactic acid), and salts (chiefly of potassium and calcium). The flesh of poultry and fish (except eels) contains very little fat, and is therefore often eaten with bacon or butter. All these nitrogenous meats contain a quantity of carbon, for it will be remembered that proteid itself contains about 50 parts of carbon to 15 of nitrogen.

Such articles as bread and vegetables, though often spoken of as non-nitrogenous, do contain some nitrogen. Only butter, the fat of milk, and the fat of meat are in reality non-nitrogenous. Peas, indeed, contain as large a proportion of nitrogen as meat, but their nitrogen is not as easily assimilated, and they are not, therefore, as nutritive as meat. The proteid of bread is chiefly gluten, and the carbohydrate is in the form of starch. Starch, indeed, is the chief carbohydrate of all cereals.

Green vegetables contain about 90 per cent. of water, and are of little nutritive value, and their chief value is due to the presence of organic acids and salts.

**97. Requisites of a Suitable Diet.**—We have learnt that the daily loss of matter from the body is about 8 lbs. —6 lbs. of water and 2 lbs. of other matter. The water required to repair the daily loss, less the small amount formed in the body, will be replaced by the water taken as drink, and in the articles of food; the oxygen required will be obtained from the air breathed, and the hydrogen will come with the other food. We may, therefore, confine our attention to the important elements *carbon* and *nitrogen*, for the nutritive value of a food depends chiefly on the amount of these elements in it. The daily loss of carbon in the carbon dioxide given off is about 8 ozs., and the daily loss of nitrogen combined in the urea of the urine is a little more than $\frac{1}{2}$ oz. The proportion of carbon to nitrogen required to replace this loss is, therefore, about 15 to 1, and our daily allowance of food should contain these elements in this proportion.

We understand, then, in the first place, that some amount of proteid, or nitrogenous food, is essential to life, for if an animal is fed solely on carbohydrates and other non-nitrogenous foods, it soon dies, as it continues to excrete the nitrogenous compound urea in the urine when no nitrogen is being supplied, and, to do this, it must be consuming part of its own body substance. But to feed an animal on proteid food-substances alone is injurious, since, in order to get the requisite amount of carbon, he would have to take an excess of nitrogen, which would throw useless work on the digestive organs and kidneys. From $\frac{3}{4}$ lb. of lean meat a sufficient quantity of nitrogen to repair the daily waste can be obtained, but to get a sufficient amount of carbon to repair the daily waste he would require to eat 4 lbs. of the lean meat. Excess of proteid is in part wasted, and excreted as urea, and leads, in part, to more rapid oxidation of tissue. To eat 4 lbs. of lean meat a day for some time is impossible, as it soon becomes nauseous, and produces sickness and diarrhœa.

Again, bread contains carbon in the starch and sugar compounds in it, and nitrogen in the proteid, called glutin. It has, therefore, both carbon and nitrogen, but the quantity of nitrogen is small in comparison with the carbon. Enough carbon could be obtained from a little more than 2 lbs. of bread, but we should require nearly 5 lbs. to get the necessary nitrogen, and this would be far too much for the body.

These considerations point to the advisability of a *mixture* of nitrogenous and non-nitrogenous food-stuffs.

In arranging a suitable diet, therefore, we must find the quantity of a suitable proteid that will replace the amount of nitrogen lost, and supplement this with a carbohydrate, or carbohydrate and fat, which will bring the quantity of carbon up to the required amount. The mineral salts (about 460 grains, or 30 grams) are supposed to be contained in the food-stuffs, while the water required is partly contained in the food and is partly taken in as water, with or without tea, coffee, etc.

The staple articles of diet, meat and bread, may be so adjusted as to supply the nitrogen and carbon in nearly the right proportion :—

| | N. grams. | C. grams. |
|---|---|---|
| ¾ lb., or 12 ozs., of lean meat (340 grains), containing | 10 | 37 |
| 2 lbs., or 32 ozs., of bread (906 grains), containing ... | 9 | 252 |
| | 19 | 289 |

But this is not a customary diet, as a certain proportion of fat is taken with the meat, and part of the bread is usually replaced by potatoes, rice, etc. Various combinations from the common articles may be made, of which the following is given as an example of a liberal diet :—

| | N. grams. | C. grams. |
|---|---|---|
| 16 ozs. bread, containing ... ... ... ... | 5·0 | 125 |
| 8 ,, meat ,, ... ... ... ... | 7·5 | 34 |
| 4 ,, fat ,, ... ... ... ... | — | 84 |
| 16 ,, potatoes ,, ... ... ... ... | 1·3 | 45 |
| ½ pint milk ,, ... ... ... ... | 1·7 | 20 |
| 8 ozs. eggs ,, ... ... ... ... | 2·0 | 15 |
| 4 ,, cheese ,, ... ... ... ... | 3·0 | 20 |
| | 20·5 | 343 |

Both experience and science teach that a **mixed diet**, that is a diet made up of different articles of food, is the most suitable for health and comfort, for none of the common articles of food contain the two great classes of food-stuffs—nitrogenous and non-nitrogenous—in the right proportion. Milk comes nearest, where the proportion of nitrogenous to non-nitrogenous is as 1 to 12. It is very suitable for children, who are forming new tissue rapidly, in their growth, for all new tissue contains nitrogen. But for adults, the proportion of nitrogen is rather in excess, and for them the high percentage of water is objectionable. Mixed with oatmeal or rice, however, milk makes an admirable and cheap food, with the right proportion of nitrogen and carbon.

A purely vegetable diet does not appear to be well suited for man. Most vegetables contain but a small percentage of proteids, so that a large quantity must be taken to get the proper amount of nitrogen. Even in those like peas and beans, that have much proteid, the proteid is more difficult of digestion than that in animal food, and much of it passes off in the fæces unused. All vegetable food also contains a large amount of indigestible cellulose.

Of course the diet should vary with the weight, work, and age of the individual. A man who works hard needs more than a man at rest, more proteid to build up tissue, and more fats and carbohydrates for fuel to supply the energy expended in movement. Dr. Waller states that a man in full work requires daily 1 per cent. of his body weight in solid food and 3 per cent. in water, the 1 per cent. of solid food being made up of 0·2 per cent. of proteid, 0·15 per cent. of fat, 0·6 per cent. of carbohydrate, and 0·05 per cent. of salts. The diet for idleness would be less, as the waste of tissue and the output of energy in work and heat would be more easily balanced. In children a larger proportion of food to body weight is required, as they require food to put on flesh and fat so as to increase in size, as well as food to repair waste of tissue and supply energy.

## EXPERIMENTS WITH FOOD-STUFFS AND FOODS.

**98. Carbon contained in all Organic Substances.**—Heat a small piece of dry starch in a clean test-tube over a Bunsen flame. Notice that the starch soon chars or blackens, while droplets of water condense on the cooler parts of the tube. The black residue that remains is carbon. On taking this out and heating it in the air, it takes up oxygen and forms carbon dioxide. The test for carbon dioxide is lime-water, for carbon dioxide renders lime-water milky. Other organic substances like meat, wood, sugar, potato, etc., on being heated in a limited supply of air as above, leave a residue of carbon. On heating fat or butter in a similar way, it will first melt and then give off inflammable vapour, but when the air supply is limited a black residue of carbon remains.

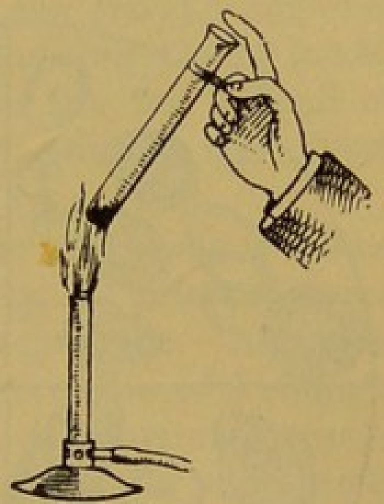


FIG. 97.—Showing that starch is an organic compound containing carbon.

**99. Proteids are Organic Bodies containing Nitrogen.**—All organic bodies contain carbon, but only the class called **proteids** contain nitrogen. Heat some white of egg or gelatine in a test-tube, and notice not only the charring but a pungent smell like that of burnt feathers. This is due to a gas called **ammonia** that is driven out. A red litmus paper, moistened with water, is turned blue by the alkaline action of the ammonia. Ammonia is a gas containing nitrogen, and nitrogen must therefore be one of the elements in the white of egg. Ammonia is more readily driven out of an organic body containing nitrogen if the body be mixed with soda-lime, a substance that contains no nitrogen itself.

Another test to show the presence of nitrogen in a substance is the following. Take some boiled white of egg and pour on it a little strong nitric acid. Heat this in a test-tube and it then becomes yellow. Wash with water and then pour on a few drops of ammonia. The colour deepens to orange. These colour changes with nitric acid and ammonia on heating are peculiar to proteid compounds. Try this nitric acid and ammonia test, with sugar and fat; you will not get the colour changes. Try it with a piece of boiled chicken and with some peas; you will get the colour changes, for both these foods are proteids and contain nitrogen.

**100. Starch.**—Starch belongs to the class of compounds called carbohydrates. It exists in microscopic grains in all cereals, in potatoes, and in many roots, having been formed by the

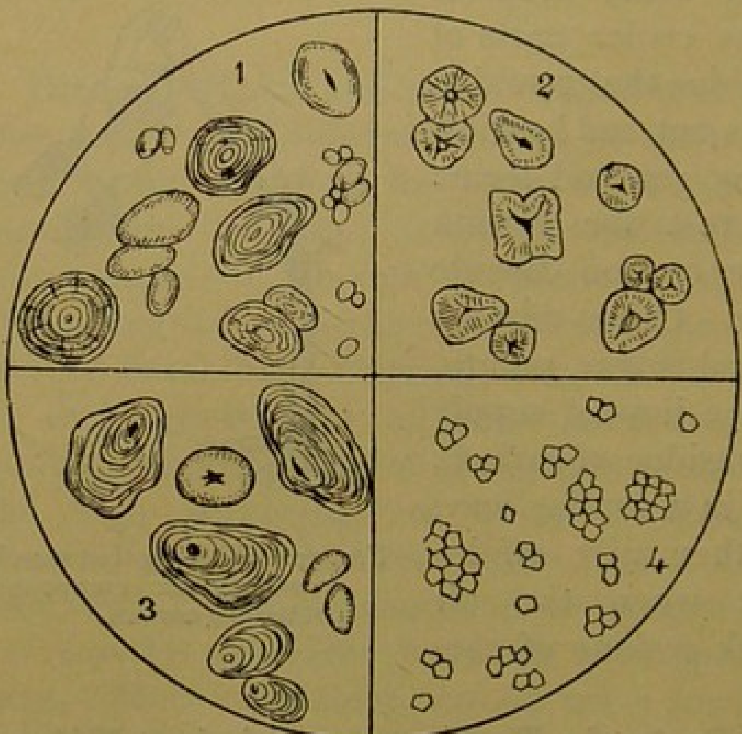



FIG. 98.—Varieties of starch grains, highly magnified. 1, wheat; 2, maize; 3, potato; 4, rice. (*From Paul's "Domestic Economy."*)

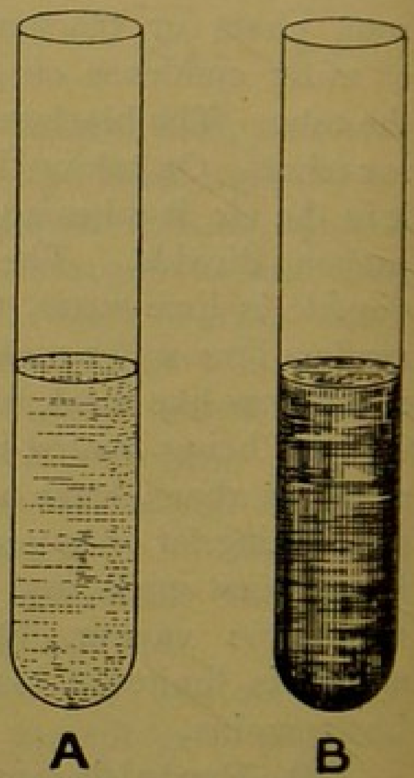



FIG. 99.—A, solution of starch; B, the solution turned dark blue by iodine.

plants out of inorganic substances. Laundry starch has been prepared from rice or wheat. Drop a little iodine solution on a piece of starch. A deep blue colour is formed. **All kinds of starch are coloured blue by iodine solution.** Take a little laundry starch, powder it and shake it up with cold water in a test-tube. Filter. The process of filtration allows a liquid to carry through the pores of a filter-paper any substances that have dissolved, but stops the particles of the substances that have not dissolved. To the liquid that passes through, called the filtrate, add a few drops of a solution of iodine. No blue colour is formed, showing that starch is insoluble in cold water. Now put a little powdered starch in water and heat, with shaking and stirring. The starch dissolves in boiling water to form a kind of paste, for, on adding a drop or two of iodine solution to a filtrate of such heated starch, a deep blue precipitate is formed.

To show that starch is present in potato, cut off a slice and pour on a drop or two of the iodine solution. In a minute or two, blue spots appear as the solution reaches the starch grains. Soaked grains of wheat, oats, and maize, on being cut, can be shown to contain starch in the same way. Seen under the microscope, starch is found to consist of small solid grains, having a definite shape and structure in each kind of plant. Each grain is enclosed in a covering of *cellulose*, but heating in hot water causes the grains to burst the covering, and the starchy contents then dissolve out. This indicates the need of cooking starchy foods, for the cellulose coverings of raw starch grains are too difficult of digestion for man, though many herbivorous animals can digest cellulose.

**101. Sugar.**—Obtain a little dextrose, or grape sugar. Show that it contains carbon like starch. Taste it. It is not so sweet as cane sugar. Dissolve a little in water in a test-tube. Add to a small portion of the solution, several times its volume of Fehling's solution. (Fehling's solution is a blue solution containing cupric sulphate, caustic soda, and Rochelle salt. It must be used fresh and give no yellow colour on boiling.) On boiling a solution of dextrose with Fehling's solution, the mixture becomes turbid, and a yellow or red precipitate of cuprous oxide forms. Dextrose acts as a reducing agent, and changes the cupric salt to a cuprous compound. This precipitate, on heating with Fehling's solution, distinguishes dextrose, and also maltose and lactose, from cane sugar, though maltose and lactose reduce the cupric sulphate in a less degree than dextrose. Cane sugar, or saccharose, does not give a precipitate with Fehling's solution, as it is not a reducing sugar. It can thus be distinguished from dextrose and maltose.

If a strong solution of cane sugar be boiled with about one-tenth its quantity of strong hydrochloric acid for an hour, and tested after cooling with Fehling's solution, it gives a red precipitate.

The cane sugar so heated has been "inverted," or turned into invert sugar. Invert sugar is known as **glucose**, and consists of a mixture of dextrose and levulose. A ferment in the intestinal juice has the power of inverting cane sugar.

**102. Flour.**—Take a handful of wheat flour and mix with water into a stiff dough. Tie up the dough in fine muslin, and then knead the dough in the muslin bag over a bowl of water, dipping the bag in the water frequently. A white milky fluid is found in the basin, and a grey sticky substance left in the bag. The milky fluid consists of the starch granules suspended in water. The granules have been washed out of the flour and have passed through the meshes of the muslin. Test a small portion with the iodine solution. On allowing the milky fluid to stand, the starch granules settle down. The water may then be poured off, and the starch collected on a filter-paper to dry. The grey sticky substance left in the muslin bag is mainly a proteid, or nitrogenous organic compound, called **glutin**. Test a portion with nitric acid and ammonia to prove the presence of nitrogen. A small percentage of mineral salts is also found in flour. The best flour contains only traces of sugar.

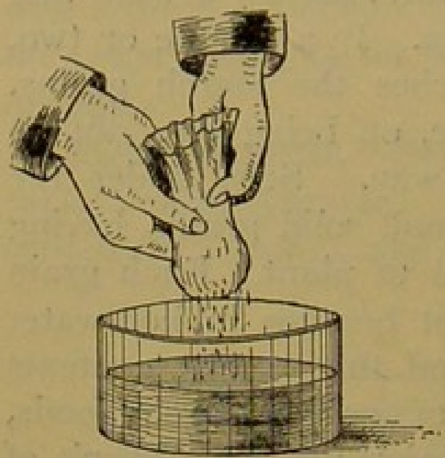


FIG. 100.—Method of obtaining the gluten and starch out of wheat flour when mixed with water and kneaded in a muslin bag.

Bread contains the same constituents as flour, except that some of the starch has been converted into dextrin and dextrose during baking. Test for the sugar.

Common salt may also have been added. Yeast is put into dough to grow and produce fermentation. In doing this, it produces alcohol from the sugar and gives off carbon dioxide. The bubbles of this burrow through the bread, and make it light and spongy. During baking, the carbon dioxide and alcohol are driven off and the yeast killed.

**103. Milk.**—Milk is a fluid in which float numerous minute globules. The fluid contains proteids, lactose or milk sugar, and certain salts in solution. The globules consist of fat in a state of fine subdivision. Examine a drop of milk under the microscope, and note the globules floating in a clear liquid. (Fig. 101). On standing, most of the fat rises to the surface as cream, and if the cream is shaken until the globules run together, we get butter. Milk is a little heavier than water, the specific gravity of cow's milk being about 1030, water being 1000. On skimming off the cream, its specific gravity is increased, as we take away the lighter part. Most of the proteid in milk is casein, but there is a little albumin. Casein does not coagulate on boiling like albumin, but on adding dilute acetic acid or vinegar, coagulation occurs, and a curd of casein with entangled fat globules is obtained, the liquid residue being called whey. A ferment called rennin, produced in the stomach, coagulates milk taken as food.

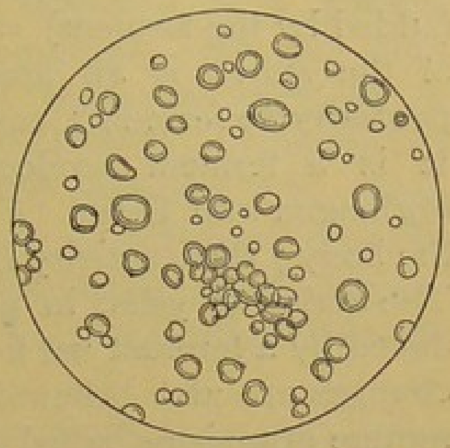


FIG. 101.—Fat globules in milk as seen under the microscope.

**104. Emulsification.** — When a fat or oil is broken up into very small globules that remain suspended in a fluid, such a mixture is called an **emulsion**. All fluids do not emulsify fats. If we shake up a little olive oil or melted butter with water in a test-tube, the oil is broken up in the water by the shaking into little globules, but on putting aside the test-tube, the oil soon separates and rises to the surface. Now shake up a little oil with a solution of caustic soda. This alkaline fluid forms with the oil an emulsion, the globules of oil remaining suspended in the liquid. Oil shaken up with the raw white of an egg also forms an emulsion. Milk is an emulsion of fat and liquid proteids. The fat taken as food is melted in the stomach by the warmth of the body, but it does not form an emulsion with the acid gastric juice. It is only when it gets into the intestine that a part of it is emulsified by the action of the pancreatic juice. Another part undergoes a chemical change, being converted into a soap and glycerin (par. 116).

**105. Ferments.**—Certain pecular nitrogenous substances, called **ferments**, are produced from the blood by the living cells of some of the glands in the body, *i.e.* the cells manufacture the ferments from materials in the blood, and these ferments are capable of producing chemical changes in certain substances in our food. A peculiar thing about these ferments is that they themselves do not appear to change or to be used up in the processes they set up, so that a very small quantity of ferment can produce a considerable change. In the processes of digestion these ferments play an important part, as we shall learn in some detail in the next chapter. Thus one class of ferments, discharged into the alimentary canal, can change insoluble starch into a kind of soluble sugar. This class of ferments is called **amylolytic** (Gk. *amulon*, starch, and *lusin*, to loose), as its chemical action is to change the composition of starch and turn it into a kind of sugar. The ferment causes the starch to take up a molecule of water, without being changed itself. The action may be put thus—Starch *plus* water (added by the ferment) = maltose (a kind of sugar). The **ptyalin** of the saliva is an amylolytic ferment. Another class, called **proteolytic** ferments, can change proteids into soluble peptones. It is a ferment produced after blood is drawn that changes fibrinogen into fibrin. Ferments act best at the temperature of the body ; their activity is suspended by cold and killed by boiling. The action of yeast in producing alcoholic fermentation is produced by a ferment set free by the living yeast cells. Putrefactive changes are also believed to be caused by ferments secreted by minute organisms called *bacteria*, or *micro-organisms*.

**106. Saliva.**—To illustrate the action of a ferment we may collect about half a small test-tube of saliva. To this add a little thin starch paste. Put the test-tube in a beaker of water and keep it for a time at about 100° F. The mixture will become clear and watery. After a little longer, test a part of the liquid in the test-tube with iodine solution. No blue colour is formed, for the starch has been changed to sugar. Apply the test for sugar with the other part, boiling with the blue Fehling's solution. The orange-red colour and precipitate prove the presence of sugar. The change is due to a ferment called **ptyalin** in the saliva. If the saliva be boiled, the ferment is killed and the change will not then occur.

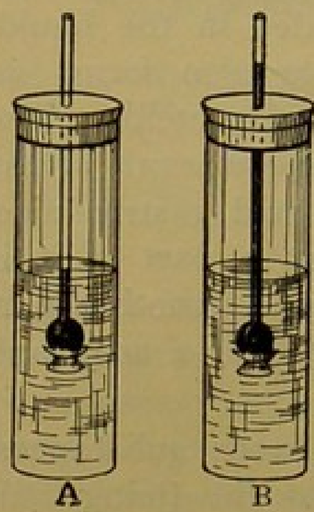



FIG. 102.—Illustrating osmosis. A, the funnel with sugar solution when first put into the liquid; B, the funnel after the water has risen above the level of that in the cylinder.

**107. Osmosis.**—Take a thistle funnel and tie a piece of sound bladder or sheep's intestine over its head. Fill the head and a short distance of the stem with a solution of grape sugar, and then invert the funnel in a beaker of water, so that at first the level in the tube and in the beaker are the same. We now have two liquids of different densities (the solution of grape sugar is of greater density than the water), separated by an animal membrane. Support the thistle funnel and allow the arrangement to stand for a few hours. The liquid in the thistle tube rises to a much higher level, so that some water must have passed from the beaker through the membrane. But some sugar has also passed from the thistle tube into the water of the beaker. This can be shown by treating some of the water in the beaker with Fehling's solution. A red precipitate with this solution proves the presence of grape sugar. Two currents have therefore been passing in opposite directions through the membrane, and the final results would be a solution of sugar of the same strength on each side of the membrane. This passage of fluids and substances in solution through a membrane is called **osmosis** (Gk. *osmos*, thrust, impulsion). Whenever two liquids of different densities are separated by a membrane, there is an exchange of substances; the liquids mingle or intermix, and the greater flow is from the less dense to the more dense liquid.

For a substance to pass through a membrane by osmosis it must be soluble. If we try the above experiment, putting in the thistle tube some starch paste, we shall find, on testing the water outside with iodine solution, that no starch passes into the beaker, though water passes into the thistle tube. If we mix the raw white of egg with water and put this in the thistle tube, we find, on testing the water outside the tube with nitric acid and ammonia, that it contains hardly any trace of the proteid of the egg. Thus, while some substances, sugars, salts, and peptones, readily pass through animal membrane, others, such as starch and proteids, will not pass.

In most parts of the alimentary canal we shall find an animal membrane, the mucous membrane of the stomach and intestines, for example, with lymph and blood on one side and food in various states on the other side. As the food must be absorbed through the membrane into the blood, in order to be carried to the tissues, we now see the necessity of certain digestive changes, such as the change of starch into sugar and of insoluble proteids into soluble peptones, before the food can pass through the membrane into the blood stream. The principle of osmosis is one of the factors of this process in the absorption of food in the alimentary canal, as well as in the exchange of material between the blood and the tissues, and the passage of fluids from a gland into its duct. But the membranes of the intestine, the blood-vessels and glands, are unlike the membrane of our experiment, living membranes, and the living cells of their walls no doubt exercise some selective activity as regards the substances absorbed or secreted.

# CHAPTER XII.

## *ORGANS AND PROCESSES OF DIGESTION.*

**108. The Digestive System.**—The organs forming the digestive system consist of a tube of varying diameter, which runs through the whole trunk, from the mouth to the vent or anus, and of certain glands that pour their secretion into the tube at some part of its course. The digestive tube is usually known as the **alimentary canal.** It begins at the mouth; the mouth leads into a funnel-shaped cavity, called the **pharynx,** and from the pharynx the alimentary canal passes as the **œsophagus,** or **gullet,** down the neck and through the thorax. After passing through the floor of the thorax (the diaphragm), the alimentary canal swells out into a bag, called the **stomach,** this organ lying to the left, just beneath the diaphragm. The tube again becomes narrow, and forms the first part of the small intestine, the **duodenum.** Into this part of the alimentary canal, which is about ten inches long, small tubes or ducts bring the secretions from the great glands, called the **liver** and the **pancreas.** The duodenum continues as the **small intestine** for about twenty feet; but this part of the canal lies in coils in the centre of the abdomen, its first portion, the upper two-fifths, being called the **jejunum,** and its second portion, the lower three-fifths, the **ileum.** The small intestine passes in the right iliac region of the trunk into a much wider tube, called the large intestine. Below the point where the small intestine enters the large intestine, the latter tube has a blind end, called the **cæcum.** A short, narrow tube at the end of the cæcum is known as the **vermiform appendix.** The part of the large intestine above the cæcum is spoken of as the colon. The alimentary canal, therefore, continues as **ascending colon** on the right side of the abdomen, **transverse colon** across the front of the upper part of the abdomen, and as **descending colon** on the left side. The descending colon terminates behind in a straight piece, called the **rectum**, and this last part leads to the outside at an opening called the **anus** (see Figs. 8, 9, and 103).

**109. The Mouth and the Salivary Glands.**—The mouth cavity, into which food is first brought, has already been described (par. 75). The teeth are set in the borders of the upper and lower jawbones, and are of various forms for the cutting and grinding of the food (see par. 24). Chewing or **mastication** is effected by the lower jaw being made to work one set of teeth against the other, the movements being effected by the action of certain muscles proceeding from the fixed bones of the skull to the movable lower jaw. The two condyles of the lower jawbone move in adapted hollows of the temporal bone (Fig. 23), and the articulation is such that the lower jaw can not only be moved up and down against the fixed upper jaw, but somewhat from side to side. Food can thus be cut, crushed, and ground by the teeth.

The mucous membrane lining the mouth consists of a thin outer layer of epithelial cells, beneath which is a dermis of close connective tissue containing blood-vessels and nerves. Many simple tubular glands opening by minute ducts (Fig. 12), into the cavity of the mouth, discharge a somewhat slimy fluid, termed **mucus**. Besides containing simple mucous glands, the mucous membrane of the tongue has many little processes, or papillæ, but as these are connected with the sense of taste, their description is reserved until we treat of the senses.

During the process of mastication in the mouth, the food has not only been moistened with mucus, but has been mixing with a fluid called **saliva**, secreted and discharged by special glands, called the **salivary glands**.

The salivary glands are large racemose glands (Fig. 12, D), situated at some distance from the cavity of the mouth. There are six in all, and they are arranged in pairs, three on each side of the mouth. A **parotid gland** lies on each side, just in

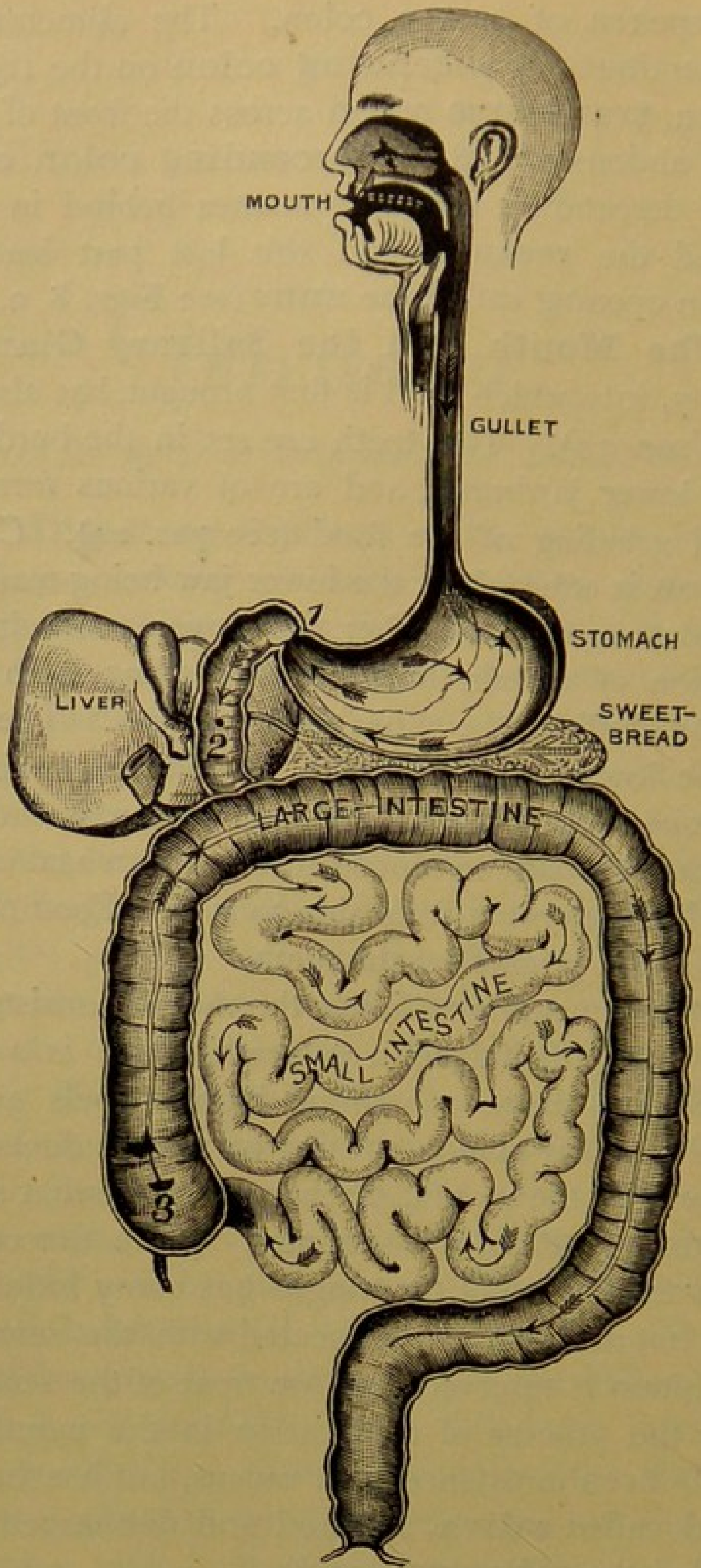



FIG. 103.—General view of the alimentary canal, the liver being turned up. 1, the pylorus, or valve between the stomach and duodenum; 2, opening of the common duct of the liver and sweetbread into duodenum; 3, valve between the ileum and first part of large intestine. The figure 3 is placed in the cæcum below the opening of this valve. Large intestine consists of ascending colon, transverse colon, descending colon, and rectum leading outside. (*From Paul's "Domestic Economy."*)

front of the ear, and behind the angle of the jaw. A tube or duct (Stenson's duct) from each parotid gland opens on the inner surface of the cheek. Two **submaxillary glands** lie under, and their ducts open beneath the middle of the tongue. Two **sublingual glands** lie in the floor of the mouth beneath

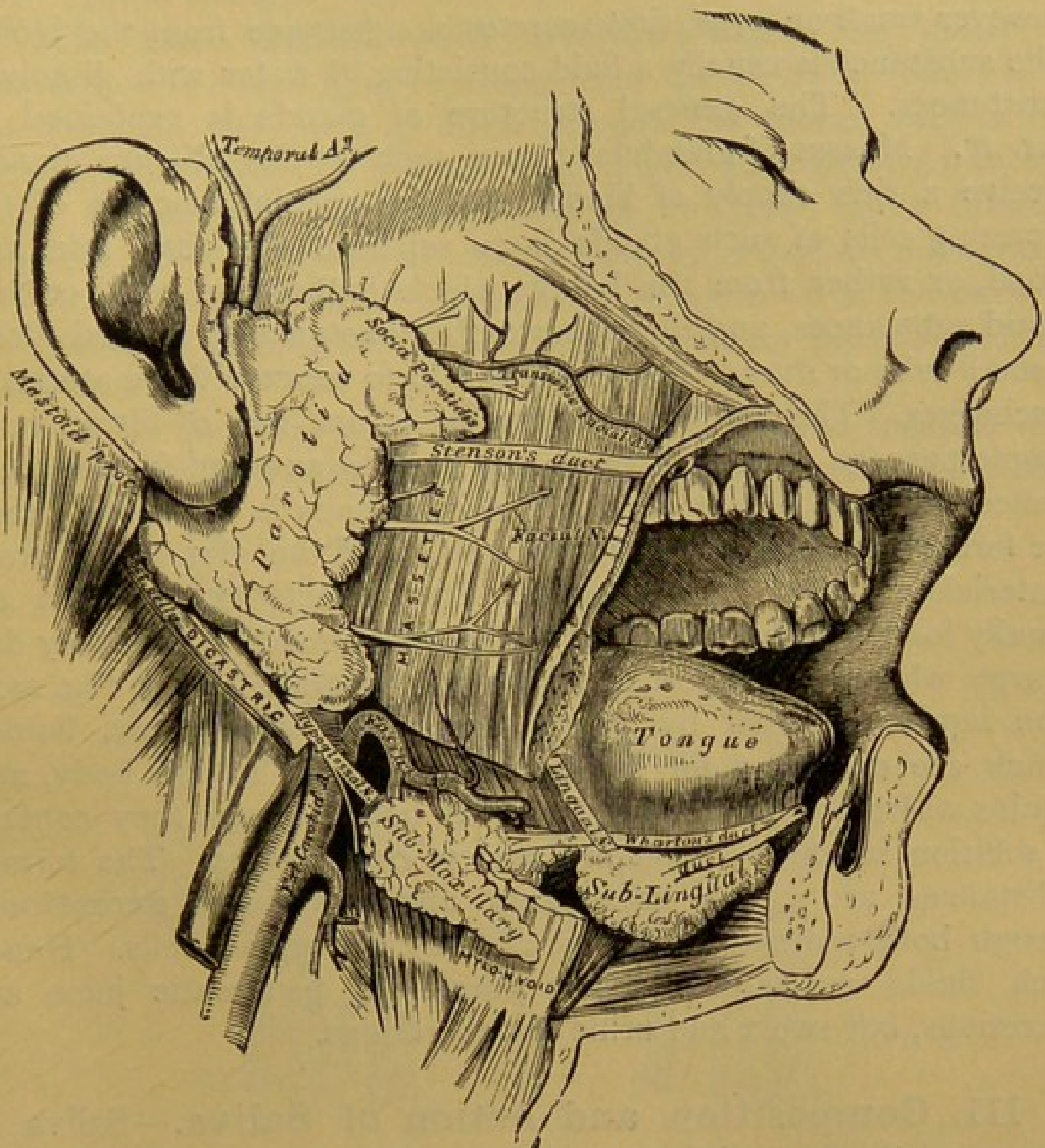



FIG. 104.—The salivary glands. One side of the lower jaw has been removed, and the face dissected, in order to show the salivary glands of the right side. (*From Gray's "Anatomy."*)

the tongue, and open by several ducts under the tongue. The taste, smell, or even sight of food leads to a flow of saliva into the mouth, for the sensory impulses aroused by these sensations pass to a certain part of the brain called the spinal bulb, and from this nerve centre other impulses pass to the glands, causing their cells to secrete more actively. At the same time nervous impulses reach the small arteries going to the gland, causing them to dilate and supply abundant blood for the glands to work upon. The result is due to reflex action (par. 154).

**110. Secretion and Excretion.**—A gland is any organ, however small or large, that secretes a substance from the blood. The substance is usually a fluid consisting of water with dissolved substances. The general structure of glands is explained in par. 17. Masses of glandular tissue, such as the salivary glands, receive a rich supply of blood, and the special function of the secreting cells of such glands is to separate and form from the blood, or rather from the lymph which bathes the cells, certain liquid substances, and to discharge the substance so formed along a small tube or duct. The gland is said to **secrete** the material it discharges. The process of secreting is not one of filtration or simple passage of a fluid from one part to another, for the substances secreted do not, as a rule, exist as such in the blood; they are formed or elaborated by the activity of the gland cells from materials supplied by the blood. During activity, the cells are usually loaded with granules of the secreted material that they discharge, while when at rest there are but few granules (see Fig. 117). The liquids secreted by glands are of two kinds; viz. liquids which are employed for some further purpose in the body, and liquids which are discharged from the body because they contain in solution substances that are useless or injurious. The former substances are called **secretions** and the latter **excretions**, though both are said to be secreted by the gland cells. Hence such fluids as saliva, gastric juice, and pancreatic juice are secretions, but sweat and urine are excretions.

**111. Composition and Action of Saliva.**—Saliva is a watery alkaline fluid, and contains in solution mineral salts, carbon dioxide gas, and a **ferment** called **ptyalin.** The saliva is manufactured from the blood by the cells lining the minute ducts of the salivary glands, and as these minute ducts unite into larger and larger ones, the liquid is at last sent into the mouth. About two pints are secreted daily. Besides moistening the food and assisting in the solution of soluble substances, the saliva has a special action on the starch in the food-stuffs, for the ferment ptyalin in the saliva changes the starch in the food into a kind of sugar called malt sugar, or maltose. A little starch kept in the mouth a few minutes, and well moistened with saliva, may be noticed to become sweet. The chemical tests for starch and sugar are stated in pars. 100 and 101.

**112. The Gullet and Swallowing.**—The gullet or œsophagus is a soft tube reaching from the pharynx (par. 75) to the stomach, and passing down through the thorax behind the windpipe and close to the vertebral column. It is about ten inches long. It consists of an outer coat of muscular fibres running longitudinally and circularly, and is lined by a mucous membrane, in which are simple mucous glands. Passing down at the back of the thorax, it pierces the diaphragm and enters the stomach on the left.

After the food has been masticated, it is gathered together into a ball or bolus by the muscles of the cheek and tongue, and

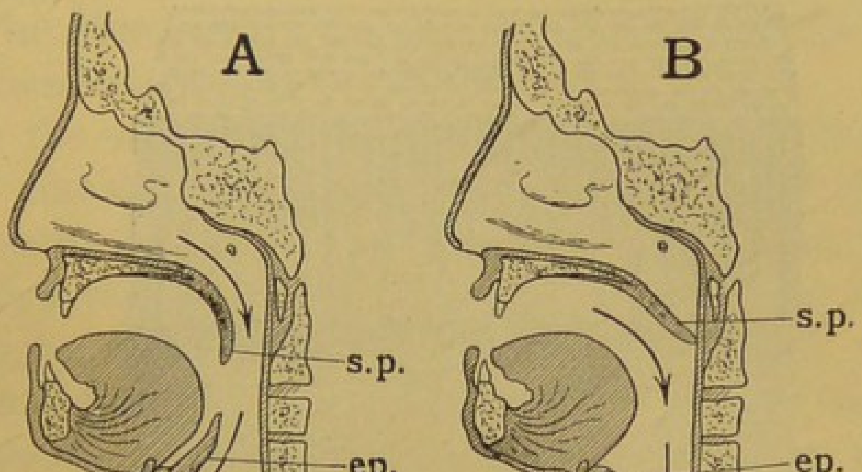



FIG. 105.—Showing position of soft palate (*s.p.*) and epiglottis (*ep.*) during (A) respiration and (B) swallowing (compare with Fig. 85).

sent down through the fauces or back part of the mouth into the pharynx. At the same time the windpipe is drawn up, and the lid-like epiglottis falls down and closes the entrance to the trachea, while the soft palate is also raised so as to shut off the upper end of the pharynx and the way into the posterior nares. As soon as the food enters the pharynx, the muscles of this funnel close upon the mass and force it into the gullet behind the trachea. If a morsel should go "the wrong way" and get into the trachea, it is expelled by violent coughing. On entering the gullet, the food is passed down this tube by the action of its muscular walls, which contract above it and push it along. Food does not simply fall down the gullet, but each part of the gullet contracts after the part above and so forces the food along. It is thus quite possible for a juggler to drink water or swallow food standing on his head. Watch a horse drinking from a stream or eating grass, and the wave-like contraction of the gullet behind the food will be readily noticed.

**113. The Stomach.**—The stomach is a pear-shaped expansion of the alimentary tube, with the broad end to the left and the narrow end to the right. The opening of the gullet into the stomach is called the **cardiac orifice** (being nearest the heart), and the opening by which the food leaves the stomach to pass into the small intestines is termed the **pylorus.** The tissues forming the walls of the stomach may be

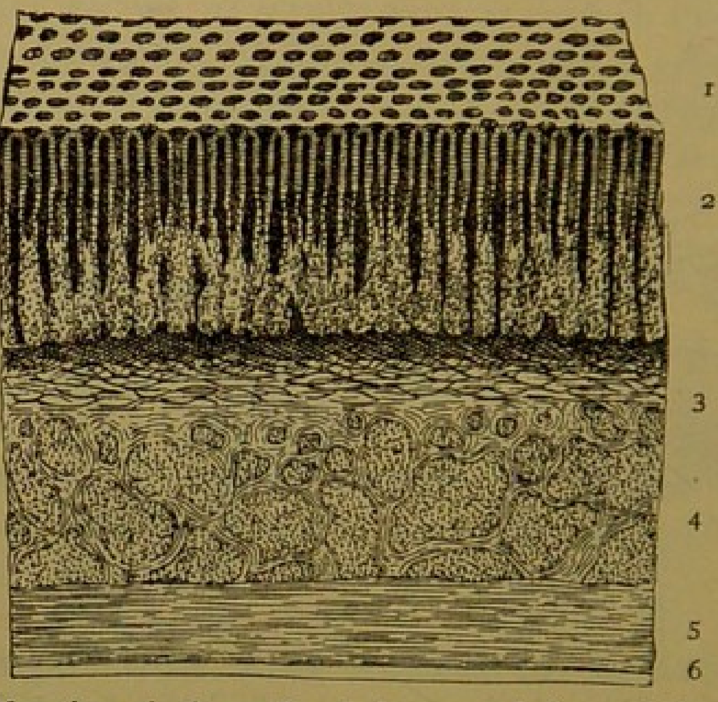



FIG. 106.—A section through the walls of the stomach (magnified 15 diameters). 1, surface of the mucous membrane, showing the openings of the peptic glands; 2, mucous membrane, composed almost entirely of glands; 3, submucous or areolar tissue; 4, transverse muscular fibres; 5, longitudinal muscular fibres; 6, peritoneal coat. (*From Furneaux's "Elementary Physiology."*)

said to consist of four layers—(1) an outer coat of peritoneum, formed of fibrous tissue; (2) a muscular coat with muscular fibres running longitudinally, and others, within these, running circularly and across; (3) a submucous coat of connective tissue richly supplied with blood-vessels; and (4) a mucous coat, containing a large number of small tubular glands among connective tissue, with minute blood-vessels running between the glands. The mucous membrane of the stomach differs from that of the œsophagus, as it is almost entirely composed of tubular glands arranged side by side, and the epithelium of the internal surface is formed of only one layer of columnar walls (Fig. 106). If we examine with a lens the inner coat of a stomach, the coat that comes next to the food, we see a number of tiny holes that form the mouths of the gastric glands; but we must examine a section under the microscope to see the forms of the glands. Most of the glands are then seen to consist of two to four secreting tubules that open near the surface into a common duct. The epithelium lining the duct resembles that of the inner surface, but that of the secreting tubules is different. In the glands near the cardiac end of the stomach the cells of the tubules are of two kinds—cuboid granular cells that secrete the pepsin, and ovoid cells that secrete the hydrochloric acid (Fig. 107). The glands near the pyloric end of the stomach do not contain these ovoid cells.

When the stomach is at rest, its mucous membrane is pale in colour and thrown into wrinkles, or **rugæ**; but when food passes into the organ, its blood-vessels dilate, the mucous membrane opens out and becomes bright red with the increased blood-supply, and the cells of the glands secrete from the surrounding lymph a fluid called **gastric juice** (Gk. *gaster*, the stomach). The gastric juice trickles out at the open ends of the small tubes into the cavity of the stomach, and then begins to act on the food. When distended a stomach will hold about 6 pints.

**114. Composition and Action of Gastric Juice.**—Gastric juice is a colourless acid liquid consisting of water with a very small amount of soluble salts, a little free hydrochloric acid, and two ferments. The hydrochloric acid only forms two parts per thousand, but it is enough to make the liquid acid. The ferments in the gastric juice are called **pepsin** and **rennin.**

The masticated food acted upon by the alkaline saliva reaches the stomach through the cardiac orifice, and for some time (fifteen to twenty minutes) the **ptyalin** ferment of the saliva continues its action on the starchy parts of the food. The amount of gastric juice poured into the stomach under the stimulus of the food that enters then renders the contents acid. The ptyalin of the saliva is then destroyed, and the gastric juice begins its action.

A large quantity of gastric juice is secreted daily (eighty to ninety ozs.), but most of it is reabsorbed into the blood with the food on which it has acted as the mass passes along the small intestine. **Rennin** ferment causes milk to coagulate and form a curd consisting of casein and entangled fat. The curd is then subjected to the action of the pepsin in the gastric juice.

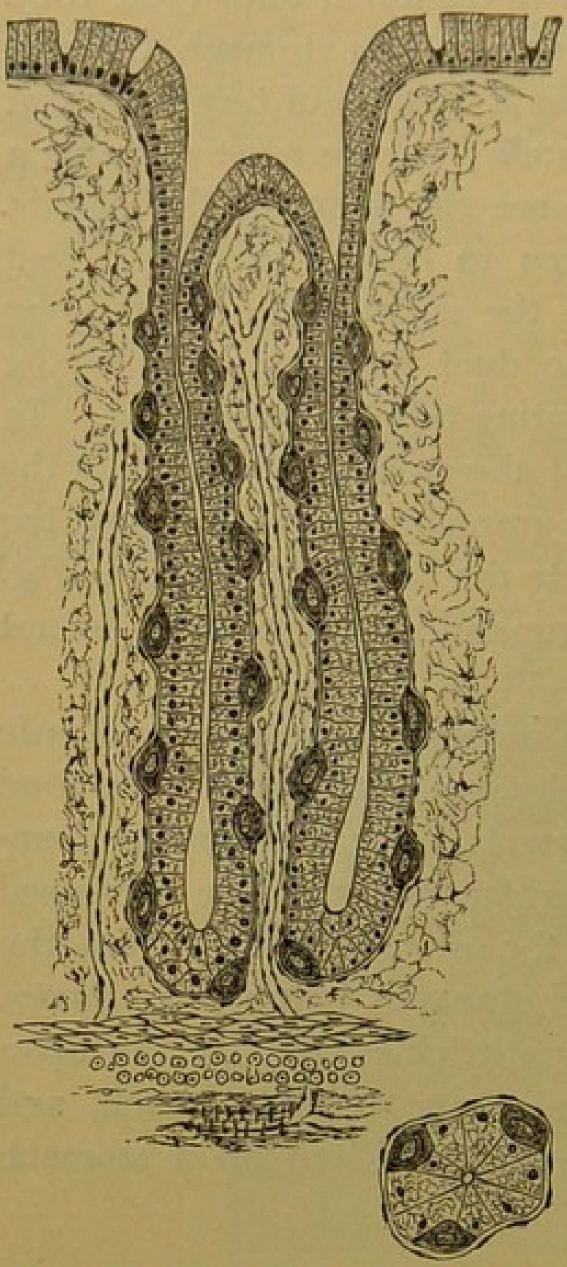


FIG. 107.—A gastric gland from the cardiac end of the stomach highly magnified. The mouth of the gland is lined with simple columnar epithelium, and branch below into two fine tubules lined by two kinds of secreting cells—cuboid central cells, with here and there ovoid acid cells. (*From Gray's "Anatomy."*)

Soon after the food enters the stomach, its walls contract in such a way as to churn the food round and round, and thus bring every part under the influence of the gastric juice. The special property of this juice is the power it possesses of turning the proteids of the food from an insoluble state into soluble forms so that they will **diffuse**, *i.e.* pass through a membrane from a strong solution to a weaker one (see Diffusion, par. 74, and Glossary). The change in the proteids of the food is produced by the pepsin ferment of the gastric juice, but only in the presence of hydrochloric acid. Thus many of the insoluble proteid matters in such foods as meat, bread, milk, and egg become changed in the stomach into soluble or diffusible proteid compounds called **peptones**. On the carbohydrates and fats of the food the gastric juice has no effect, except to dissolve the proteid covering in which some of these lie, and to melt the fats. The stomach thus contains, some time after the food has entered it (two to three hours), starchy portions of food unchanged, starchy portions changed into sugar, proteids changed into peptones, melted fats, indigestible parts of food, etc., all mixed with gastric juice. This acid mixture of gastric juice and partly digested food-materials forms a thick greyish liquid called **chyme**. Some of the sugar and peptone of this mixture becomes absorbed into the blood-vessels of the stomach, but the greater part passes on into the small intestines through the **pylorus**. Here the alimentary tube is surrounded by a band of circular muscular fibres forming a sphincter muscle. The contraction of this sphincter prevents the onward passage of food until the contents of the stomach have been softened and prepared. The time required for that part of the digestive process called gastric digestion averages from three to four hours, but it varies with the kind of food.

**115. The Small Intestines.**—The coils of the small intestines lie in the middle of the abdomen, and are divided into three parts, termed **duodenum**, **jejunum**, and **ileum**, the first part being much the shortest. The whole length of the small intestine is about twenty-three feet, and it is about three inches in circumference. The whole intestine is attached to the margin of a fan-shaped membranous fold called the **mesentery**. The mesentery is derived from the peritoneum, or lining membrane of the abdominal cavity. The **duodenum**, the first part of the small intestines, is a looped tube forming a C-shaped curve (Fig. 103), ten inches long, attached to the hinder wall of the abdomen on the left side of the stomach. Into its lower bend a duct from the liver and a duct from the pancreas open together (Fig. 118). The duct from the liver brings bile, and the duct from the pancreas brings pancreatic juice, and these two fluids mix with the chyme from the stomach and produce important changes in its composition, as will shortly be described. The part of the small intestine succeeding the duodenum for about seven feet is called the **jejunum** (Lat. *jejunus*, empty), as it is often found empty after death; while the latter part of the coils, about thirteen feet long, is the **ileum** (Gk. *eileo*, to hoist). The ileum terminates near the front of the lower part of the right ilium bone—that is, in the region of the right groin. The walls of the small intestine consist of the same layers as the stomach—(1) an outside membranous layer from the peritoneum continued from the mesentery; (2) two thin layers of plain muscular fibres, longitudinal and circular; (3) a submucous layer; (4) a mucous membrane. By the contraction of the longitudinal and circular fibres in the intestinal wall, waves of constriction pass along the tube and gradually push the food onward. Such a wave of contraction is called a **peristaltic** wave. The slow peristaltic waves of constriction running down the intestine may be observed on opening the abdomen of an animal as soon as it is killed, if the intestine be gently tapped. The mucous membrane forming the inner lining of the tube is, until the ileum is reached,

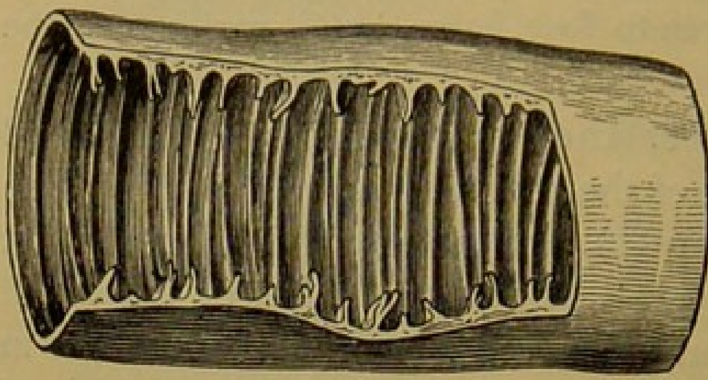


FIG. 108.—Portion of small intestine laid open to show folds of mucous membrane (valvulæ conniventes). (*From Quain's "Anatomy."*)

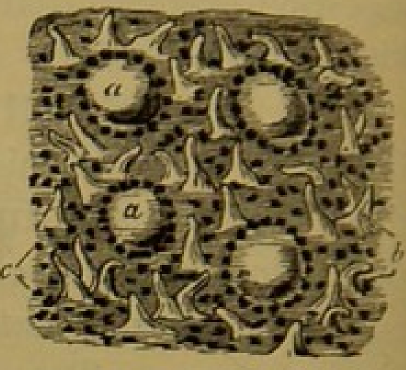



FIG. 109.—A small portion of the mucous membrane of the small intestine (magnified 12 diameters). *a*, Peyer's glands, surrounded by tubular glands; *b*, villi; *c*, opening of the tubular glands.

longer than the enclosing outer layer of the tube, so that it is thrown into circular folds or tucks, known as **valvulæ conniventes.** These increase the absorbing surface within. The mucous membrane of the small intestine is not smooth, but beset with minute processes or projections called **villi**, like the pile of velvet. This again increases the surface of absorption. Each villus is like a short projecting hair ($\frac{1}{40}$ to $\frac{1}{8}$ of an inch long), and the villi are so closely set together as to give a velvety appearance. Under a microscope, a villus is found to consist of an outer layer of columnar epithelial cells, within which is a framework of connective tissue containing blood-vessels and a lymphatic vessel, here called a **lacteal.** Between the villi are many simple tubular glands, opening into the intestine, set side by side and lined with cuboid secreting epithelial cells. They are known as the **crypts,** or **glands of Lieberkühn.** They secrete and pour out during digestion a fluid termed intestinal juice.

Embedded in the mucous membrane here and there are small nodules of lymphoid tissue, consisting of leucocytes in a fine meshwork of connective tissue like a lymphatic gland.

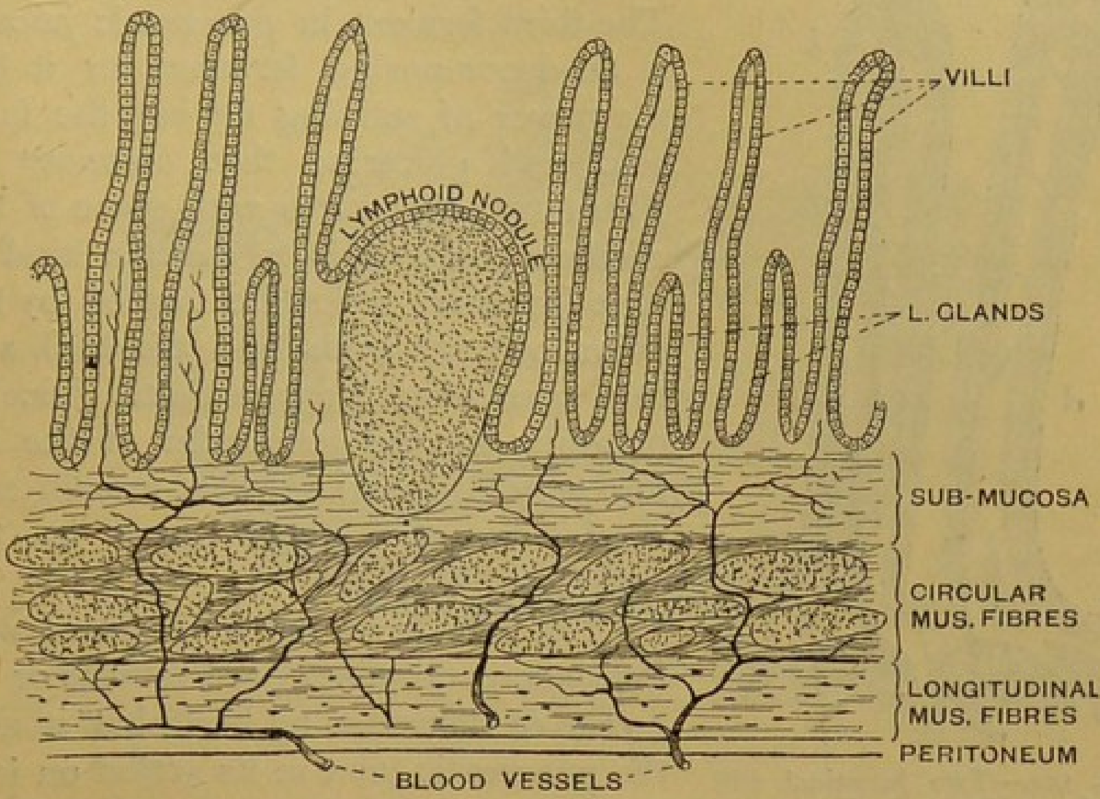



FIG. 110.—Diagrammatic section to show the structure of the wall of the small intestine. The mucous membrane consists of villi with small tubular glands (Lieberkühn's glands) between. Lymphoid nodules are also found in it here and there. Beneath the mucous coat is a thin layer of loose connective tissue, the submucosa. Under this is a layer of circular muscular fibres, and then a layer of longitudinal muscular fibres. Outside is the serous coat of the peritoneum.

Though they have no duct or outlet, they are spoken of as **Peyer's** glands, or, when packed together, as **Peyer's** patches. Over these nodules the villi are absent.

**116. Digestion in Small Intestine.**—The duodenum receives the partly digested food called chyme from the stomach, and the digestive process is for the most part completed in the small intestine by the action upon the food of certain secretions from the pancreas, liver, and intestinal glands, while the fully digested food is then absorbed partly by the blood-vessels and partly by the lacteals of this part of the alimentary canal.

Pancreatic juice is an alkaline colourless fluid containing in solution proteid and mineral matters. About three-quarters of a pint is secreted daily. It also contains three ferments, by means of which it acts upon three classes of food-stuffs—a ferment, **amylopsin**, that changes starch into sugar like saliva ; a ferment, **trypsin**, that changes proteids into peptones like gastric juice, but gastric juice operates on the proteids in an acid solution, and pancreatic juice in an alkaline solution. Pancreatic juice also emulsifies and in part saponifies fats. The third ferment in pancreatic juice is a fat-decomposing ferment, for it has the power of splitting fat into the fatty acid and glycerine that compose it. This fatty acid unites with some of the alkaline compounds to form a kind of soap (ordinary soaps are formed by the union of fatty acids and alkalies), and this soap aids the pancreatic juice in breaking up the remainder of the fat into very fine particles that remain suspended in the liquid mass in the intestine.

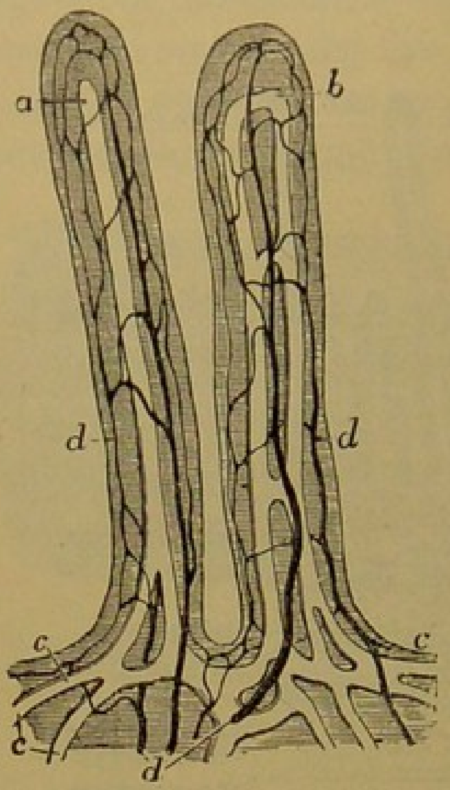



FIG. 111.—Two intestinal villi (magnified 100 diameters). *a*, *b*, and *c*, lacteals for absorbing fat; *d*, blood-vessels. (*From Quain's "Anatomy."*)

The bile from the liver enters with the pancreatic juice. It has little or no power of digestion by itself, but it aids the pancreatic juice in its action on fats. It also serves in some way to assist in the absorption of the fat into the lacteals. It further acts as an antiseptic in the intestines.

The intestinal juice from the multitude of Lieberkühn glands has recently been shown to be of considerable importance in digestion. It assists and intensifies the pancreatic juice in its action on proteids. It contains also a ferment termed **erepsin**, which breaks up the peptones into simpler compounds. Neither peptones nor these simple compounds are present in blood, so that they must be reformed into the proteids of the blood during absorption. Intestinal juice also contains a ferment called **invertin**, that changes cane sugar into glucose or invert sugar (par. 91).

**117. Absorption in the Small Intestine.**—Food is digested or changed into a more or less soluble form in order to be absorbed into the blood-stream, and it is absorbed in order that it may be carried to various parts and assimilated—that is, made part of the living substance of the tissues. From what has been said, it is clear that, though water and such a salt as sodium chloride are absorbed unchanged, the three great classes of organic food-stuffs undergo great changes, owing to the action of the digestive juices, in order to prepare them for absorption. A little absorption of water and easily soluble

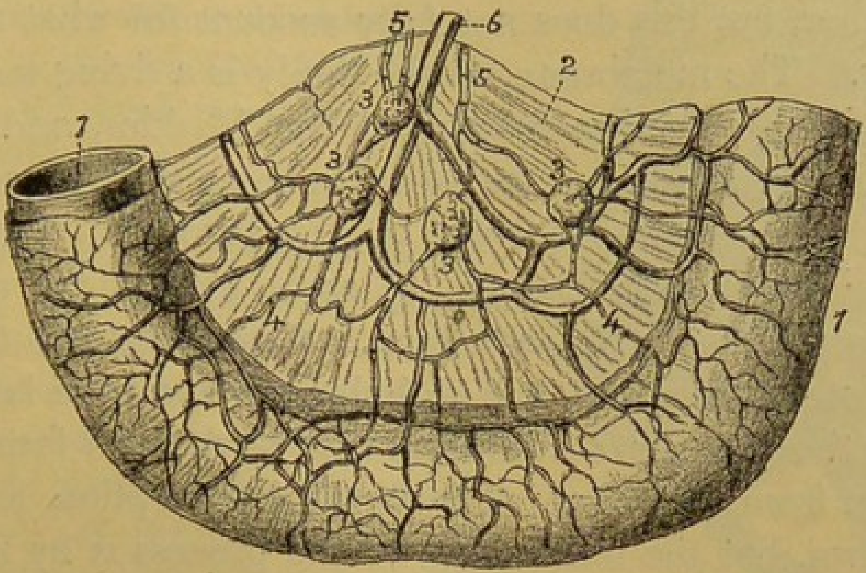



FIG. 112.—Lymphatics of the intestine. 1, portion of small intestine; 2, with layer of mesentery, 3, mesenteric lymphatic glands with lacteals (4) passing in, and (5) passing out; 6, branch of portal vein formed by smaller branches from intestine.

material takes place in the mouth; more absorption takes place into the blood-vessels in the walls of the stomach; but the great channels of absorption are the blood-vessels and lacteals in the mucous membrane of the small intestines. The columnar cells covering the inner surface of the small intestine—a very great surface when we remember the length of the small intestine and the increase in the amount of surface due to its ridges and millions of villi—have the power of taking up the digested food and passing it on into the countless capillary blood-vessels and lacteals beneath. In some strange way the digested proteids and carbohydrates are directed to the blood-capillaries, and the emulsified fats to the lacteals, for the lacteals are the great channel of fat absorption, the milky fluid absorbed during digestion being called **chyle**. The blood-capillaries unite with others at the base of the villi, and so form veins which pass away in the mesentery to unite with other veins to form the great portal vein going to the liver (par. 57). The lacteals also pass from the villi to unite with others, and these carry the fatty emulsion they contain when absorption is taking place along small vessels in the mesentery to lymphatic glands, from which other lacteals proceed to the thoracic duct (par. 70).

Absorption may be partly explained by the physical process called osmosis (par. 106), which shows that liquids of different densities separated by animal membranes tend to diffuse into one another, but this does not fully account for what occurs in the body. The membrane in the body is a living membrane, and not like the dead membrane of the bladder, and the cells of this living membrane are able, in some way, to select and regulate the substances allowed to pass through. Besides, the living columnar cells change, to some extent, the nature of the substance passing through them. Peptones reach the blood as the proteids, albumin, and globulin, while all the fat appears to reach the lacteals as droplets that have been formed in or passed on from the cells. The facts of absorption are pretty well known, but the true nature of the process is by no means fully understood.

**118. Structure and Functions of the Large Intestine.**—The small intestine passes into the large intestine in the right iliac region of the abdomen, joining it at right angles, and not quite at its beginning, so that a blind end is below (Fig. 8). This blind end of the large intestine is called the **cæcum** (Lat. *cæcus*, blind), and from it a narrow, short, blind tube projects called the **vermiform appendix.** Beyond the cæcum the large intestine is called the **colon.** It goes up on the right side as the **ascending colon,** across in front below the liver and stomach as the **transverse colon,** and then down the left as the **descending colon.** After a sharp twist or flexure (the sigmoid flexure) in the left iliac region (not shown in Fig. 103), the large intestine passes on behind the pelvic cavity as the **rectum.** This terminates at the opening called the **anus.** The large intestine is five or six feet long and much wider than the small intestines. Its longitudinal muscular fibres are shorter than the other parts of the tube, and, being arranged in three bands, throw it into a series of pouches or bags that give it a puckered appearance. The opening leading from the ileum, or last part of the small intestine, into the beginning of the large intestine above its blind part is called the **ileo-cæcal valve,** as the projecting folds of mucous membrane serve to protect from backward passage.

The mucous membrane of the large intestine differs from that of the small intestine in having no valvulæ conniventes, no villi, and no Peyer's patches. It is lined with columnar epithelium, and is beset with numerous simple tubular glands that secrete a mucous discharge.


FIG. 113.—The ileo-cæcal valve. *a*, ileum; *b*, ascending colon; *c*, cæcum; *d*, junction of the cæcum and colon; *e* and *f*, loose folds of the mucous membrane, forming the ileo-cæcal valve; *g*, vermiform appendix.

Most of the digested food is absorbed in the small intestine, so that a semi-fluid mass is left to pass through the ileo-cæcal valve. A small portion still absorbable is taken up by the large intestine, which also absorbs water. The contents of the large intestine thus become a firmer mass consisting of indigestible parts of the food, some constituents of the bile, and parts of the digestive juices not absorbed. What is thus left becomes the excrement, or **fæces**, and is forced along by the peristaltic contractions of the intestinal wall. It collects in a curved portion of the large bowel just above the rectum, until uneasy sensations lead to its expulsion at the anus. The excrement, therefore, contains, not the waste products of the body's oxidation, but the refuse of the food, as woody fibres and fibres of gristle, besides remains of the digestive juices that cannot be again used, cast-off cells from the intestinal mucous membrane, and even parts of food that, owing to their size or hardness, have escaped digestion. We find, also, products of bile decomposition, and to this last the excrement owes its colour. Its unpleasant smell is not the consequence of the digestive processes, for, in spite of the disinfecting action of bile, processes of decomposition, and putrefaction are set up in the last part of the intestine by the agency of microscopic living creatures called **bacteria,** or micro-organisms—agents which are the cause of decay and putrefaction everywhere.

**119. Summary of Digestion and Absorption.**—We have followed in the preceding paragraphs the digestible constituents of the food through the digestive apparatus, until they have been taken up in a dissolved and changed condition, through the cells lining the mucous membrane of the stomach and intestines, and have also learnt how they are then handed on directly and indirectly into the blood-stream. It may be useful for the student to have the following summary of the digestive changes and absorbing processes in the alimentary canal. The term **digestion** is given to the processes of chemically changing and transforming the food taken, so that the various kinds of food-stuffs become soluble and diffusible substances capable of passing through the lining membrane of the alimentary canal. The term **absorption** is applied to the passage of the digested food through the lining cells of the alimentary mucous membrane into the numerous blood-vessels and lacteals that lie beneath. The process of converting the absorbed food into the tissues of the body is termed *assimilation* (*see* Glossary).

SUMMARY OF DIGESTION AND ABSORPTION.

| Part of alimentary canal. | Secretion discharged. | Action of secretion and digestive processes carried on. | Absorption carried on. |
|---|---|---|---|
| MOUTH . | **Saliva**, an alkaline fluid consisting of water, in which inorganic salts (sodium chloride, sodium carbonate, calcium carbonate, and calcium phosphate) are dissolved. It also contains the ferment **ptyalin**. **Mucus** also discharged. | During mastication the food is mixed with saliva and mucus. Some of the starchy portions of the food are changed into sugar by the action of the ptyalin ferment in the saliva. | A small amount of water and soluble sugar and salt. |
| STOMACH . | **Gastric juice**, an acid liquid consisting of water with a small amount of salts and hydrochloric acid in solution. It also | Pepsin changes the proteids of food into peptones in the acid solution. Rennin curdles the casein of milk, and it is then changed | A small amount of water, salts, sugars, and peptones during the churning of the food by the muscles |

| Part of alimentary canal. | Secretion discharged. | Action of secretion and digestive processes carried on. | Absorption carried on. |
|---|---|---|---|
| | contains two ferments, **pepsin** and **rennin,** in solution. | into a peptone by the action of the pepsin. The proteid covering of fat-cells dissolved and the fat set free. Total result of gastric digestion is to change the food into a thick grey fluid called **chyme.** | of the walls of the stomach. |
| SMALL INTESTINE | **Pancreatic juice,** an alkaline liquid consisting of water, soluble salts, proteids, and ferments. Its ferments are **trypsin, amylopsin,** and a fat-splitting ferment. | Trypsin changes proteids into soluble peptones, the proteolytic action being aided by a ferment in intestinal juice. Amylopsin turns starches into sugars. The fat-splitting ferments decompose and emulsify fats. | Much absorption — sugars, peptones, and water pass through the epithelium of the villi into their blood-vessels; the changed fats pass through the epithelium of the villi, and, reforming as fat, then pass to the central lacteals of the villi. |
| | **Bile,** composed of water, the sodium salts of the bile acids, some inorganic salts, and some fatty matters. | Assists pancreatic juice in emulsifying fats; assists mucous membrane in absorption. It is antiseptic to the contents of the intestine. | |
| | **Intestinal juice** from the tubular glands of Lieberkühn in the mucous membrane of the small intestine. It is an alkaline fluid containing salts and ferments in solution. | Reinforces and strengthens the action of the pancreatic juice by a ferment; converts cane sugar and maltose into glucose. | |
| | | The white fatty fluid formed in the small intestines after the action of the digestive juices on chyme is called **chyle.** (The term | |

| Part of alimentary canal. | Secretion discharged. | Action of secretion and digestive processes carried on. | Absorption carried on. |
|---|---|---|---|
| | | "chyle" is also used for the milky fluid found in the lacteals during digestion. | |
| LARGE INTESTINE | **Intestinal juice** and mucus. | Little digestive change | Absorption of small amount of remaining nutriment and some water. |

## 120. Experiments with Digestive Juices.

**Saliva.**—Saliva may be obtained for experimental purposes by chewing indiarubber, and collecting the saliva in a test-tube. Breathing the vapour of strong acetic acid stimulates the flow. On testing the opalescent fluid so obtained with a red litmus paper, a slight alkaline reaction is obtained. The action of saliva on starch has already been shown (par. 106).

**Gastric Juice.**—Obtain from a butcher the stomach of a recently killed pig. Wash it out, and then pull or scrape off the soft mucous membrane. Mince the mucous into fine shreds, add to this a dilute solution of hydrochloric acid (0·2 per cent.), and place this mixture in a water-bath at about 100° F. for two or three hours. After this draw off some of the liquid, and you have a fluid very like gastric juice, for it is a solution of pepsin in 0·2 per cent. of hydrochloric acid.

To show that the fluid obtained will digest proteids, add to a quantity in a test-tube a few shreds of fibrin, and to another a few bits of the white of an egg. Place the tubes in a warm place, and notice that the fibrin and albumin begin to dissolve, so that in an hour or so the fluid is nearly clear. The fibrin and albumin have been converted into soluble peptones. If the fluid be boiled before using, it fails to act, as heat kills the pepsin, as it kills other ferments.

The essential constituents of gastric juice besides water are **pepsin, hydrochloric acid,** and **rennin.** The action of rennin appears to be confined to the curdling of milk. An artificial gastric juice, to show its action on proteids, may therefore be obtained by dissolving a little pepsin in water slightly acidulated by hydrochloric acid. Pepsin can be bought at the chemist's. Benger's *liquor pepticus* may also be used to supply the pepsin. Try the artificial gastric juice made as above, and you will obtain the same results.

Rennin is the ferment that causes milk to curdle or clot before it is acted on by the pepsin and hydrochloric acid. Procure from the chemist a little **rennet**—an artificial preparation containing rennin, and obtained from the stomach of the calf. Add a few drops of rennet to some milk in a test-tube, and allow it to stand a few minutes in a warm water-bath. Notice the curd of casein that forms. Put a little casein into another test-tube, and add some of the artificial gastric juice, keeping the tube for two or three hours at about the body temperature. The casein dissolves.

**Pancreatic Juice.**—To show the action of pancreatic juice, obtain a fresh pig's pancreas from the butcher, mince it finely, and warm it for three or four hours with a dilute solution of sodium carbonate. Draw off the fluid, and you have something resembling ordinary pancreatic juice. (An artificial pancreatic juice may be made by dissolving 5 grains of pancreatin and 15 grains of sodium carbonate in 100 c.c. of water.) Show that the pancreatic juice you have prepared will change starch into sugar, and proteid into peptone. Show, also, that your pancreatic juice will emulsify fat (par. 104).

**Bile.**—Obtain an ox's gall bladder containing bile from the butcher. Empty the bile into a beaker. Notice its yellow-green colour in the ox and sheep (in man it is a golden yellow). Notice also its slimy feel, due to mucus and some of its alkaline salts. Besides these alkaline salts, bile contains an important fatty-looking, crystallisable substance called *cholesterin*. The colouring matter of bile is due to pigment formed in the liver from the hæmoglobin of the red corpuscles. Pour a little bile on to some fuming nitric acid in a test-tube, and notice the succession of colours—green, blue, red, and yellow—at the junction of the two liquids. Fill a test-tube three-fourths full of bile, and add about one-fifth as much olive oil. Shake well. An emulsion is formed, but it does not last as long as one made with pancreatic juice.

# CHAPTER XIII.

## *THE LIVER, PANCREAS, AND SPLEEN.*

**121. The Liver.**—The large brown-red organ called the liver lies in the top of the abdomen just beneath the diaphragm on the right side, and under cover of the lower ribs at this side and towards the front. Behind, it is in contact with the muscle forming the posterior wall of the abdomen (Figs. 8 and 9). It is the largest gland in the body, weighing between three and four pounds, and measuring about twelve inches from its thick right to the thinner left, where it overlaps the stomach. Below and in front it tapers to a thin, sharp edge. A layer of the peritoneum covers and adheres to the liver, and folds of this membrane form ligaments and attach it to the diaphragm and other parts. A round ligament connects the liver with the navel. A fissure divides the liver into a large right lobe and a smaller left lobe. Other grooves and fissures beneath give rise to smaller lobes. Between one of these smaller lobes and the large right lobe there lies on the under surface, towards the front, a long, pear-shaped bag, called the gall bladder.

The blood supply of the liver is peculiar, coming as it does from two distinct sources. At a transverse fissure on the under surface two blood-vessels enter the organ—

(*a*) The large **portal vein**, which brings **venous** blood from the stomach, spleen, and intestines;

(*b*) The **hepatic artery**, which comes from a branch of the aorta, with a supply of arterial blood, to nourish the tissues of the liver (Figs. 71 and 83).

This peculiar blood supply of the liver indicates that the portal blood, charged with the absorbed products from the digestive organs in the abdomen, will undergo some changes of composition before being passed into the general circulation again. Both the portal vein and the hepatic artery break up

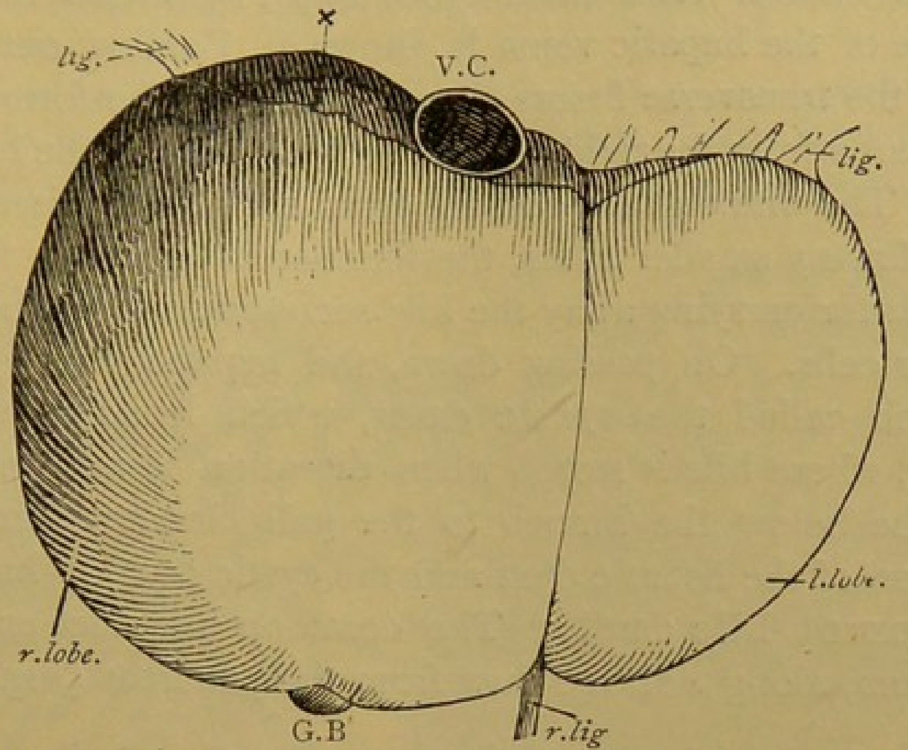



FIG. 114.—Upper surface of liver from before. *Lig.*, ligament ; *r.lig.*, round ligament V.C., lower vena cava ; G.B., gall bladder ; *r. lobe*, right lobe ; *l. lobe*, left lobe.

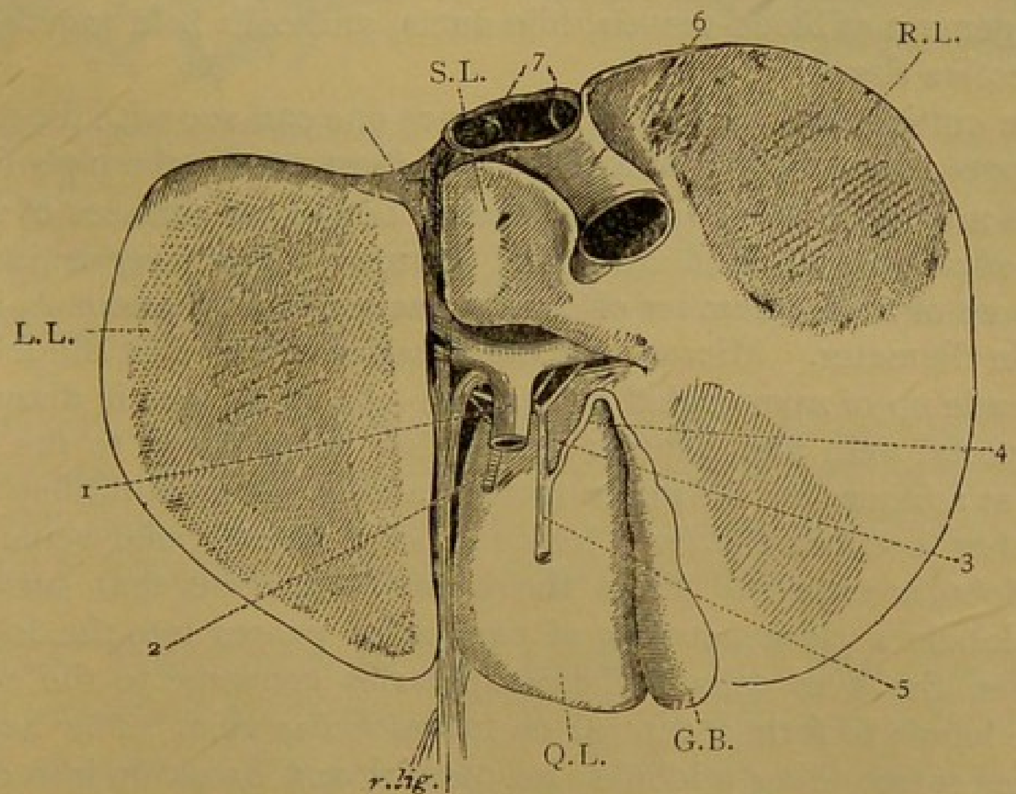



FIG. 115.—Under surface of liver seen from behind. 1, portal vein ; 2, hepatic artery ; 3, hepatic duct ; 4, cystic duct ; 5, common bile duct ; 6, vena cava inferior showing (7) entrance of hepatic veins ; L.L., left lobe ; R.L., right lobe showing the impression of the right kidney ; S.L., spigelian lobe ; Q.L., quadrate lobe ; G.B., gall bladder ; *r. lig.*, round ligament.

in the liver into capillaries, and these capillaries are gathered up by a common system of veins that unite into larger veins, called **hepatic veins.** The hepatic veins from the liver unite with the inferior vena cava. (See Fig. 115, where the inner entrance of the hepatic veins is shown.) Coming out of the liver at the transverse fissure there is seen a tube formed by a branch tube from the right and left lobes. This is the **hepatic duct.** The branch tube coming from each lobe arises by the union of many smaller tubes, the function of which is to serve as canals for carrying away the bile secreted from the blood by the liver cells. On passing down, the hepatic duct gives off a branch called the **cystic duct**, which leads to the gall bladder, where bile is stored when digestion is not going on. The tube below the branch to the gall bladder, formed by the union of the hepatic duct and the cystic duct, is known as the **common bile duct.** The common bile duct enters the duodenum, along with the duct from the pancreas (Fig. 118).

**122. Microscopic Structure of Liver.**—The microscopic structure of the liver shows that it consists of a complex arrangement of blood-vessels, bile ducts, and cells held together by connective tissue.

On cutting into fresh liver substance one can see with the naked eye spots about the size of a pin's head (best seen in the pig's liver). When magnified these spots are seen to be the cut surfaces of small polyhedral masses that are called **lobules.** The liver is, in fact, made up of a vast number of closely packed lobules about $\frac{1}{20}$ of an inch in diameter. Microscopic examination shows that the lobules are made up of many-sided cells about $\frac{1}{1000}$ of an inch in diameter. The portal vein and hepatic artery that bring blood to the liver enter at a fissure on the under surface, and break up until they form branches between the liver lobules, called **inter**lobular veins and **inter**lobular arteries. From the interlobular veins that surround each lobule a close network of capillaries passes into the lobules between the liver cells. These capillaries converge to the centre of the lobule to form a central or **intra**lobular vein. The hepatic arteries surrounding a lobule also pass in, and break up into capillaries in the lobule, but these capillaries unite with the capillaries from the interlobular vein to form the central intralobular vein. Two sets of blood-vessels thus carry blood to each lobule of the liver, but only one set leaves it. The veins formed in the centre of each lobule unite with similar veins from other lobules, and these unite again to form larger and larger trunks, ending at last in **three hepatic veins**, which leave the liver behind and open into the great inferior vena cava.

The tubes that convey the bile from the liver *begin* in minute passages between the cells of the globules. These bile capillaries then pass to the circumference of each lobule, and there are formed

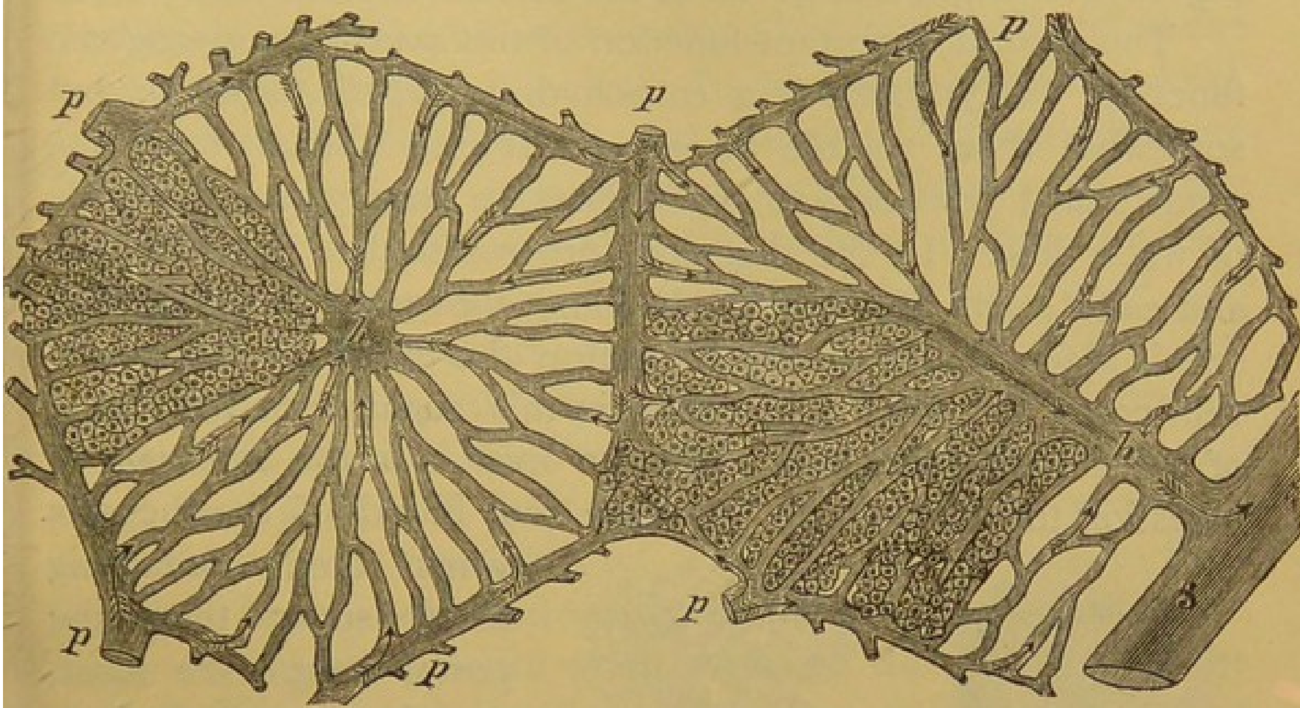


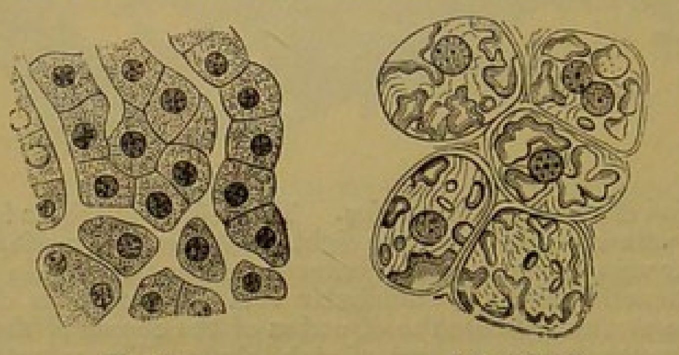

FIG. 116.—Diagrammatic representation of two hepatic lobules. The left-hand lobule is represented with the intralobular vein cut across; in the right-hand one the section takes the course of the intralobular vein. *p*, interlobular branches of the portal vein; *h*, intralobular branches of the hepatic veins; *s*, sublobular vein; *c*, capillaries of the lobules passing inwards. The arrows indicate the direction of the course of the blood. The liver-cells are only represented in one part of each lobule. The minute channels for the bile that begin between the liver cells are not indicated in the figure. (*From Quain's "Anatomy."*)

in this way between the liver lobules interlobular bile ducts. The interlobular ducts unite to form larger branches, until by union they form one large duct in each large liver lobe, these two large ducts uniting to form the hepatic duct, as just explained.

**123. Functions of the Liver.**—The liver discharges three important functions—(1) *it secretes bile*; (2) *it forms and stores glycogen*; (3) *it forms urea.* In saying that the liver produces these three substances, we mean that the liver cells produce these substances from the blood brought to it by the portal vein, the great vein that enters it laden with the products of digestion from the stomach, intestines, spleen, and pancreas.

About two pints of bile are secreted daily by the liver cells, and carried away, as just explained, to be poured into the duodenum. The bile, to a large extent, is an excretory product, and as such is discharged from the body with the other fæces. It is also in part a secretion, for it takes a share in the digestive changes that go on in the intestine (par. 116).

The second important function of the liver is its glycogenic function. **Glycogen** is a carbohydrate allied to starch, but somewhat more soluble in water. It only differs from the sugar called dextrose, as starch does, in having one molecule of water less. In the digestive processes the carbohydrates and cane sugar of the food become converted into dextrose, and it is found that during digestion the blood of the portal vein coming to the liver is richer in this sugar than the blood of the hepatic veins that leave the liver. In the intervals of digestion the opposite is the case, the blood of the hepatic veins then containing more sugar than the portal vein. We must, therefore, conclude that, in the first place, the liver arrests a part of the sugar which reaches it in the portal vein, and that it dehydrates this sugar, and stores it as glycogen in the liver cells. The process may be put thus—dextrose (sugar) *minus* water = glycogen. In fact, after a full meal of carbohydrates, granules of glycogen can be readily observed in the liver cells of an animal when it is at once killed and a microscopic examination of its liver made. In the next place, we conclude that when the blood becomes poor in sugar, during a time of fasting, the liver cells reconvert the glycogen into sugar and restore it to the blood. The process now is—glycogen *plus* water = dextrose (sugar). We thus see how the liver secretes



Fasting. After food.

FIG. 117.—Liver-cells of dog after a thirty-six hours' fast, and fourteen hours after a full meal—in the latter case swollen with glycogen. (Heidenhain.) (*From Waller's "Human Physiology."*)

and stores glycogen, but transforms it into a soluble sugar and restores it to the blood as it is required. The need for this function of the liver is due to the fact that the blood seems to be able to dispose of but a small quantity of sugar, not more than 3 grains in 2000 grains of blood. If more than this quantity passes into the blood, the functions of the body become disordered, sugar is passed in the urine, and a diseased condition known as **diabetes** results. It is generally believed that the sugar in the blood is continually being used up in the tissues, especially the muscles. Its oxidation produces heat, and results in carbon dioxide and water. Although glycogen is formed in greatest amount when carbohydrates are chiefly taken, the liver cells are able to produce it from proteids also, for it has been shown that an animal fed on proteid and water only still produces some glycogen in its liver cells. This leads us to the third function of the liver—the *formation of urea.* It appears, therefore, that when the liver forms glycogen from a proteid, it decomposes this complex compound in such a way as to take carbon, hydrogen, and oxygen to form glycogen, but that the nitrogen of the proteid remains in the urea. Nitrogenous waste goes on in all the tissues, but the final change into urea in every case seems to be completed in the liver. Urea is the compound that represents the chief nitrogenous waste of the body, and though formed in the liver, it passes into the blood, and is afterwards removed from the blood by the kidneys (par. 130).

**124. The Pancreas.**—The pancreas, or "sweetbread," is a long gland of light colour lying across the abdomen below and a little behind the stomach. It has a narrow end in contact with the lower end of the spleen, while its broad end fits into a bend of the duodenum. Its structure resembles that of the salivary glands. Its tissue consists of masses called lobes and lobules, among which are the blood-vessels and nerves. In the recesses of the gland tissue minute ducts begin, and these unite to form larger ducts, all of which enter a main duct, that runs from left to right through the organ near its front surface. The main pancreatic duct thus formed curves downward in the broad end or head, and passes into the duodenum along with the common bile duct, so that the two ducts have a common opening (Fig. 118). The chief function of the pancreas is to secrete from the blood brought to the organ the clear alkaline fluid called pancreatic juice, and to

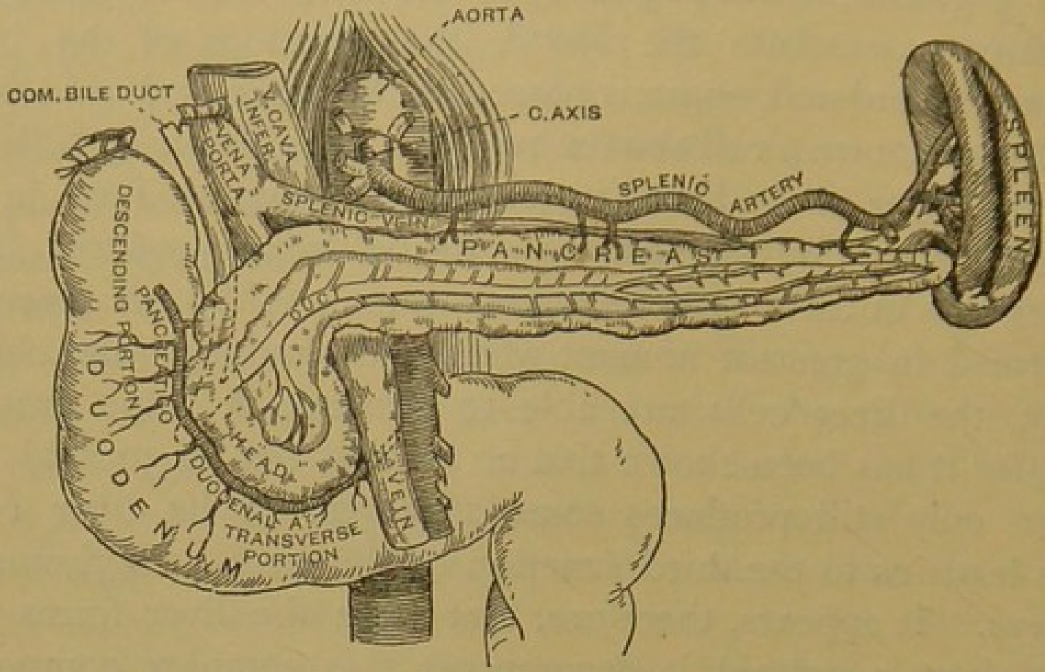



FIG. 118.—The pancreas, duodenum, and spleen.

send this along its ducts into the duodenum to aid in the digestion of food. The composition, properties, and mode of action of pancreatic juice have already been described (par. 116).

**125. The Spleen.**—The spleen is the bluish-red organ of oblong, flattened form situated partly behind and below the stomach (Fig. 9). The substance of the spleen consists of a soft pulpy mass made up of blood-corpuscles (red and colourless) and protoplasmic matter lying in meshes of fibrous bands that run through the organ. The white corpuscles or leucocytes are so crowded together in some places that they appear as white spots in the darker pulp, as may be seen on cutting through the spleen of a sheep or ox. An artery, called the **splenic artery**, carries a large supply of blood to the organ. This artery divides and subdivides until its smallest branches open into the pulpy substance of the spleen, but of this pulp small veins begin and unite to form larger veins. The large **splenic vein** carries away the venous blood of the spleen to the great portal vein which goes to the liver.

Much discussion has taken place regarding the functions of the spleen. It undergoes curious changes in size, generally becoming distended with blood while gastric digestion is at a standstill, but becoming small when that action is going on. It also undergoes regular expansion and contraction every minute or two during the digestion of food. Two functions may be admitted. In the first place, the spleen, like the lymphatic glands, is engaged in the formation of leucocytes or colourless blood-corpuscles, for the blood of the splenic vein contains an unusually large proportion of them. Secondly, the spleen takes some share in the disintegration, or breaking up, of old and worn-out red corpuscles.

As the spleen has some resemblance in structure to a gland—though it has no duct—it is sometimes called **a ductless gland.** Two other ductless glands may be here mentioned. They are the **thyroid gland** and the **suprarenal bodies.** The thyroid gland is situated in the front of the neck, just below and on each side the larynx. The suprarenal bodies are two small glands, in shape something like a cocked hat. They are situated in the abdomen, one resting on the top of each kidney. The functions of the thyroid and suprarenal bodies are not well understood. They appear to elaborate some internal secretion that aids in the proper discharge of certain functions of the body.

# CHAPTER XIV.

## *THE KIDNEY.*

**126. Excretion and Excretory Organs.**—We have now learnt that the tissues are nourished by the lymph that passes out of the capillary blood-vessels, for this lymph contains the chemical compounds—proteids, carbohydrates, fats, and salts—and the oxygen that the tissues need. As a result of tissue activity certain waste products are formed, which pass into the venous blood either directly or indirectly through the lymph stream. The waste products thus passed into the blood must be got rid of, for if they accumulate to any great extent they produce injury and ultimately death. The chief waste products are carbon dioxide, urea, and other allied nitrogenous bodies, and certain salts. Water, too, after it has served to assist in the solution of the food materials, and to carry the absorbed nutriment to the tissues, becomes the carrier of certain waste products, for it holds in solution the urea and salts that must be excreted. Further, the evaporation of water from the skin is, as we shall shortly see, closely connected with the regulation of the body heat. Hence water, though not strictly a waste product, must be regarded as a substance that has continually to be removed and continually to be renewed. It is, in fact, removed by the same channels as the true waste materials. The organs that eliminate or remove the waste of the body are called **excretory organs**, and the substances removed are often termed **excretions**.

The chief excretory organs are the lungs, the kidneys, and the skin. Some waste matter is also excreted by the lower bowel in the fæces (par. 118). The liver, too, as explained in par. 123, has both secretory and excretory functions.

The structure and function of the lungs has been described in Chapter X. There we learnt that they not only take in oxygen, but that they act as excretory organs, by discharging daily a large quantity of carbon dioxide and water as vapour. In the next chapter we shall describe the structure and various functions of the skin, and shall there learn that it contains small glands—sweat glands—that excrete a variable quantity of water, a very small amount of salts, and a little carbon dioxide. The kidneys, now to be described, are exclusively excretory organs. They belong to that class of bodies frequently referred to called glands (par. 17). A gland has been explained to consist essentially of secreting cells lining a pouch or tube from which a passage or duct leads to the surface. The materials separated by a gland from the blood are either substances that are of further use in the body—secretions—or useless and injurious substances that are to be removed. The kidneys are excretory glands.

We now proceed to give an account of these glandular organs, the kidneys, in the complicated tubular structure of which much water, with urea and other substances in solution, is separated from the blood, and afterwards discharged as an excretion.

**127. Situation of the Kidneys and their Connections.**—The kidneys are two organs in the upper part of the abdomen, on each side of the spinal column against the dorsal wall just below the attachment of the diaphragm (Fig. 9), and partly under cover of the lower ribs. Above the right kidney is the liver, and the spleen is just above the left, while the upper part of the intestinal canal lies in front of both, so that these organs cannot be seen on opening the thin wall of the abdomen until the intestines are raised or removed (see Figs. 8 and 110). The kidneys are usually surrounded by a mass of fat, and capped by small organs called the **suprarenal bodies.** Each kidney is about four inches long, two and a half inches broad, and one and a quarter inches thick, and each weighs between four and five ounces. The outer edge of each kidney is convex, and the inner edge is concave. The hollow at the middle of the inner border is called the **hilus**, or **hilum**, and here branches of a **renal artery**, proceeding from the aorta, enter each kidney, to break up into smaller vessels. The blood

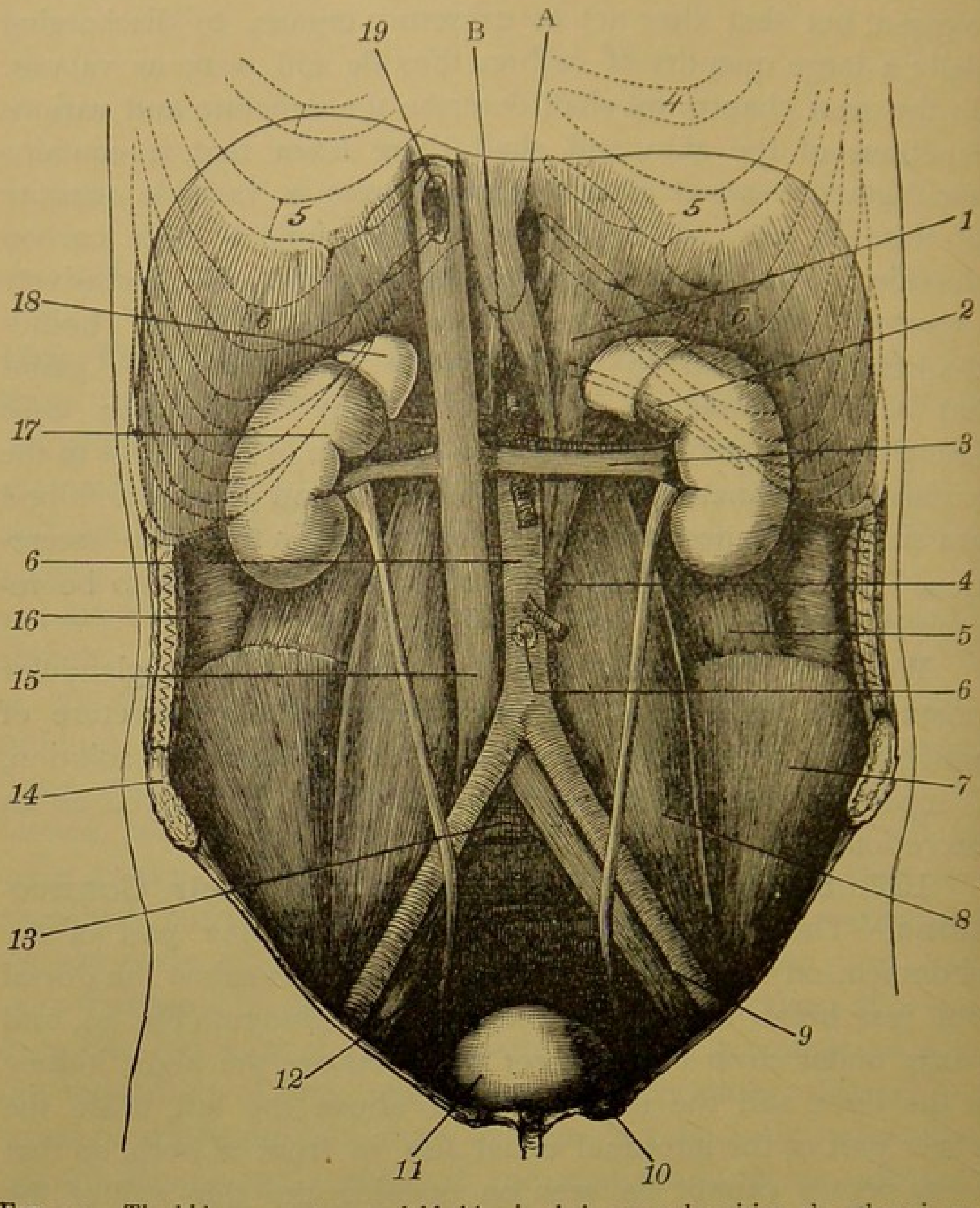



FIG. 119.—The kidneys, ureters, and bladder in their natural position, the other viscera of the abdomen being removed—ribs in dotted outline. 1, diaphragm; 2, left kidney; 3, renal vein with renal artery behind; 4, muscular pillar of diaphragm; 5, muscle of loin; 6, 6, aorta; 7, iliac muscle; 8, psoas muscle; 9, between iliac artery and iliac vein; 10, pubic bone; 11, the bladder; 12, one of the ureters; 13, sacrum; 14, crest of ilium; 15, lower vena cava; 16, muscle of back; 17, right kidney; 18, suprarenal body; 19, place of entrance of hepatic veins into inferior vena cava; A indicates the point of entrance of œsophagus through diaphragm (stomach removed); B, the place where aorta is passing through the diaphragm.

returns from the kidneys by **renal veins**, the large renal vein of each kidney passing out at the hilus and on to the inferior vena cava. From the hilus of each kidney there proceeds also a whitish tube about the thickness of a lead pencil. This conveys the urine from the kidneys, and is called the **ureter.** The two ureters pass downwards at the back of the abdomen and open below obliquely into the **bladder,** a somewhat triangular bag, containing in its walls plain muscular tissue, and lined inside by a mucous membrane. The bladder is situated in the lower part of the pelvis towards the front (Fig. 8). From the lower end of the bladder, a tube, called the **urethra,** leads to the outside. The beginning of the urethra is kept closed by a ring of plain muscular fibres that form what is called a **sphincter muscle.** The urine, which is constantly being brought from the kidneys by the ureters, accumulates in the bladder for a time, until at intervals the sphincter relaxes, and the liquid is driven along the urethra to the outside by contraction of the muscular fibres in the bladder wall.

The kidneys and the part in connection with them, as explained, are spoken of together as the **urinary organs.**

**128. Naked Eye Examination of the Kidneys.**—The kidney of a sheep is very like that of man, and may be used for examination. The external surface of a kidney is covered by a thin fibrous capsule that passes inwards at the concavity or hilus. On stripping off the capsule the kidney shows externally a deep-red smooth surface. On making a section of a kidney from its outer convex border to the hilus, we find that the ureter widens out in this space to form an expansion, called the **pelvis** of the ureter. The cut surfaces of the solid portions of the kidney show two distinct parts, an outer part called the **cortex** or **cortical** portion, and an inner or medullary portion. The medullary portion is streaked and of paler colour than the cortex, and it shows a number of conical portions called **pyramids.** The blunt apex of each cone or pyramid points into the pelvis and divides the broader inner end of the pelvic cavity into spaces called **calyces.** Looked at another way the calyces unite to form the pelvis. A calyx sometimes receives more than one pyramid. The broader end of the pyramid is inward, next to the cortex of the kidney. The cortical substance is redder and more granular looking than the medullary, and forms not only the outer layer of the kidney next its capsule, but forms columns that fill in the spaces between the pyramids for some distance. Five or six

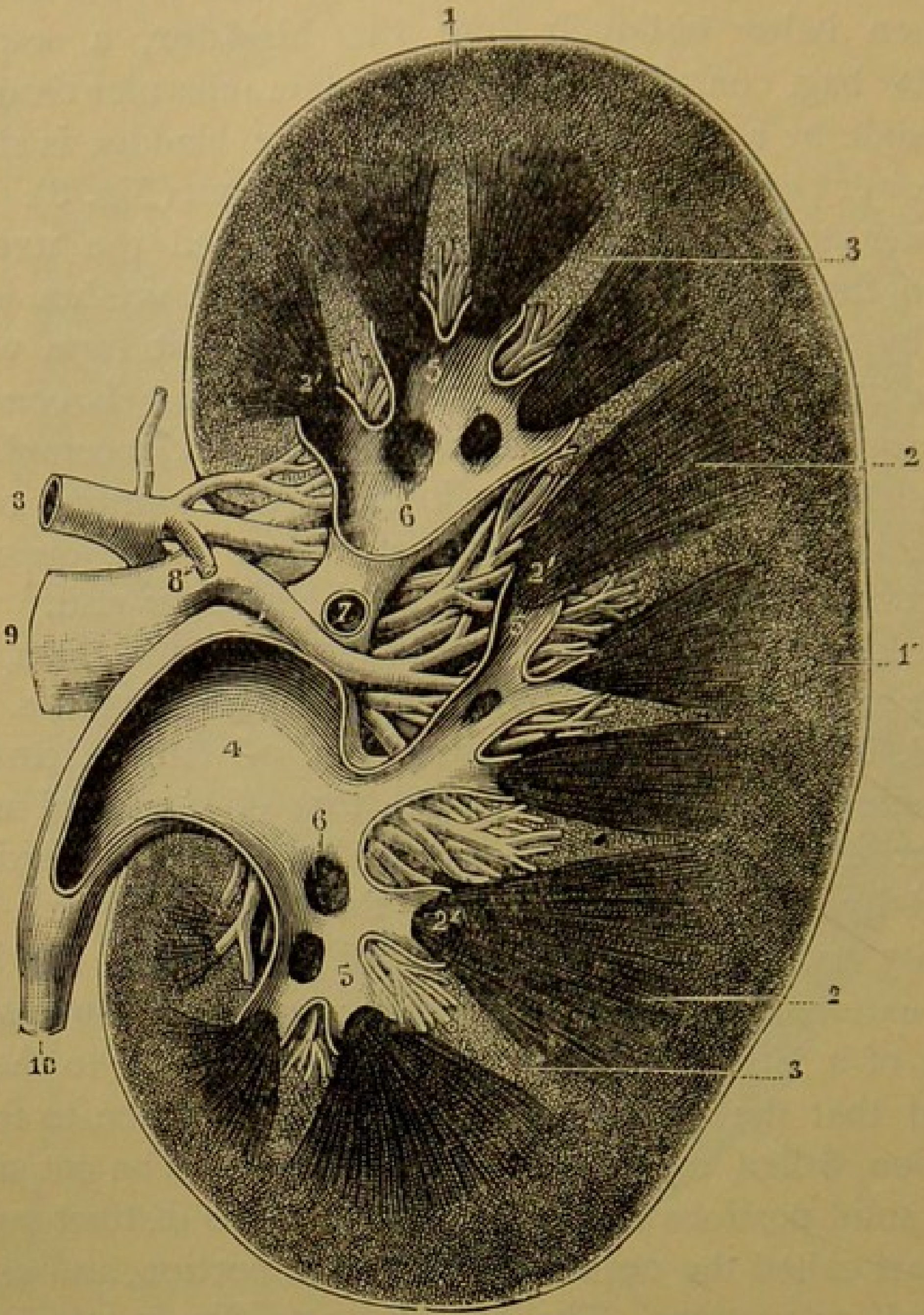



FIG. 120.—Vertical section of right kidney parallel to its two faces. 1, cortical substance; 2, malpighian pyramids with (2′) papillæ; 3, cortical substance between the pyramids; 4, pelvis or dilated end of ureter with (5) the calyces of the pelvis into which pyramids project; 6, 6, ends of papillæ situated in front of the section; 8 and 8′, renal artery; 9, renal vein; 10, ureter.

pyramids are usually seen in section on cutting a kidney through lengthway. There are others not seen in section in front and behind. A human kidney has about twelve pyramids on the average, and the sheep's kidney about the same number.

A rabbit's kidney shows only one central pyramid. The renal artery enters at the hilus, and divides into branches that run in between the pyramids and break up into a complex network of capillaries. These latter are gathered together to form veins,

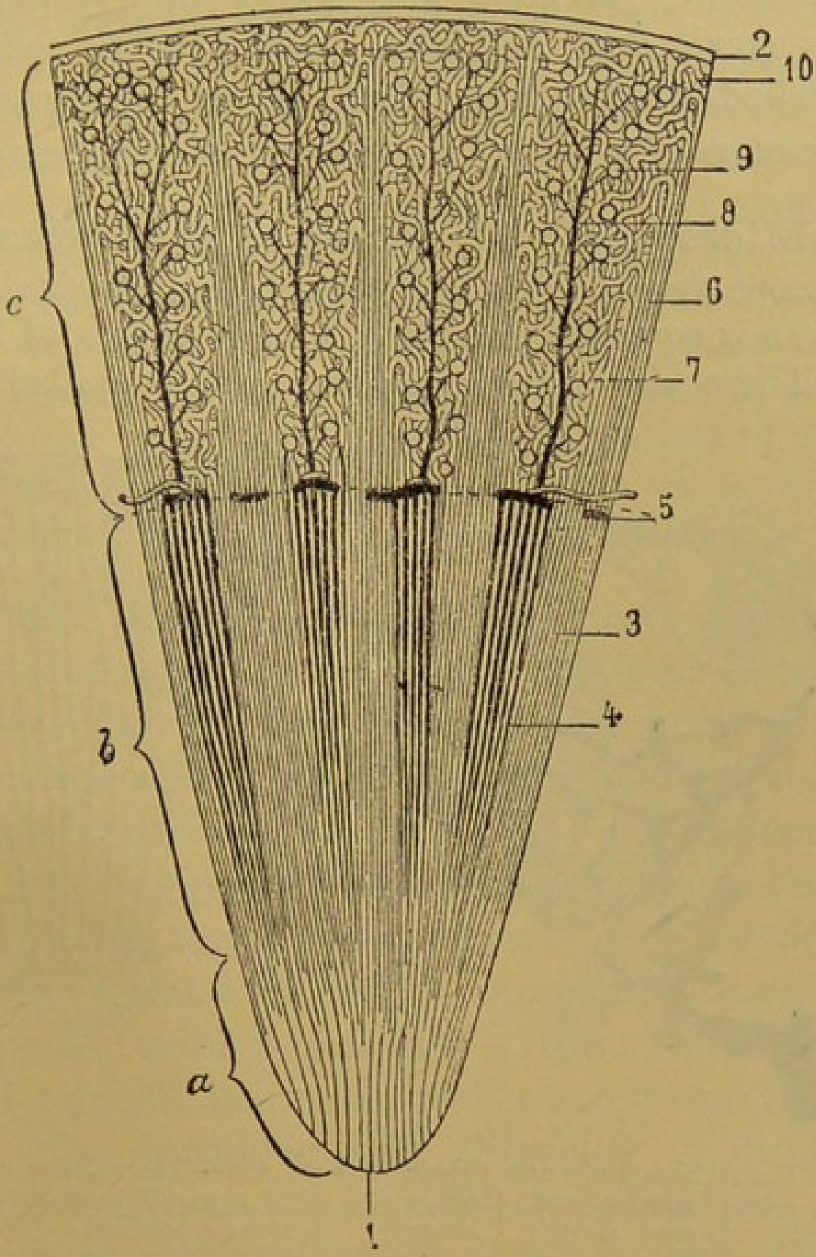



FIG 121.—Diagrammatic section through a part of the kidney from cortex to end of a papilla—moderately magnified. *a* and *b*, papillary part containing tubules and blood-vessels; *c*, cortical part containing Malpighian bodies, tubules from these, and small blood-vessels (compare with Fig. 121); 1, apex of papilla where tubules open into a calyx of the pelvis; 2, capsule of kidney; 3, straight part of tubules; 4, blood-vessels from 5; 6, tubules in medullary part; 7, convoluted part of tubules; 8, vessels; 9, Malpighian bodies; 10, layer beneath capsule. (Testut.)

which at last unite to form the outgoing renal vein of each organ.

If the reader takes another sheep's kidney and slits open the ureter until he reaches its funnel-shaped expansion called the pelvis, he will see the narrow ends of the pyramids projecting into this pelvis. On squeezing a pyramid, a few drops of urine come out into the pelvis, for the pyramids consist mainly of very small tubes, the openings of which are at the narrow end of the pyramid. A good lens shows the openings of the tubules as small dots, and also enables us to see small red masses, called **Malpighian bodies,** in the cortex, but the minute structure of a kidney requires the aid of the microscope.

**129. Microscopic Structure of the Kidney.**—Under the microscope the kidney is found to be a compound tubular gland, for the organ is composed mainly of a vast number of long coiling tubules. These tubules are lined with secreting epithelial cells, and

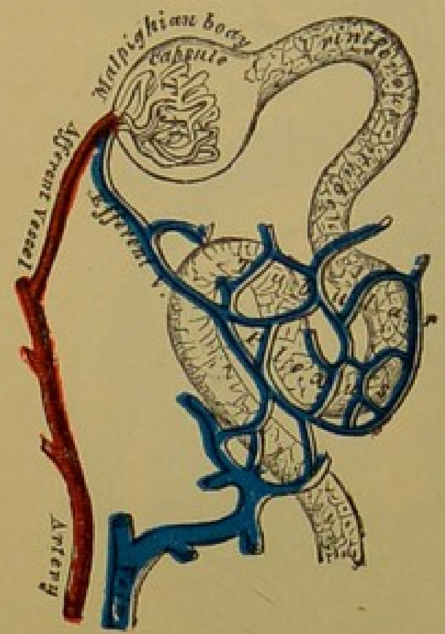



FIG. 122.—A Malpighian body and tubule from it, blood supply, etc. (highly magnified) (*From Gray's "Anatomy."*)

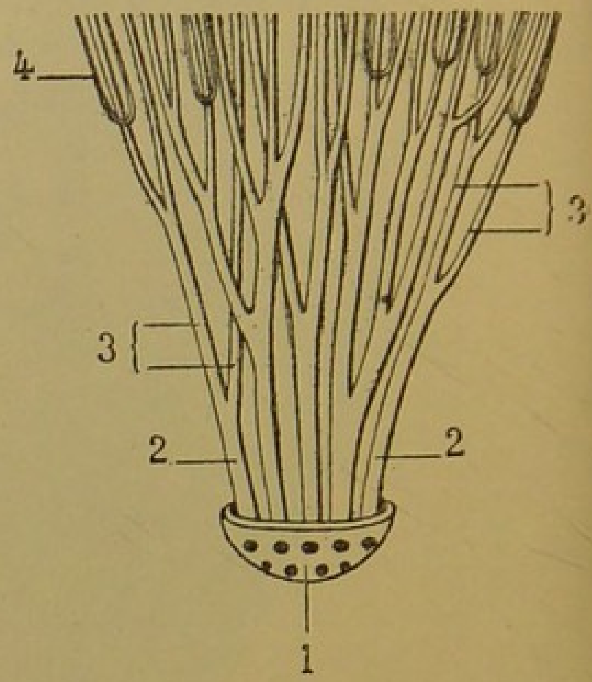



FIG. 123.—The tubules at the lower end of a papilla and the openings of the same magnified. (Testut.)

are surrounded by a fine meshwork of capillaries, while fine connective tissue binds together tubules, vessels, and nerves to form the substance of the kidney.

Every uriniferous tubule begins in the cortex in a small cup or **capsule,** called a "Malpighian capsule." From the capsule the tubule continues in the cortex as a convoluted tubule. It then passes down into the pyramid as a straight tubule, turns back again into the cortex, again becoming convoluted, finally turning down again into the pyramid, where it joins others to form an excretory tubule, opening by a small hole of a papilla into the pelvis. The dilated beginning of a tubule, called a Malpighian capsule, contains a rounded cluster of blood capillaries called a **glomerulus**, for a small artery enters each capsule, and breaks up into minute vessels. These capillaries of the capsule unite to form a small vein proceeding from the capsule, which is less in calibre than the ingoing artery. This vein from the capsule again breaks up into capillaries, which form a network over and among the convoluted tubules. This arrangement of large ingoing vessels and smaller outgoing vessels with the two sets of capillaries (1) in the glomerulus and (2) around the tubules must cause the blood to move through (1) under great pressure and through (2) more slowly. These and other capillaries then unite into veins, which run together to form the main vein passing out at the hilus. The renal vein must contain *the purest blood of the body*, as the waste products of tissue action taken into the blood, especially the proteid waste, are removed from the arterial blood brought by the renal arteries.

**130. The Urine and its Excretion.**—The function of the kidney is to secrete urine. The urine is an amber-coloured liquid, a little heavier than water bulk for bulk. It holds in solution certain organic and inorganic substances, so that when a quantity is evaporated to dryness a solid residue remains. The chief organic substance in solution in urine is a nitrogenous compound called **urea**. Its chemical composition is represented by the formula $CON_2H_4$. Another nitrogenous waste product found in urine is *uric acid*. It is a less oxidized waste product of proteids than urea, and is only found in very small quantity. The inorganic salts dissolved in urine are the chlorides, sulphates, and phosphates of sodium and potassium. About 2 ozs. of solids, of which $1\frac{1}{4}$ oz. is urea, are secreted daily, dissolved in about $2\frac{1}{2}$ pints of water, but the quantity of water varies with the amount of liquid taken and with the amount lost in perspiration.

We must now inquire how the urine is secreted or separated from the blood. In a Malpighian capsule the tuft of capillaries forming the glomerulus is separated from the cavity of the tube only by the thin wall of the capillaries, and by the thin layer of flattened cells pushed in, as it were, from the wall of capsule where the small blood-vessels enter and leave (see

Fig. 122). Through these two thin walls of living cells, water, with some of the salts in solution, passes from the blood into the space of the capsules round the glomerulus and then on into the tubule itself. The process is partly a process of filtration, but the living cells regulate which soluble substances in the blood shall pass. (In ordinary filtration all the substances in solution in water can pass through a filter-paper.) The secreted liquid passes from the Malpighian capsule into the convoluted part of the tubule. But this convoluted tube is

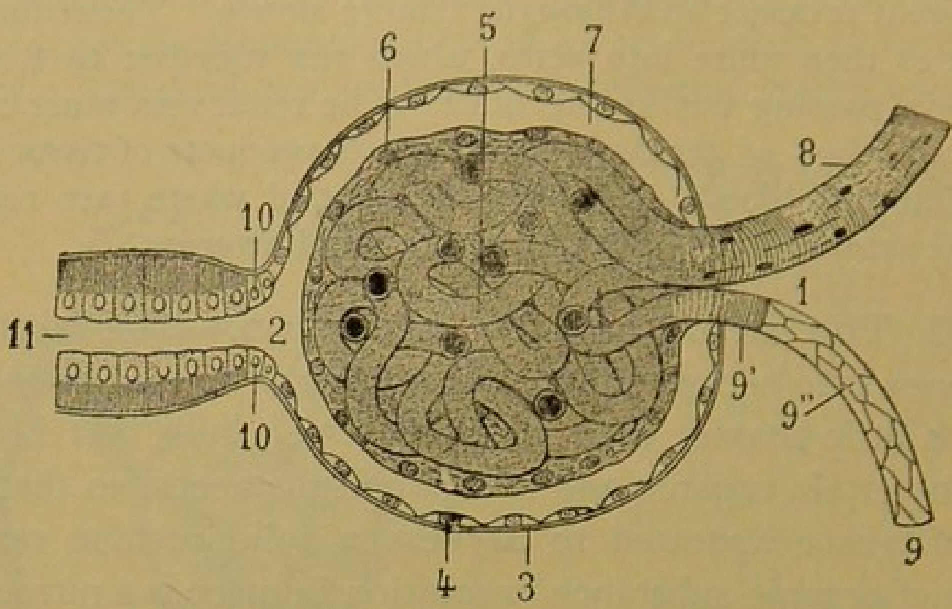



FIG. 124.—Diagrammatic section showing the minute structure of a Malpighian body with capsule (very highly magnified). 1, side on which blood-vessels enter and leave; 2, in beginning of tubule; 3 and 4, its coat of epithelial cells; 5, the glomerulus or tuft of capillary vessels inside of capsule; 6, epithelium over the glomerulus; 7, space between tuft of blood-vessels and wall of capsule; 8, small artery or afferent blood-vessel; 9, smaller vein or efferent blood-vessel; 10, neck of tubules; 11, beginning of uriniferous tubule with columnar epithelium. (*From Testut's "Traité d'Anatomie."*)

surrounded by the fine network of capillaries formed by the splitting up of the vein that leaves the capsule (Fig. 122). Experiments show that by the activity of the secreting cells lining this part of the tubule, urea and some other substances are drawn from the slowly moving blood of this network of capillaries into the watery liquid already in the tubule. This urea, drawn from the blood, was formed in the liver and perhaps in other organs, for it must not be thought that the kidneys manufacture the urea, they only remove it.

The secreting part of the kidney thus consists of two parts—

(1) the glomerulus, in which water with salt in solution is separated from the blood flowing under pressure; (2) the cells in the upper part of the uriniferous tubules, which secrete the urea from the blood flowing slowly in the capillary network.

The amount of urine formed by the kidneys depends largely on the quantity of blood sent through the glomeruli. A great flow of the blood to the kidneys increases the quantity of liquid drawn from the blood, though the quantity of *urea* and other solids separated keeps the same unless an increased quantity of proteid food is being taken at this time. Cold weather increases the flow of blood to the kidneys, for the cold constricts the blood-vessels of the skin, causing more blood to reach the kidneys and other internal organs and thus increases the watery part of the urine. Hot weather, on the other hand, dilates the vessels of the skin, allows more blood to run through them, and more sweat to be excreted from the skin. Less urine, therefore, as far as the amount of liquid is concerned, is discharged in hot weather than in cold weather, but the quantity of urea excreted daily is about the same. Thus the kidneys and the skin work together in the removal of water from the body.

# CHAPTER XV.

## *THE STRUCTURE AND FUNCTIONS OF THE SKIN.*

**131. Structure of the Skin.**—The skin is composed of two layers—

(1) The **epidermis, cuticle,** or **scarf skin,** which is at the surface.

(2) The **dermis, corium,** or **true skin (cutis vera),** which is below the epidermis.

The epidermis is a form of stratified epithelium, composed of many layers of epithelial cells, and varies in thickness in different parts from $\frac{1}{200}$ to $\frac{1}{20}$ of an inch. On the soles of the feet and the palms of the hand, where there is much pressure, it is still thicker. The layers of epithelial cells forming the epidermis are of different form at different depths. The deepest layers, lying next to the dermis, are columnar nucleated cells, and over these are several layers of cubical nucleated cells (Fig. 3). Near the surface the layers of cells become hard, horny, and are much flattened. The lower part of the epidermis, containing the nucleated cells, is called the *Malpighian layer*, or *rete mucosum*, and the upper horny part the **corneous layer.** No blood-vessels of any kind pass into the epidermis, the living cells being nourished by absorbing nourishment from the lymph below. The dry scale-like cells at the surface are constantly being rubbed off and replaced by cells from below, which become flattened, while these cells are in return replaced by others from deeper layers, for a division and multiplication of cells goes on in the lower parts of the Malpighian layer of the epidermis. In coloured races the colour is due to pigment in the lowest cells of the Malpighian layer. After a burn or other irritant applied to the skin, lymph passes out from the injured capillaries of the true skin and collects between the Malpighian and horny layer of the epidermis as a blister. The blister on a negro's skin is thus white, the fluid being above the cells containing the pigment. The under surface of the epidermis is not plane, but thrown into ridges and furrows (as seen in section in Fig. 3) by projections on the upper surface of the dermis on which it rests.

The **dermis**, or true skin, beneath the epidermis, consists

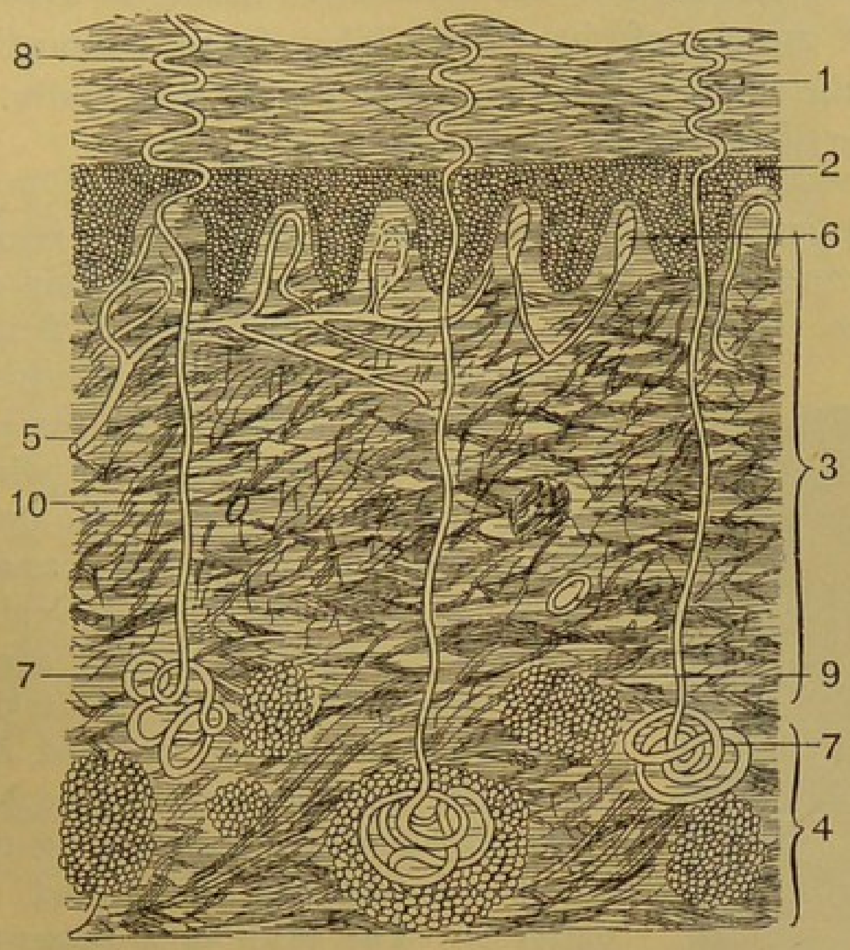



FIG. 125.—Vertical section of skin, somewhat diagrammatic. 1, horny layer of epidermis; 2, Malpighian layer of epidermis; 3, dermis; 4, subcutaneous tissue; 5, blood-vessel giving off loops into the papillæ of dermis; 6, touch-corpuscle in papilla of dermis; 7, sweat glands with tubes passing to the surface; 8, coiled part of tube passing outwards; 9, groups of fat cells; 10, cut end of a blood-vessel.

of a dense felt work of connective tissue (Fig. 125) (white fibrous tissue and yellow elastic fibres), with a rich supply of blood-vessels and nerve fibres.[1] There are no blood-vessels in the epidermis, though a few very fine nerve fibres pass into the

[1] It is the dermis of an animal that is tanned and made into leather, the epidermis being usually scraped off.

lower part of it. At the surface of the dermis there is in the sensitive parts of the body a large number of small conical processes called **papillæ**, arranged in close-set parallel rows (Fig. 142). These papillæ fit into the depressions on the under surface of the epidermis. In each conical papilla of the dermis is found a plexus of blood capillaries, or a peculiar oval nerve ending, called a **touch-corpuscle**. The function of these nerve endings found in the skin are described later (par. 158).

The subcutaneous tissue, that is, the layer of tissue beneath the dermis, consists of loose connective tissue, in which there is generally groups of fat cells. This loose connective tissue beneath the skin enables us to pinch up the skin easily. Beneath the subcutaneous tissue lie the muscles.

On the surface of the epidermis there are found in most parts distinct creases and folds that correspond with similar creases in the dermis. These simply show the lines of frequent flexure during movement. Besides these distinct creases there are on the surface in some parts, as on the soles of the feet, the palms of the hands, and on the balls of the thumbs and fingers, certain finer ridges and furrows. These fine ridges of the epidermis seem to correspond largely with the arrangement of the underlying papillæ of the dermis on which the epidermis is moulded, and partly on lateral pressures during growth. Whatever their causes, the ridges on the finger-tips run in curious curves and scroll-like patterns. The print of a finger-tip taken in soft wax shows a pattern distinct for each person. No two are exactly alike. The ridges never change, but keep the same pattern during life, unless destroyed by serious injury of the skin. Hence they give characteristic "prints" on wax. Examine those of your own thumb or finger-tips. Finger-prints of criminals are often used afterwards as a means of identification.

FIG. 126.—Ridges and furrows on the surface of a thumb. (Testut.)

**132. Sweat Glands and their Function.**—On examining the tip of the finger or the surface of the palm with a good lens rows of small holes may be seen running along the fine ridges. These are the openings of the sweat glands beneath, and are spoken of as the **pores** of the skin. Each pore leads to a spiral tube, which passes through the epidermis into the dermis, or subcutaneous tissue. Here the tube ends blindly in coils, and this coiled part is a **sweat gland**, and the spiral

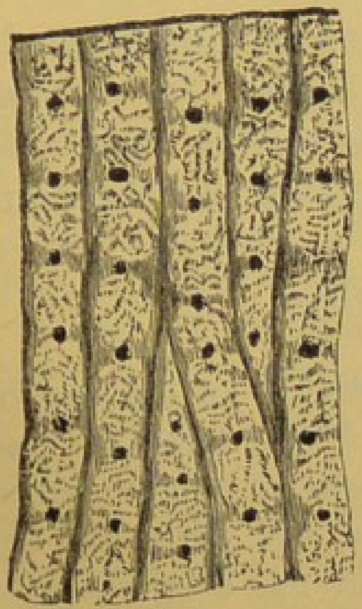


FIG. 127.—Magnified view of four ridges of the epidermis, showing on them pores or surface openings of sweat glands. (*From Quain's "Anatomy."*)

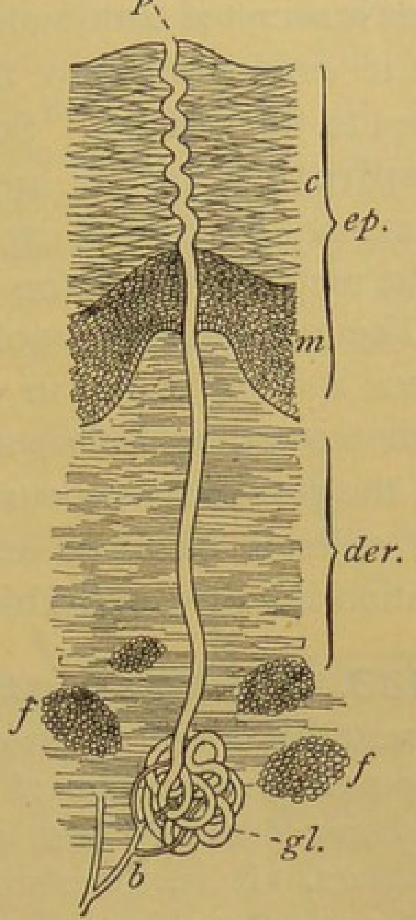



FIG. 128.—A sudoriferous or sweat gland, *gl.*, with capillary vessel, *b*, passing around and among its coils. *p*, pore, or opening of sweat gland; *ep.*, epidermis, with, *c*, horny layer, and, *m*, Malpighian layer; *der.*, dermis; *f*, fat cells.

tube is the duct. Duct and gland are lined by cubical epithelial cells, and the larger cells of the coil, or gland, secrete sweat from the blood in the capillaries around and among the coils. The sweat is then passed along the duct to be discharged at the surface through the pores. Each tube is about $\frac{1}{4}$ of an inch long on the average, and the coils about $\frac{1}{25}$ of an inch in diameter. The number of glands per square inch varies in different parts from 3000 on the palm to 300 on the back. The function of the sweat glands is to secrete sweat from the blood. The sweat, or perspiration, is a slightly alkaline liquid, containing in solution a little sodium chloride and traces of urea. A little carbon dioxide ($CO_2$) is also excreted, partly dissolved in the sweat.[1] When the secretion of the sebaceous gland attached to the hairs of the skin (par. 134) is mixed with sweat, the fatty acids in this secretion give the sweat an acid reaction. Sweat is secreted continuously, but usually in such small quantity that it evaporates into the air from the pores as fast as it comes to the surface. Such perspiration is called **insensible perspiration**, for we are not conscious of it. Yet it is going on, as may be proved by the moisture left on a cold glass or bright metallic surface on touching it.

The average amount of sweat secreted and evaporated at the surface is about a pint in twenty-four hours. In hot weather, or when standing before a large fire or during vigorous exercise, the perspiration pours out faster than it can evaporate. It then collects in drops and runs over the surface. Such perspiration is called **sensible perspiration.**

**133. The Evaporation of Sweat.**—In the evaporation of sweat water passes from a liquid to the gaseous condition. During the evaporation of any liquid heat is being used up, the heat being obtained from any substance with which the liquid is in contact. It is, therefore, evident that the evaporation of the sweat cools the skin, and so withdraws heat from the body. The amount of heat lost by the body through the evaporation of sweat varies at different times. In hot weather, or during vigorous exercise, when increased oxidation goes on in the muscles, more heat is absorbed from without or produced in the body. But the body temperature in health remains about the same at all times. With increased heat production there must, therefore, be increased loss of heat. This increased loss of heat is brought about by the increased production of sweat when the temperature of the air is high or vigorous exercise is being taken, for an increase in the amount of sweat implies that more heat is withdrawn from the body to

[1] The excretion of carbon dioxide by the skin may be shown by moistening the inside of a watch-glass with baryta-water and inverting it over the palm of the hand a short time. A milkiness soon becomes apparent. Baryta-water is a more sensitive test for carbon dioxide than lime-water.

evaporate it. In cold weather, on the other hand, little sweat is produced and little heat used up by evaporation. The skin, therefore, by means of the sweat glands, acts as a regulator of the body temperature.

The increase in the production of sweat when the body temperature tends to rise is due (1) to the increased flow of blood in the skin capillaries, owing to the action of the vaso-motor nerves in causing the small arteries of the skin to dilate, (2) to the special secretory nerves of the sweat glands stimulating these organs into increased activity. Generally, the vaso-motor nerves dilate the small arteries of the skin and flush it with blood at the same time as the sweat nerves stimulate the glands to secrete. But this is not always the case. In a "cold sweat" the blood-vessels of the skin are constricted; yet, owing to a sudden fear, though the skin is pale and cold, the sweat nerves may cause the glands to secrete so abundantly that beads of perspiration roll down the face and other parts.

**134. Hairs and Sebaceous Glands.**—A hair consists of a mass of modified epidermal cells lying in a deep pit of the skin, called a **hair follicle.** The hair follicle is a down-growth of the epidermis into the lower part of the dermis. It is, therefore, lined with epidermal cells, and it has at its bottom a small vascular papilla of the dermis. This is not at the surface, but in the deepest part of the dermis. The cells on the top of this vascular papilla multiply, push outwards, and becoming horny form a hair shaft in the follicle that at last passes to the outside. A fully formed hair is seen under the microscope to consist of a loose inner cellular pith covered outside by cells flattened into overlapping scales. Colouring matter deposited in the outer cells of the hair shaft give the hair its colour. The root, or bulb, of each hair consists of the small deep dermal papilla surrounded by the epidermal covering, and the newly formed cells that go to form the hair. The papillæ of hairs are supplied with minute blood-vessels and with a branch of a small nerve. When a hair is torn

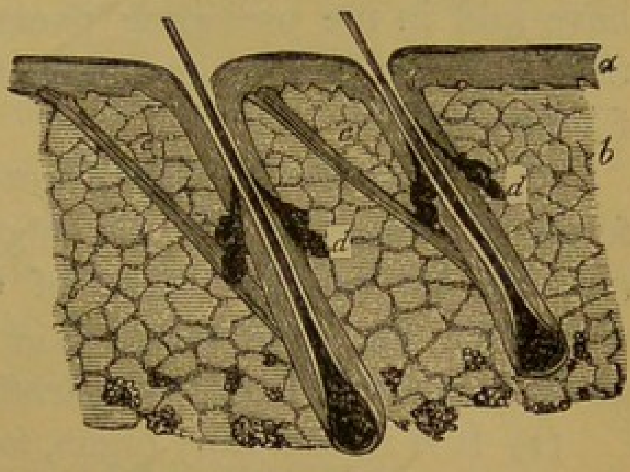



FIG. 129.—Section of the skin, showing the hair follicles, sebaceous glands, and the muscles of the hairs. *a*, epidermis; *b*, dermis; *c*, muscles of the hair follicles; *d*, sebaceous glands. (*From Quain's "Anatomy."*)

from its root a new outgrowth of cells from the layer over the papilla often produces a new hair.

Hairs are provided with small glands, situated in the dermis and called *sebaceous glands* (Lat. *sebum*, suet). These glands consist of flask-shaped bags, with a duct that leads into the follicle in which the hair lies. The glands secrete and discharge an oily substance that serves to lubricate the hairs and soften the skin.

Attached to the hair follicles are small muscles composed of involuntary muscular fibres. They pass from the side towards which the hair slopes obliquely to the upper surface of the dermis, so that when these muscles contract they tend to make the hair "stand on end."

**135. Nails.**—Nails consist of densely packed, horny, epidermal cells. Beneath the hind part of the nail there is a very vascular dermis, with papillæ on its surface. This dermis, called the *nail-bed*, is covered with a layer of epidermal cells that multiply and grow rapidly. The cells so formed become horny and compressed, and are constantly being pushed forward, so that a nail thus formed is constantly being increased in length.

**136. Summary of Skin Functions.**—From what we have said in the preceding paragraphs of this chapter, we see that the skin has various uses, for it performs the following functions :—

(1) It is in the first place protective. The horny epidermis forms a protection for the highly sensitive dermis beneath (witness the painful effect of contact when the dermis is removed), while the whole skin may be said to protect the muscles and other organs beneath it.

(2) It is an excretory organ, for through the surface openings of the sweat glands the body loses daily in the sweat about two pints of water, in which is dissolved some carbon dioxide gas, a little salt, and traces of urea. Sebaceous matter is also excreted from the sebaceous glands.

(3) It acts as the chief regulator of body temperature, for, as a result of the evaporation of the water sent out from the sweat glands, the body loses its surplus heat.

(4) It contains the peripheral terminations of many sensory nerves, and thus becomes a sense organ for sensations of contact and touch in the widest sense.

# CHAPTER XVI.

## *ANIMAL HEAT.*

**137. Temperature of the Body.**—The average surface temperature of a healthy human body, taken in the mouth or arm-pit, is 98·6° F. (in the blood of the interior about 2° F. higher), this nearly uniform temperature being brought about by the circulation of the blood, which carries heat from the parts where it is produced (oxidation is most active in the muscles and glands) and distributes it to the surface, where heat is lost. In the interior of the body, especially where chemical changes are most active, the temperature is somewhat higher than at the surface, where heat is being constantly lost. The warmest organs of the body are the liver, the brain, and the muscles; the coolest parts are the skin and the extremities. Active muscular exercise may raise the temperature of the body one or two degrees, a feeling of great warmth being produced by


FIG. 130.—A clinical thermometer for finding the temperature of the body. (*From Paul's "Domestic Economy."*)

the increased blood supply to the skin, consequent on the dilatation of its vessels. In fact, our **feeling** hot or cold is due to the state of the capillaries of the skin. When these vessels are full of warm blood, the sensory nerves terminating in the skin are affected with the sensation of heat, but when the vessels are contracted and comparatively empty, we feel the cold of the external air affecting the nerves of the skin.

Thus we feel warm when the skin is warm, and cold when the skin is cold; but our feeling is no real guide to the body temperature as a whole, which, in health, is always about the same, however hot or cold we feel.

**138. Production of Bodily Heat.**—Though heat is produced in all parts of the body wherever chemical changes go on, the chief tissues in which heat production occurs are the *muscles*, the glands, and the nervous centres. Every manifestation of muscular energy has been found to be accompanied by evolution of heat and carbon dioxide, and, as the carbon dioxide is given off, though in a less degree even by resting muscles, it is evident that active chemical change with production of heat must also go on in muscles at rest. The secreting glands, especially the liver, are also the seat of processes that result in heat, and the temperature of an organ is greater during activity than during rest. The brain is also a source of heat, as the temperature of the blood leaving this organ when mental effort is going on is distinctly higher than the temperature of the blood entering it. Vigorous muscular exercise leads to more rapid oxidation of tissue and increased production of heat, while it also increases the action of the heart and the rapidity of the circulation. The various food-stuffs differ in the amount of heat they produce when oxidized. Weight for weight, fats and oils produce twice as much heat energy as proteids and carbohydrates, provided they are digested and assimilated. As one of the functions of food is the production of heat, we take more food, especially more fat, in winter, when we lose heat at a greater rate.

The energy produced by oxidation of food is not only the source of the bodily heat, but also of the mechanical work of the body, though only about one-sixth of the energy so produced is used to do this work.

The temperature of the body is kept nearly uniform in all parts by the circulation of the blood, which distributes the heat produced in the active tissues. A muscle in action has warmer blood leaving it than that entering it, and the skin exposed to the air has colder blood than that entering it, but the circulation soon mixes them, and keep the temperature about the same.

**139. Loss of Heat from the Body.**—As the temperature of the surrounding air is below that of the body in all temperate climates, heat will be lost from the surface of the body by conduction and radiation, as well as by evaporation of the water from the skin and lungs. By conduction heat passes to the air in contact with the body and from one air particle to another; by radiation heat passes from the body into the surrounding medium by producing in it progressive waves of energy derived from the particles of the body. When the external temperature is below that of the body, the loss of heat by conduction and radiation, together with the heat consumed in warming the respired air, may be almost sufficient to remove the heat not required for maintaining the body at its normal temperature, except during times of vigorous activity. Active muscular exercise leads to increased chemical changes, with increased activity of respiration and increased perspiration. Where the external temperature is higher than 98·6° F., as in the tropics or in a Turkish bath, no heat will be lost from the body by conduction and radiation, but a gain from the surrounding medium will occur. In these circumstances a large quantity of heat is lost in evaporation of water from the skin and lungs. "The conversion" of water into water vapour uses up a large quantity of heat. In hot air the capillaries of the skin dilate, the vessels becoming flushed with blood, the sweat glands increase in activity, and evaporation of the sweat goes on rapidly. When the secretion of sweat is but small, it evaporates as fast as it reaches the surface, and the skin remains dry—*insensible perspiration.* When the secretion is abundant, sweat may be formed faster than it is evaporated, and it then appears on the skin in drops—*sensible perspiration.* Even in cold weather, after severe muscular exertion and consequent production of heat, sweat is produced in abundance, so that evaporation leads to the removal of this excess of heat. It should be noted, too, that the degree of moisture in the air is of great importance. Air almost saturated with water vapour interferes with the evaporation from the skin, and thus hinders the loss of heat in this way. But in dry air a temperature much higher than that of the body may be borne for some time, especially if liquid be taken freely, as perspiration is then copious and evaporation takes place rapidly, so that the body temperature is kept from rising.

Clothing is used in temperate and cold climates to keep in the heat of the body by protecting the skin from the chilling influences of the cold air, which, if allowed to come freely into contact with the body, would carry off its heat. The clothing does not yield heat to the body, but only checks conduction and radiation. The low conducting power of atmospheric air renders a number of layers of clothing with sheets of air between them more efficacious than one thick layer.

It has been estimated that the loss of heat by the skin in the two ways already mentioned—*i.e.* (1) by radiation and conduction in an atmosphere below that of the body temperature, and (2) by the conversion of sweat into water vapour—amounts to 77 per cent. of the total loss. By respiration, in which the inspired air when cooler than 98·6° F. is warmed, and in which much water vapour evaporates from the lungs, 20 per cent. of the total loss occurs. About 3 per cent. of the total heat loss passes off in the urine and fæces. A small quantity of heat is expended in warming the food and drink ingested.

**140. Regulation of the Heat of the Body.**—We have learnt that the temperature of the body as a whole, in health, is always about 98½° F. (37° C.) in summer and in winter, near the equator and in the Arctic regions, although the warmth or coldness of the skin may vary with the amount of blood circulating in it, and, as we judge of the temperature of the body from that of the skin, this may lead us astray (par. 137). The temperature of the body is regulated or kept uniform by the regulation of (1) the heat production of the body, and (2) the heat loss of the body.

The regulation of the heat production is brought about, in part, by an individual's own will. Increased muscular activity in cold weather, as beating the arms across the chest and stamping about, lead to increased tissue oxidation and increased heat. More food may also be taken, especially of a fatty nature, to supply more combustible material for the tissues. In hot weather a man eats little and avoids active movements.

The increased muscular contractions during active exercise leads to increased production of heat. At the same time more blood is sent to the surface of the body, and the sweat glands increase in activity, so that the person perspires more freely.

Heat is taken from the body to evaporate the increased quantity of sweat. Thus, while muscular activity increases the production of heat, more heat at the same time is lost from the body, and its temperature is kept from rising above the normal. But the regulation of heat loss is also largely effected by the nervous system. It can, on the one hand, by the vaso-motor nerves, control the supply of blood to the vessels of the skin, and on the other hand the amount of activity of the sweat glands, increasing both these actions in a hot atmosphere and diminishing them in a cold atmosphere. This explains why the skin becomes pale and almost bloodless in cold surroundings, and why it becomes red and flushed with blood in a warm atmosphere. A person can remain for a time in a Turkish bath or a large oven where the air temperature is far above that of the body, provided his nervous system helps him to keep the heat out by profuse perspiration. Civilized man also uses clothing to assist him in checking and regulating the loss of heat from his body.

# CHAPTER XVII.

## *THE NERVOUS SYSTEM.*

**141. General Plan.**—The nervous system of man may be divided into two related systems, known as the **cerebro-spinal** or **central nervous system,** and the **sympathetic** or **ganglionic system.** The cerebro-spinal system is much greater than the sympathetic system, and consists of the brain and spinal cord — two great united masses of nerve matter that lie in the dorsal or neural tube of the body, with the branches, called nerves, that pass to all parts of the body. The neural tube is that cavity formed by the interior of the skull and the spinal cord (par. 10). The portion of the cerebro-spinal nervous system that lies in the skull is the brain, and the connected portion that lies in the spinal canal is the spinal cord. The sympathetic nervous system consists of a series of

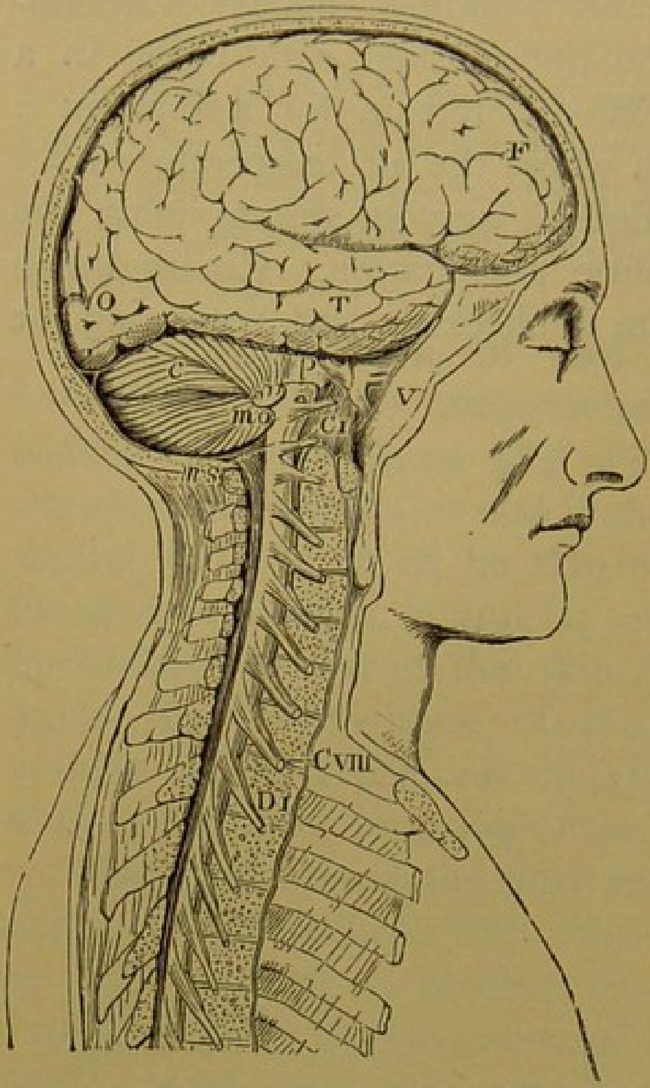



FIG. 131.—Side view of the brain and upper part of the spinal cord, after removal of the membranes. Two cranial nerves are shown, and the spinal nerves of the right side. F, T, O, frontal, temporal, and occipital lobes of cerebrum; C, cerebellum; P, pons varolii; *mo*, lies on the left of the medulla oblongata; *ms*, points to the upper end of the spinal cord; $C_I$, the first cervical nerve; $C_{VIII}$, the eighth or lowest cervical nerve; $D_I$, the first dorsal nerve. (*From Quain's "Anatomy."*)

**ganglia** or knots of nervous material lying outside the spinal canal on each side of the spinal column, together with nervous cords uniting the ganglia and nerve fibres to the cerebro-spinal system. The two sets of nerve centres and nerves are thus closely connected together, though it is convenient to describe them separately. Fig. 13 gives a general view of the whole nervous system. The two fine lines running near the spinal cord, and parallel to it, indicate the chain of the sympathetic system.

The importance of the nervous system arises from the fact that all the actions of life are regulated by some part of this system. It determines the various movements of the body by starting or preventing the action of the muscles; it regulates the processes of secretion in the cells of the various glands; by its action on the small arteries it determines the supply of blood to various parts; it receives impulses from the outer world; while all our sensations and mental activities are correlated in some way with the activities of the nervous system.

We proceed first to describe the nature of nerve matter, and then give an account of the various parts of the nervous system, and of the functions of these parts.

**142. Nerve Cells.**—The nervous matter forming the brain, spinal cord, and ganglia consists of grey matter and white matter. Under the microscope the grey matter is seen to consist largely of nerve cells, while white matter consists of nerve fibres. Nerve cells from various parts vary in shape (see Fig. 2, H). Many of them are of irregular form, and all give off one or more processes or **poles**. According to the number of processes, the cells are spoken of as unipolar, bipolar, or multipolar. Most of these processes break up into branches, called **dendrons** and **dendrites**, but one process is distinguished from the rest by not branching. This unbranched process is continuous with the central part or axis cylinder of a nerve fibre, and is called the **axon** of the nerve cell. The protoplasm of the nerve cell is granulated, and in the central part of the cell there is a round nucleus containing a small nucleolus.

Each nerve cell, with its axon, is an independent structure, and the connection of one nerve cell with another is made by the adjoining of the fine branches of one cell with that of another, but there is no actual structural union of these fine

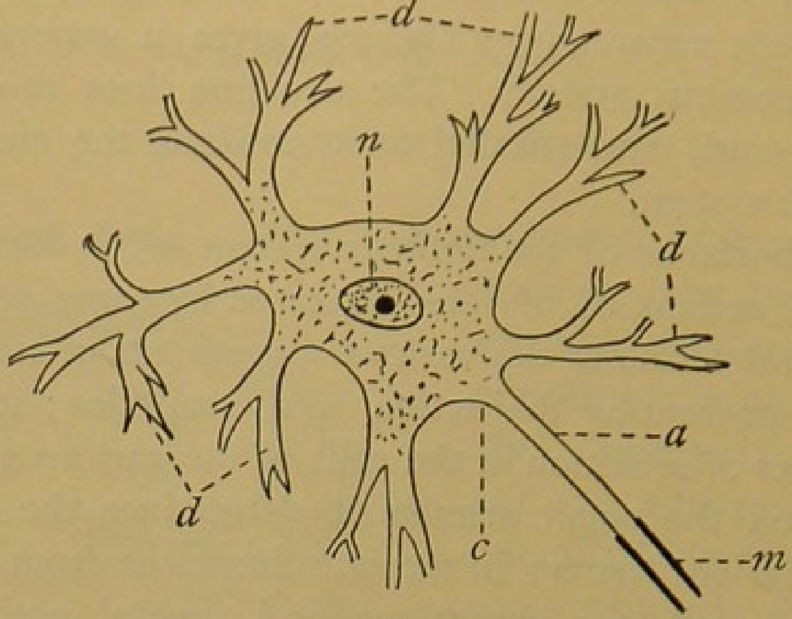



FIG. 132.—Diagram of multipolar cell from grey matter of spinal cord (highly magnified). *a*, axon, or axis cylinder process; *m*, medullary sheath to same; *c*, cell body, showing granules; *n*, nucleus with nucleolus; *d*, dendrites, or branching processes. Processes of one cell often interlace with those of another, or the branching fibrils of a nerve fibre may interlace with the dendrites of the cell.

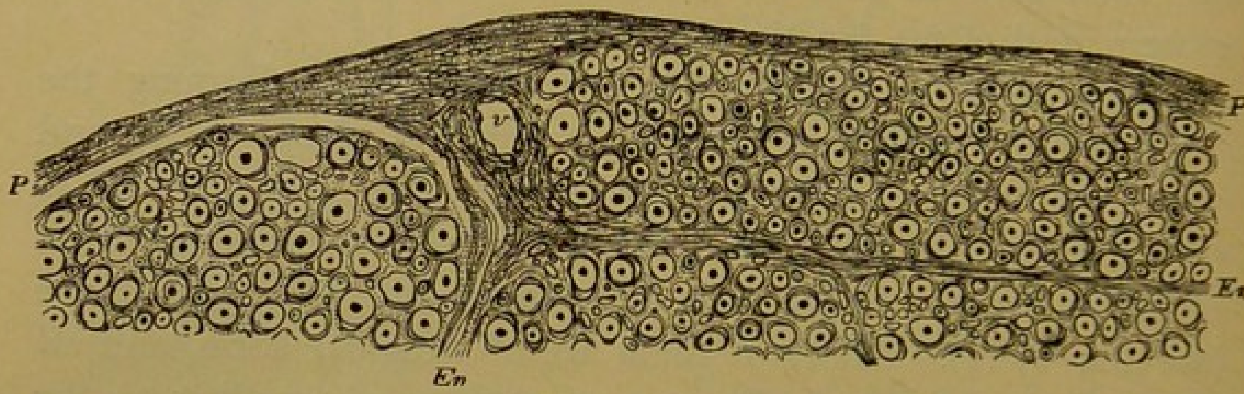



FIG. 133.—Part of a section of one of the nerve bundles of the sciatic nerve of man. *P*, perineurium, consisting of a number of closely arranged lamellæ. *En*, processes from the perineurium passing into the interior, and becoming continuous with the endoneurium or delicate connective tissue between the fibres. The nerve fibres are cut across, and are represented by a ring with a dot in the centre. The dot is the axis cylinder cut across; the ring is the cut section of the primitive nerve sheath; the clear space between represents the medullary sheath. (*From Quain's "Anatomy."*)

branches. Nerve cells vary in size from $\frac{1}{400}$ of an inch to $\frac{1}{4000}$ of an inch.

**143. Nerve Fibres.**—The nerves that pass off from the brain and spinal cord, and which appear as white cords on being teased out, are found, under the microscope, to consist of fine fibres, so that each nerve is really a bundle of fine fibres, held together by fine connective tissue (perineurium and endoneurium) that passes between and around them (Fig. 133). Nerve fibres vary in size in different nerves, their average diameter being about $\frac{1}{400}$ of an inch. The fibres are held together by fine connective tissue, similar tissue surrounding the whole nerve. An ordinary nerve fibre examined shortly after death appears as a translucent, glistening thread. On adding various reagents a nerve fibre is seen to consist of three different parts—(1) a central core of semi-solid matter, called the **axis cylinder**; (2) a sheath of fatty substance covering the axis cylinder, and called the **medullary sheath**; (3) an outer sheath of fine membrane, called the **neurilemma**. The axis cylinder of a nerve fibre is continuous, and has its origin in some place or other as the axon of a nerve cell. The neurilemma or outer sheath of the fibre is also continuous, but the medullary sheath is wanting at short intervals, the interruption being termed "the nodes of Ranvier." Between two nodes a nucleus lies just beneath the neurilemma. Near their terminations nerve fibres lose their medullary sheath, and end in fine fibrils.

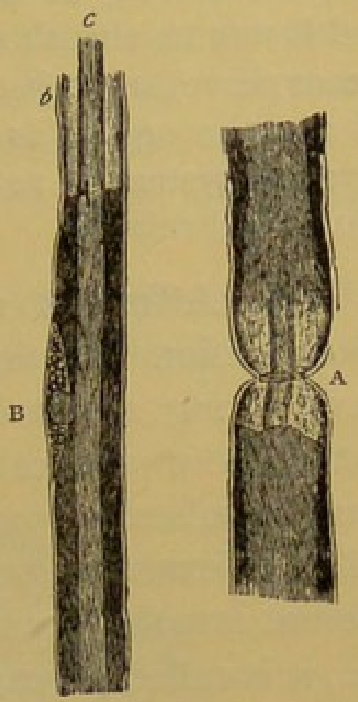



FIG. 134.—Two portions of medullated nerve fibres, after treatment with osmic acid, showing the axis cylinder and the medullary and primitive sheaths. A, node of Ranvier; B, middle of internode with nucleus; *c*, axis cylinder, projecting at the broken end; *p*, primitive sheath within which the medullary sheath, which is stained dark by osmic acid, is somewhat retracted. (*From Quain's "Anatomy."*)

Some nerve fibres, especially those of the sympathetic system, have no medullary sheath. These are known as **non-medullated nerve fibres**, or, from their colour, **grey nerve fibres**.

**144. Neurons.**—It is important to note that although it is convenient to speak of nerve cells and nerve fibres, yet a nerve fibre is only a particular process of a nerve cell and not a separate structure. A complete nerve unit, that is, a nerve cell with its axon or axis cylinder process, and its branching processes, is termed a **neuron**, and each neuron is separate structurally from every other, the connection between one another being made by the contact or touching but not union of the fine branches, into which the axis cylinder breaks up at its termination (Fig. 140). The nerve cell is the centre of nutrition of the neuron, and if the axon or any part be cut off from the nerve cell it will degenerate and die. The axon or axis cylinder is the essential part of what we call the nerve fibre, being but a very long process of a nerve cell, and having no neurilemma or medulla as it leaves the cell, and losing its sheath also as it ends on a muscle (in the case of a motor nerve), or as it connects itself with the special epithelial cells of a sense organ (as in the case of the sensory nerves). The nervous system is really a collection of neurons, variously associated and related.

**145. Afferent and Efferent Nerves.**—Various kinds of excitation or stimulus cause a molecular disturbance to travel along a nerve from the point of stimulation. Such disturbances are called **nervous impulses.** Nerves that carry impulses to some part of the central nervous system are called **afferent** nerves (Lat. *ad* or *af*, to; *fero*, I carry). If the afferent impulse gives rise to a sensation of heat, light, sound, etc., it is called a **sensory** nerve. Nerves which carry impulses from the central nervous system to the muscles, or to glands, are called **efferent** nerves (Lat. *ex* or *ef*, out of). If the impulse leads to the contraction of a muscle, an afferent nerve may also be called a **motor** nerve. It will be seen that the terms *afferent* and *efferent* are more general, or of wider signification, than *sensory* and *motor*; for all nerve fibres leading impulses to the central nerve system are not sensory, though all are afferent; while all fibres leading from a part of the central system are not motor, though efferent. If the efferent impulse leads to secretion in a gland, the nerve may be called a **secretory** nerve, while if it is connected with a blood-vessel, so as to regulate its calibre and the flow of blood, the nerve is called a **vaso-motor** nerve. The function of all nerves is to carry impulses, but whether a nerve is afferent or efferent in function is determined by its mode of origin, its distribution, and its physiological behaviour. The rate at which a nervous impulse travels is about one hundred feet per second—far slower than the speed of light, or of the electric current.

**146. The Brain.**—The brain is enclosed in the skull, a bony box of many pieces, fitting together by sutures. Besides the bony case, the brain is invested by three membranes. There is first a tough membrane, called the **dura mater,** that lines the cranial bones and forms the outer covering of the brain. Closely investing the brain itself, and dipping down into all the furrows, is a more delicate membrane, called the **pia mater.** This membrane is very vascular, and from it the brain receives its supply of blood by small vessels. Between the dura mater and pia mater is another membrane, called the **arachnoid membrane.** Inflammation of these membranes produces acute forms of brain disease.

A brain taken from the skull, and with the membranes removed, is found to consist of several connected parts.

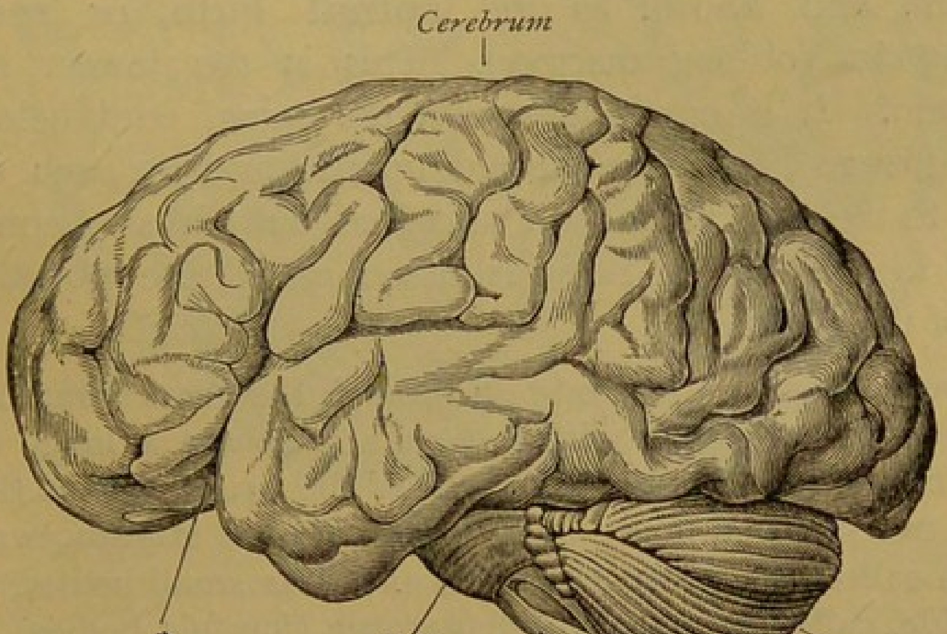



FIG. 135.—Side view of brain removed from the cranium. The left cerebral hemisphere, with its fissure and furrows, is seen forming the fore-brain and overlapping behind. *Cbl.*, the cerebellum. M.O., medulla oblongata, or spinal bulb; P.V., pons Varolii; the star points to one of the larger fissures, the fissure of Sylvius.

Looked at from above, we see a great hemispherical mass, called the **cerebrum.** This is divided by a central longitudinal fissure about two inches deep into **a right and left cerebral hemisphere.** Each hemisphere has meandering furrows, which are of various depths, and divide it into folds or rolls, called the cerebral **convolutions**, as is well seen in a top or side view. The deeper depressions or furrows mark off each cerebral hemisphere into five masses called **lobes**, a frontal lobe, a parietal lobe, an occipital or posterior lobe, a lower lobe, and a central lobe. The two hemispheres are united at the bottom of the fissure by a band of nervous tissue, called the **corpus callosum.** The cerebrum constitutes more than three-fourths of the whole brain, and occupies the whole of the upper and front part of the skull, and projects behind over the other portions of the brain.

Beneath the hinder part of the cerebrum (Fig. 135) is found another part, consisting of two halves, and known as the **cerebellum.** It shows outside a streaked surface, due to linear furrows.

Beneath the cerebellum, and growing into it, as it were, is an expanded portion of the spinal cord lying within the cranium, and known as the **spinal bulb**, or **medulla oblongata** (oblong marrow). This is the lowest part of the brain. It is continuous with the spinal cord below, but bends forward, and is connected upward and on each side by fibres to the cerebellum. The spinal bulb is also connected above to a bridge of nervous tissue, called the **pons**, at the base of the brain.

A vertical section of the brain through the great fissure and the corpus callosum shows within each hemisphere a long, sinuous cavity called the **lateral ventricle** of the brain, and at the base of this two streaked masses called the **corpora striata**, two round masses called the **optic thalami**, and four small bodies, two on each side, called **corpora quadrigemina** (fourfold bodies).

Looking at the base of the brain, which rests on the uneven floor of the cranium, we see how the cerebrum overlaps the other portions. A view of the base shows the following parts—(1) the **spinal bulb**, or medulla, lying beneath the cerebellum, with its broad end forwards. Six pairs of nerves are seen springing from its surface; (2) the **pons Varolii** (bridge of Varolius), a bridge of tissue above the medulla, consisting mainly of nerve fibres passing to the cerebellum on each side; (3) the **crura cerebri** (legs of the cerebrum), striated masses of nervous matter emerging from the pons and entering the under part of each cerebral hemisphere; (4) small masses of nervous matter; (5) the first

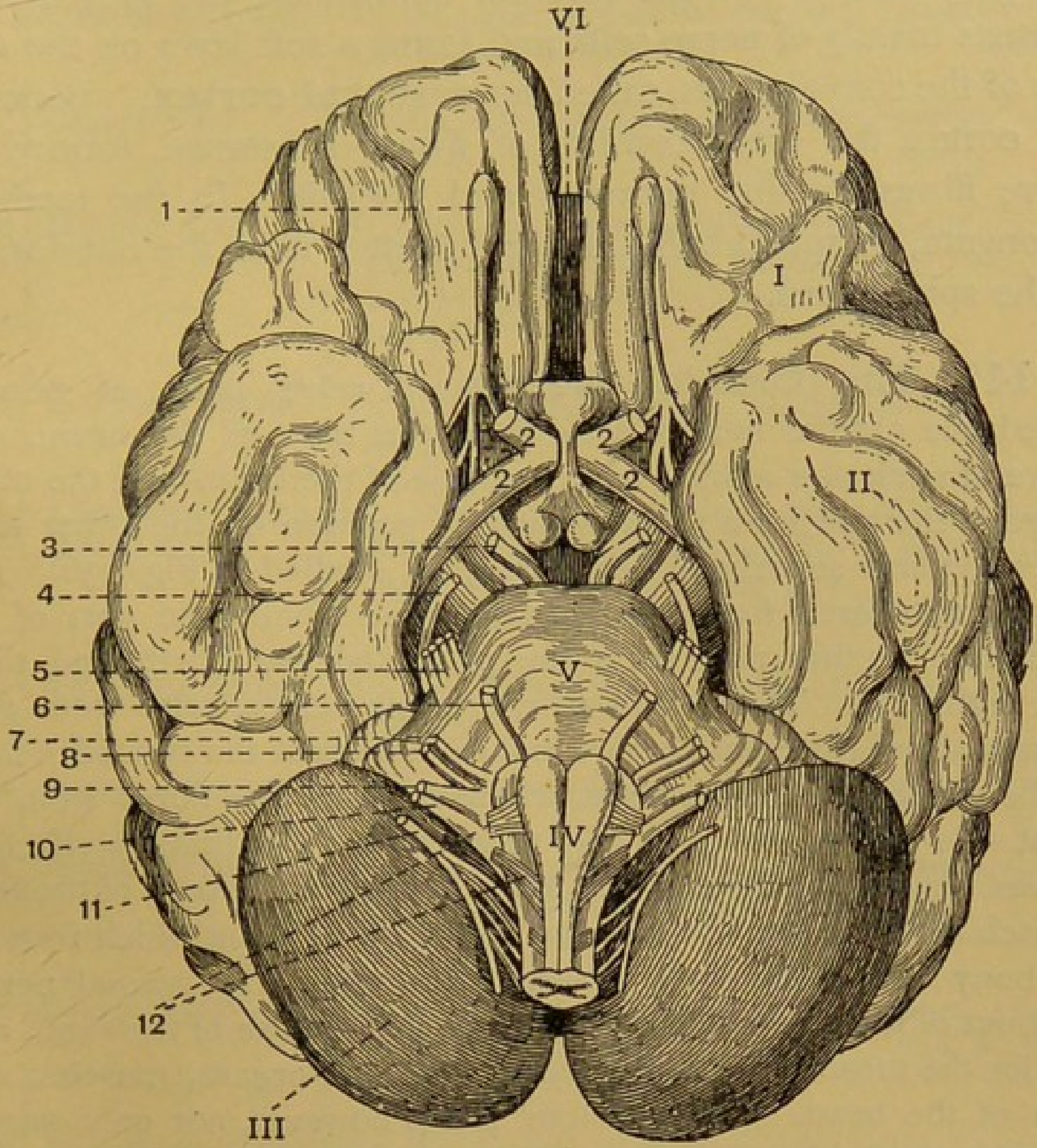



FIG. 136.—The base of the brain. I, frontal lobe of cerebrum; II, parietal lobe of cerebrum; III, cerebellum; IV, medulla oblongata, or spinal bulb; V, pons Varolii (the crura cerebri run outwards just above the pons); VI, corpus callosum. The Roman numerals indicate the twelve pairs of cranial nerves. 1, olfactory nerves; 2, optic nerves; 3, motores oculi; 4, trochlear nerves; 5, trigeminal nerves; 6, abducens nerves; 7, facial nerves; 8, auditory nerves; 9, glossopharyngeal nerves; 10, pneumogastric, or vagi nerves; 11, spinal accessory nerves; 12, hypo-glossal nerves.

six pairs of cranial nerves arising from parts of the brain in front of the bulb. The second pair of nerves, the optic nerves, cross at the optic commissure, just behind a small body called the **pituitary body**. The last six pairs of cranial nerves arise from the bulb.

All the parts of the brain are connected with fibres running from one part to another, so that the various parts unite to form one complete organ.

The nervous substance of the brain consists of white matter and grey matter. In the cerebral hemisphere the grey matter consists mainly of nerve cells, and forms a soft layer on the *outside* of the convolutions, called the **cerebral cortex.** Beneath the cortex the brain consists of firmer substance, formed of nerve fibres passing outwards and inwards. In the medulla oblongata, or spinal bulb, the grey matter is in the interior, as in the spinal cord.

**147. The Cranial Nerves.**—Twelve pairs of nerves, called the cranial nerves, arise from the base of the brain, one nerve of each pair arising from one side of the brain and the other nerve of the pair from a corresponding position on the other side. Their general superficial origin may be studied in Fig. 136. The nerves numbered from six to twelve arise from some part of the medulla ; the fifth rises from the pons, and the fourth and third still higher up. The second pair, or optic nerves, arise from grey masses above the crura cerebri, and the nerves of the two sides meet in the middle line of the brain, where most of the fibres from the right side pass to the left, and *vice versâ.* The first, or olfactory nerves, rise as processes of the brain from the front part of the base of each cerebral hemisphere, and pass to a swelling which rests on the bony base of the skull between the eyes. The cranial nerves pass out of the cranium through holes in the base of the skull, and are, for the most part, distributed to the sense organs, muscles, and skin of the head. The last four pairs, however, not only supply branches to the head, but send branches down to other parts of the body. The tenth pair, the **pneumogastric** or **vagus** (vagus = wandering), is very widely distributed, the branches to the lungs and stomach giving rise to the name "pneumogastric." Some of the cranial nerves are entirely sensory, and some motor, while others are mixed, having both sensory and motor fibres. All the spinal nerves, on the other hand, are mixed, or **sensori-motor.** The following table gives further information regarding the distribution and function of the cranial nerves.

FUNCTION AND DISTRIBUTION OF THE CRANIAL NERVES.

| Pair. | Name. | Distribution. | Function. |
|---|---|---|---|
| 1st | Olfactory nerves | To the upper part of the mucous membrane of the nose | Sensory (smell) |
| 2nd | Optic nerves | To the retina at the back of the eyeball | Sensory (vision) |
| 3rd | Motores oculi | To four of the muscles that move the eye, to the ciliary muscle, and to the sphincter muscle of the iris | Motor |
| 4th | Trochlear nerves | To the superior oblique muscle of the eye | Motor |
| 5th | Trigeminal or trifacial nerves | To the skin of the face, the muscles of the jaws, and to the mucous membrane of the fore part of the tongue | Mixed (motor and sensory) |
| 6th | Abducens nerves | To the external rectus muscle of the eye | Motor |
| 7th | Facial nerves | To the muscles of the face | Motor |
| 8th | Auditory nerves | To the labyrinth of the inner ear by two main branches (see par. 178) | Sensory (hearing) |
| 9th | Glossopharyngeal | To the hind part of the tongue, to the soft palate, and to the muscle of the pharynx | Mixed (motor and sensory) |
| 10th | Pneumogastric nerves, or vagus nerves | To the larynx, the lungs, the liver, the stomach, and the heart | Mixed (sensory and motor) |
| 11th | Spinal accessory | To certain muscles of the neck | Motor |
| 12th | Hypo-glossal, or lingual | To the muscles of the tongue | Motor |

More will be said on the functions of the chief sensory nerves in the chapters on the senses. The action of the branches of the vagus have been already referred to in several places (see pars. 65 and 85).

**148. Functions of the Medulla, or Spinal Bulb.**—The spinal bulb is a very important part of the brain, for, besides giving origin to a number of cranial nerves, it acts (1) as a conductor of impulses and impressions, (2) as a collection of nerve centres.[1]

Sensations that arise on the skin or muscles pass into the spinal cord and on through the medulla, in order to reach the cerebral hemispheres, where alone they are felt. So voluntary impulses pass from the cerebral hemisphere through the medulla and cord to reach the motor fibres that put in action the muscles. It is important to note that the nerve fibres which transmit impulses from the right cerebral hemisphere cross in the medulla to the left side of the cord and on to the left side of the body, *i.e.* the nerve fibres which supply the muscles of the left side of the body are connected with the right side of the brain, while the left side of the brain governs the right side of the body. Sensory impressions also cross over, partly in the cord itself and partly in the medulla, so that a burn on the right side is perceived in the left hemisphere of the brain. Hence it is that injury or disease of one hemisphere produces both paralysis or loss of voluntary movement, due to interruption of motor impulses, and loss of sensation *on the opposite side of the body.*

As a collection of nerve matter acting as centres of reflex action, we find in the bulb parts regulating respiration (par. 85), and centres regulating the heart-beat (par. 65), the state of the small arteries, swallowing, and the secretion of saliva. Ordinary respiration is a reflex act, for the state of distension of the air cells and the venous condition of the blood in the lung capillaries stimulate the fibres of the vagus nerve, and this nerve transmits the impression to the medulla. The medulla reflects the impression to the muscles of inspiration, and these act so as to cause a fresh supply of air to be drawn in. When food is passed into the throat, impressions are set up that result in muscular action in the gullet, by which the food is passed on independent of the will, the first part of the action of

[1] A nerve centre may be regarded as a group of nerve cells mingled with nerve fibres, closely associated with one another, and acting together in the performance of some function.

swallowing being voluntary, and the next part involuntary, or reflex (par. 154). Injury to the medulla from "breaking the neck" or any other cause, owing to its acting as the regulator of respiration and the beating of the heart, produces death at once.

**149. Functions of the Cerebral Hemispheres.**—The cerebral hemispheres, especially the nerve cells in the grey matter of the cortex, are the seat of conscious sensations, of perceptions, of intelligence, and of will.[1] After the destruction of the cerebral hemisphere, an animal may, if fed by hand, continue to live for several days, but in a completely unconscious and idiotic condition.

A frog deprived of its cerebral hemispheres only, feels nothing, and performs of itself no movement. It will sit up, and may be made to move when touched, it will recover its natural position when placed on its back, and it will swim when placed in water till it reaches a place of rest. Such movements are due to stimulations or afferent impulses reaching the lower parts of the brain, and setting up reactions, or reflex actions, that result in movements that lead to a useful end. Thus the contact of water with its skin sets up the action of swimming until the contact ceases. But the animal manifests no hunger, makes no effort to obtain food, and shows no sign of fear. It is a mere machine, performing certain reflex acts due to external stimulation. It has lost its power of willing and initiating movement, and will die where it is, if left alone. The complete animal acts very differently. It starts movements of its own accord, and, driven by hunger, goes in search of its food. From these observations and considerations we may conclude that conscious actions and voluntary movements depend on the activities of the cells in the cerebral hemispheres. The lower parts of the brain may, on receiving suitable afferent impulses, give rise to important and complicated reflex actions ; but consciousness, intelligent sensation, memory, and judgment, are functions of the cerebral hemispheres alone.

[1] Any cause which injures the cerebral hemispheres, or stops the supply of pure blood to these parts, leads to unconsciousness. Thus a violent blow on the head may produce concussion of the brain, and cause a person to fall down senseless (par. 44). Temporary failure of the heart to supply the needful pure blood, owing to the effect of an unpleasant sight, may cause a person to *faint* and lose consciousness. Certain vapours and drugs so affect the blood that unconsciousness comes on. As the disturbance passes off, and pure blood reaches the cerebral hemisphere, consciousness returns.

# CHAPTER XVIII.

## *THE NERVOUS SYSTEM—continued.*

**150. The Spinal Cord.**—The spinal cord is the column of nervous matter contained in the spinal canal, which is formed, as already explained, by the superposed rings of the vertebræ (par. 21). It is about 18 inches long in a man of medium height, and about $\frac{3}{4}$ of an inch in diameter. It extends from the margin of the great hole in the occipital bone to the lower part of the first lumbar vertebra, where it terminates in a slender thread that runs on among a mass of nerve roots. Above, it is continued into the part of the brain called the **medulla oblongata**, or bulb which lies within the cranium.

The spinal cord, like the brain, is invested by three membranes—(1) an outer tough membrane, called the **dura mater**, (2) a loose connective tissue membrane, called the **arachnoid membrane**, and (3) a closely fitted vascular membrane, called the **pia mater.** When the outer membranes are removed, the spinal cord is seen to be divided into a left and right half by two deep fissures running along the length, one in front called the **anterior fissure**, and one behind called the **posterior fissure.** The two halves are connected by a narrow bridge of nervous matter, in the centre of which is a small canal, known as the **central canal** of the cord. The pia mater dips into the fissures, and from it fine blood-vessels pass into the cord. Passing from the cord at intervals will be seen the spinal nerves, given off in pairs. There are thirty-one pairs in all, and each pair arises from the cord by two strands, or nerves, that soon unite. On cutting across a spinal cord (as may be seen on obtaining that of the ox from a butcher) it will be seen to be composed of a white substance lying outside, and a pinkish-grey matter lying inside. The grey matter is arranged in each half of the cord in columns, cut ends of which have the form of a crescent, the two crescents being united by a narrow band of the same material. Thus the grey matter is arranged roughly in the form of an **H**, with the white matter around it. The proportion of grey matter to white matter varies in different parts of the cord, being greatest in the cervical and lumbar regions, where the nerve supply for the upper and lower limbs, as well as for a part of the trunk, are given off, and least in the dorsal regions. The part of a crescent in front of the grey connecting bridge is called the **anterior horn**, and the part behind the bridge the **posterior horn**. There are thus two anterior horns of grey matter and two posterior horns of grey matter. The

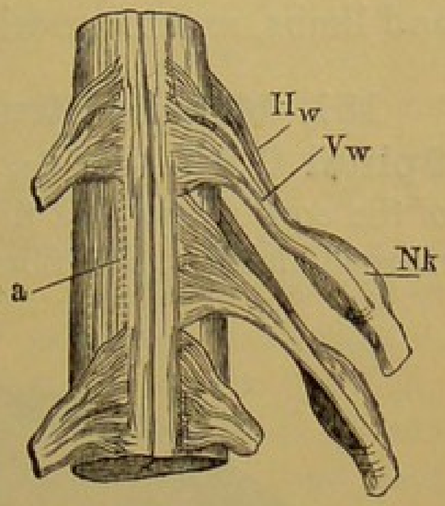



FIG. 137.—A piece of spinal cord with spinal nerves passing from it. Hw, hinder or posterior root; Vw, front or anterior root; Nk, ganglion on posterior root; *a*, place where an anterior root has been torn away.

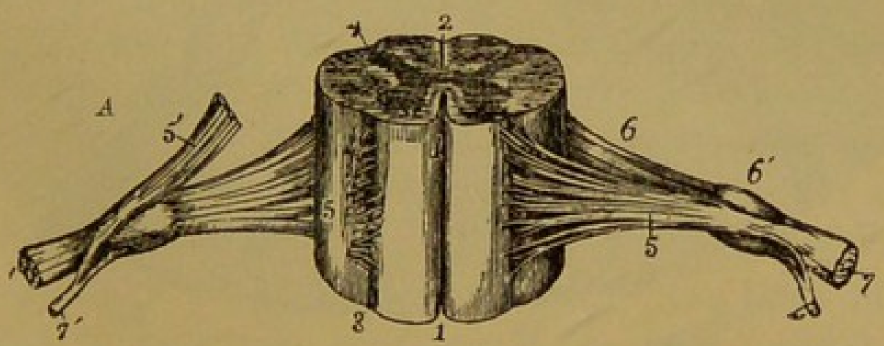



FIG. 138.—A piece of spinal cord seen from the front, and showing the origin of a pair of spinal nerves. 1, anterior median fissure; 2, posterior median fissure; 3, antero-lateral groove from which anterior root arises; 4, postero-lateral groove for posterior root; 5, anterior root; 6, posterior root, the fibres of which are united with the ganglion, 6′; 7, the united or compound nerve; 7′, first branch of compound nerve. (*From Quain's "Anatomy."*)

anterior roots of the spinal nerves arise at the sides of the cord from the anterior horns of the grey column, and the posterior roots from the posterior horns of the grey column. The anterior and posterior roots of a spinal nerve soon unite to form one nerve trunk, as already stated, but just before they unite there is a knob-like enlargement on the posterior root, called the **ganglion of the posterior root.** The united nerve leaves the spinal canal between the arches of two vertebræ, and then passes on to be distributed to the muscles of the trunk and limbs, and to certain parts of the surface of these.

**151. Minute Structure of the Nerve Matter of the Spinal Cord.**—Under the microscope a thin transverse section of the cord shows that the white part of the cord consists mainly of medullated nerve fibres intermixed with some fine connective

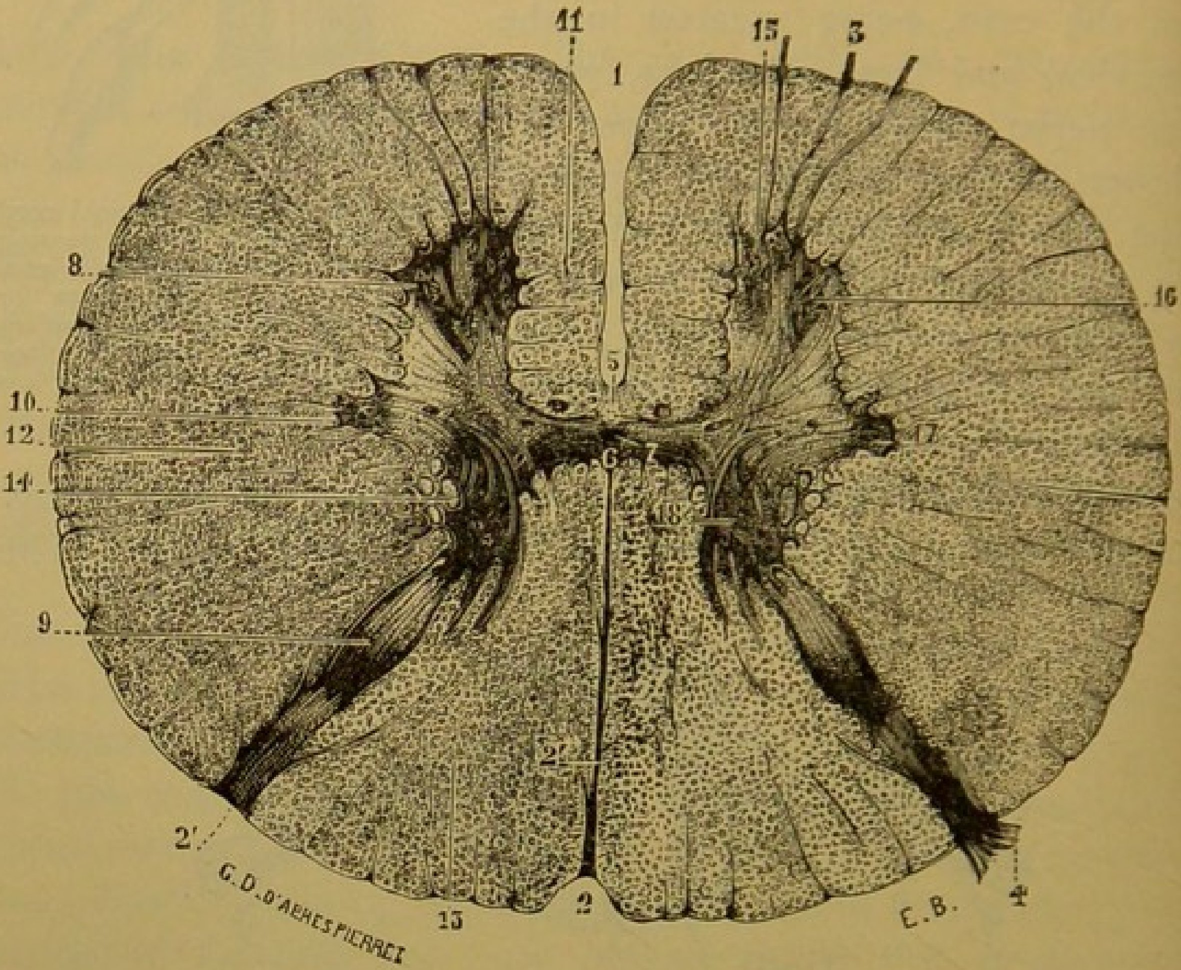



FIG. 139.—Section of spinal cord in dorsal region slightly magnified, showing arrangement of grey matter in crescentic horns, the surrounding white matter (cut ends of nerve fibres mainly) and the various fissures. 1, anterior fissure; 2, posterior fissure; 3, anterior roots of afferent nerve fibres; 4, posterior root of afferent nerve fibres; 7, central canal in grey matter connecting the two crescents; 8, 16, anterior horns of grey matter; 9, posterior horn of grey matter.

tissue. The fibres run lengthwise, and therefore appear in the section as circles, with a dot in the centre marking the axis cylinder, as in Fig. 133. The grey matter is seen to be made up of some fine medullated fibres, some grey non-medullated fibres, and a large number of nerve cells. The nerve cells of the cord vary in size and shape according to their position. Those of the anterior horn of grey matter are the largest, and show a number of branching processes, or dendrons, with a single large unbranched process that forms the axon of the cell (Fig. 132). The axon process of a large cell in the anterior horn becomes the axis cylinder process of a nerve fibre that passes into the anterior root of a spinal nerve, and it is thus seen that the anterior root of a spinal nerve has its origin in the large nerve cells of the anterior horn of grey matter.

The nerve cells in the posterior horn of grey matter are smaller than those in the anterior horn, and do not appear to give rise to nerve fibres like those of the anterior horn. The fibres that are in the posterior root, as well as some in the posterior white matter, spring, in fact, from cells in the ganglion that lie on the posterior root. The cells of these ganglia have a **T**-shaped process, one branch of which passes as a nerve fibre into the spinal cord, and the other branch of which passes outwards to the muscles or the skin. The fibres that thus enter the cord pass up and make connections (not structural) with cells in the other part of the cord or in the medulla oblongata.

**152. The Spinal Nerves and their Function.**—Thirty-one pairs of spinal nerves pass from the spinal cord, each single nerve arising from the sides of the cord by two roots, an anterior root and a posterior root, but the two roots unite to form one nerve, which passes outwards, to give off branches that go for the most part to the muscles and skin of the body. Before the two roots unite, a ganglion is found on the posterior root. The nerves from the right side of the cord pass, for the most part, to the right side of the body and the right limbs, and those from the left side of the cord to the left of the body (Fig. 31). The united nerve trunks pass out of the spinal canal through notches that form foramina, or openings, between the successive vertebræ.

Now, experiment has shown that the fibres of the posterior root of a spinal nerve are **afferent** fibres carrying sensory impulses, for if the posterior root only of a spinal nerve be cut across or injured, a stimulus (pinching, pricking, burning, etc.) applied to that part of the surface of the body to which the nerve is distributed is not felt at all, as the sensory connection with the spinal cord and brain has been cut off, though movement of the part could still be brought about. A similar experiment shows that the fibres in the anterior roots of a spinal nerve are **efferent**, and carry motor impulses from the spinal cord to the muscles. For, if the anterior roots of the nerves going to the leg, for example, be cut, the animal cannot move the limb. It hangs limp and is said to be paralyzed. A needle, or hot iron, applied to the leg could, however, be felt, as the sensory impulses could pass as before into the cord and on to the brain by the posterior roots. If a nerve be cut after the two roots have united, both sensation and power of movement would be lost in the part to which the nerve is distributed. Pinching the cut end of the nerve attached to the cord would produce sensation but no movement, while pinching the cut end not joined to the cord would lead to movement, but no sensation would be felt. Such experiments prove—(1) that the spinal nerves convey sensory impulses into the cord, (2) that they also convey motor impulses from the cord, (3) that the sensory impulses pass into the cord by fibres in the posterior roots, (4) that motor impulses pass out by the anterior roots.

The first pair of spinal nerves come off between the skull and atlas vertebra, one nerve on each side, the next pair between the atlas and axis, and so on between every two vertebræ down the spinal canal, the last pair coming off between the sacrum and coccyx. The upper spinal nerves spring from the cord and pass out at fairly regular intervals, dividing into a large anterior branch and a small posterior branch, and then running transversely outwards to supply smaller branches to the muscles and skin of that region of the body. But since the cord proper ends just below the first lumbar vertebra, a slender filament only running on, the lower pairs come off the cord close together from the thickened part of the cord opposite the last dorsal vertebra. They then run downwards in the spinal canal in a bunch, the *canda equina*, or "horse's tail," to reach their points of exit in the lumbar and sacral regions (Fig. 13). (In Figs. 26 and 32 are seen the holes in the sacrum through which the anterior branches of the sacral nerves make their exit.) The great **sciatic nerve**, the largest nerve in the body, is formed mainly by the united anterior branches of the sacral nerves. It passes down through the pelvis, and then runs along the back of the thigh, supplying branches to nearly all the skin of the leg, as well as to the muscles at the back of the thigh and leg.

**153. The Functions of the Spinal Cord.**—The spinal cord has two great functions—

(1) It acts as a conductor of impressions and impulses.

(2) It acts as a series of nerve centres, *i.e.* it has reflex functions.

As a conductor, the spinal cord conveys impressions made on the surface of the body and received by the sensory nerves to the brain. It also acts as a conductor of motor impulses from the brain to the muscles, the impulses from the right side of the brain crossing to the left side of the cord, and those from the left side of the brain to the right of the cord. Any injury to the cord will thus stop these impressions from passing on to the brain and the impulses from the brain getting to the muscles, if the impression and impulses enter and leave the cord below the seat of injury. When a man "breaks his back," for example, about the middle, we mean that the spinal cord at this part has been so far crushed or severed that connection with the brain has been destroyed. His legs and the part of the body supplied by nerves arising from the cord below the injury will be completely paralyzed.[1] No sensations can pass from the legs and lower part of the body to the brain, and no voluntary impulses can be sent from the brain to the muscles of these parts, for the conducting function of the cord is destroyed at the place of injury. Life may continue with an injured spinal cord as long as the injury is below the point in the neck where the nerves come off that give rise to the phrenic nerve that passes to the diaphragm and controls the chief part of the mechanism of breathing. "Breaking the neck," however, is fatal (par. 148).

**154. Reflex Action.**—The injured man will serve to illustrate the second great function of the cord—its action as a series of nerve centres. After the shock of the injury has passed off, the man may live for some time, and although he can no longer move his legs by an effort of the will, or feel

[1] Paralysis of a limb or any other part is a condition in which the nervous impulses between it and the brain are interrupted. In motor paralysis, the transmission of motor impulses from the brain is interrupted ; in sensory paralysis, sensory impulses to the brain are stopped ; in complete paralysis both kinds of impulses are interrupted.

any pinches, pricks, or hot things applied to them, yet if the soles of the feet be pinched or tickled the legs are drawn up and put into lively movements without the person himself feeling or knowing. **Movements that arise from sensory impulses and are carried out without consciousness are called reflex movements.** The spinal cord is thus seen to be a centre for **reflex action**, the result being brought about as follows. The sensory nerve endings in the feet are excited by the tickling, and these cause nervous impulses to pass along the afferent or sensory fibres in the nerves of the feet. These sensory impulses enter the spinal cord by the posterior roots, but the injury to the cord prevents any sensation passing on to the brain. The sensory impulses, however, pass on and affect the nerve cells in the anterior horn of the cord, so that these send out motor impulses by fibres passing out in the anterior root to the muscles. As a result, the muscles contract and are drawn away. The sensory nervous impulse from the feet is, as it were, sent back or reflected by the cord as a motor impulse to muscles without the action of the will.

It might be supposed that tickling the feet affects the muscles directly and makes them contract, just as a muscle can be made to contract directly by an electric shock. But this is not the case; for, if the great sciatic nerve that passes from the lower part of the spinal cord down the back of each leg and gives off many branches (Fig. 13) be cut, tickling the feet produces no responsive movements. Hence the message from the skin does not pass directly to the muscles, but must pass by a branch to the sciatic nerve and then to the spinal cord, in order that a motor impulse may be reflected back to the muscles.

The simplest mechanism or structures necessary for a reflex act, therefore, are—(1) a sensory surface; (2) a sensory or afferent nerve; (3) a nerve cell or centre; (4) a motor or efferent nerve, (5) a muscle or gland.

The reflex actions of the spinal cord are most easily studied in a cold-blooded animal like the frog. If a frog's spinal cord be severed just where it enters the skull, and the brain then destroyed, the animal can no longer feel nor move of its own will. Unlike the frog that has had its cerebral hemispheres only removed (par. 149), it lies prone and it ceases breathing, and it cannot be got to move forward. Yet if left until the shock of the operation is over its spinal cord is still capable of reflex actions. On scratching one flank slightly, the muscles of that side twitch, and on pinching this spot or irritating it with acid, the leg on that side makes a sweeping movement to wipe away the irritation, and if this leg is held the other will try to effect this. Pinching a toe causes the leg to be drawn up out of the way. The sensory impulses set up by the stimulus must therefore pass by sensory nerves into the cord, and these impulses reaching the grey matter of the anterior horn are reflected to muscles that act so as to attain an end. The reflex actions of the brainless frog are, in fact, orderly, co-ordinated, and *purposeful* in character. But violent and prolonged irritation leads to convulsive and spasmodic movements in the animal.

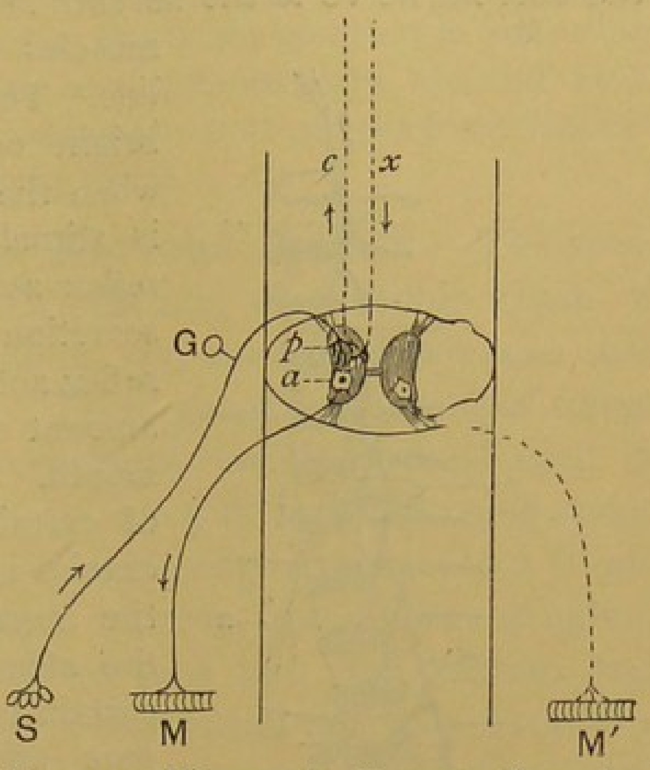



FIG. 140.—Diagram to illustrate the reflex action of the spinal cord. S, some sensory surface from which a nervous impulse passes by a sensory nerve to the spinal cord by the posterior root of a spinal nerve; G, ganglion on posterior root; at *p* the nerve fibre breaks up and transmits the impulse to a nerve cell, *a*, in the anterior horn of grey matter; from *a* a motor impulse passes outward along a motor or efferent nerve to the muscle M. Sometimes an impulse passes on to the other side of the cord and then to a muscle, M′, on the other side of the body. When the brain is concerned in an action, the passage of the impulse to that organ is indicated by the dotted line *c* and the passage of an impulse from that organ by the dotted line *x*.

Many of our common movements are brought about by reflex action, for they are the involuntary responses of some part of the central nervous system to sensory impulses that reach it. It is not only the spinal cord that reflects movements in response to impulses sent in by an afferent nerve, but parts of the brain give rise to reflex actions also. Winking at a flash of light or at an object suddenly approaching the eye is a reflex action in which all the nerves involved belong to the brain. The sensory surface is the retina, the afferent nerve is the fifth, or optic nerve, the nerve centre is in the part of the brain called the corpora quadrigemina, the efferent nerve is the seventh cranial, or facial, nerve, and the muscles that act are those of the eyelids. The contraction of the iris in a bright light (par. 164), and sneezing when the inner membrane of the nose is stimulated, are other examples of reflex actions of the brain. Glandular secretion is also for the most part a reflex action. Thus saliva increases in amount as soon as food is put in the mouth. The food stimulates the ends of certain nerves (the fifth and ninth cranial nerves, par. 149) distributed to the mucous membrane of the mouth, the afferent impulses set up pass to a certain part of the brain, and from this part efferent impulses pass out to salivary glands and cause their cells to secrete.

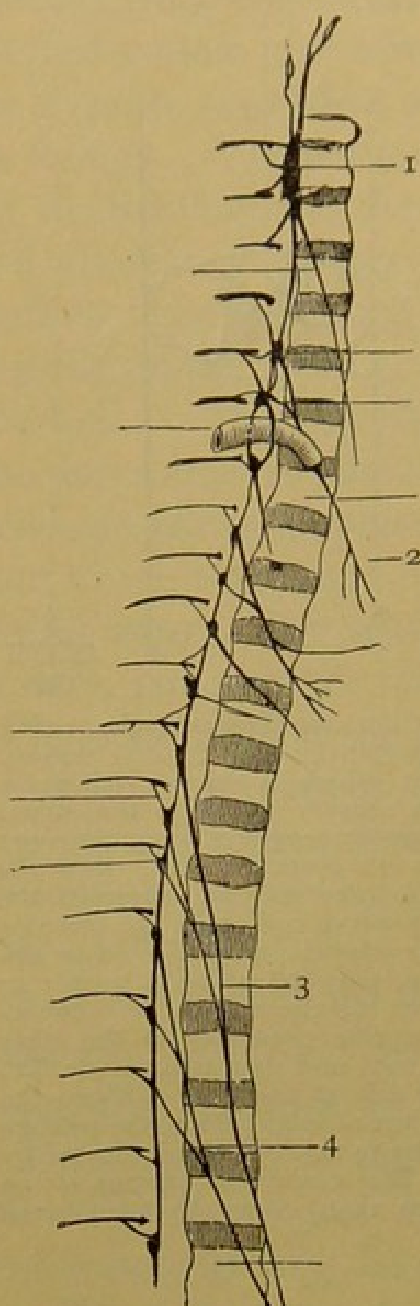



FIG. 141.—Diagrammatic figure of the upper part of the chain of sympathetic ganglia of the right side with some of the sympathetic nerves. 1, upper cervical ganglion; 2, cardiac branches; 3 and 4, splanchnic nerves.

Pressure upon a nerve along any part of its course interferes with its functions, and if pressure or stimulation be applied to a sensory nerve in its course, painful sensations are produced in the parts to which the fibres of the nerve are distributed; that is, the sensations produced by irritating a nerve trunk are referred, not to the place of stimulation, but to the area where its nerve fibres terminate. Examples of this phenomenon of *referred sensation* are frequent. A blow or strong pressure on the *ulnar nerve* as it passes over the inner side of the back of the elbow (knocking "the funny-bone," as it is commonly called) produces tingling sensations in the hand and in the little and ring fingers where the fibres of this nerve end. Pressure on the peroneal nerve on the outside of the back of the knee when sitting with the legs crossed causes in the foot the peculiar feeling called "going to sleep." A man whose leg has been amputated will, when the cut ends of the nerves are irritated, refer the pains to the place where his foot should be. All sensations, it must be remembered, are due to nerve impulses conveyed to the brain along sensory nerve fibres, and the part of the brain involved in sensation is the grey matter of the cerebral hemispheres (pars. 149 and 156). *Pain* is the name given to the sensation that results from the excessive stimulation of any sensory nerve.

**155. The Sympathetic Nervous System.**—The sympathetic nervous system consists, mainly, of a double chain of ganglia outside the spinal column, and running down each side a little in front of this column. These ganglia, or knots of nerve matter, are connected by nerve fibres with the spinal cord in the spinal canal, and also with one another by intervening cords (Fig. 141). Below, the two chains of ganglia unite into a single ganglion opposite the os coccyx. Above, from a large ganglion in the neck, on each side fibres pass into the cranium, and become connected with some of the cranial nerves. From the sympathetic ganglia on each side of the neck nerve fibres pass to the lungs and heart; from the ganglia of the thorax nerves pass off (the **splanchnic nerves**) that form a great plexus in the upper part of the abdomen, another ganglion gives off fibres to the blood-vessels going to the stomach, liver, intestines, and other abdominal organs. Another great plexus of sympathetic nerves is situated in the pelvis. The fibres of the sympathetic system originate partly in the spinal cord and partly in the ganglia themselves, and some of these last run back into the spinal cord to be afterwards distributed with the spinal nerves to the blood-vessels of the limbs. The impulses carried by the sympathetic nerves pass mainly to the involuntary muscular tissue in the heart, stomach, intestines, and glands, as well as to the walls of blood-vessels, so that the functions of this system seem to be to regulate the processes of life that go on in these organs independently of our will. But the impulses arise in some part of the central nervous system, to pass on through the sympathetic system, not in the sympathetic ganglia themselves; so that the sympathetic system is not a separate nervous system, but only an outlying part of the cerebro-spinal system.

# CHAPTER XIX.

## *SENSATION, TOUCH, TASTE, SMELL.*

**156. Sensations.**—We have learnt that the excitation of sensory nerve endings in the skin and in the organs of sense pass as inward or afferent impulses to the central nervous system (spinal cord and brain), and that there these impulses often give rise to outward or efferent impulses that lead to muscular movement or glandular action without our being aware of the sensory excitation (par. 154, Fig. 140). Hundreds of such reflex actions occur in each one of us every day, for many internal movements of the bodily organs, as well as many of our habitual actions, are carried out unconsciously by the spinal cord and lower part of the brain.

Other afferent impulses, due to the stimulation of sensory nerve endings, pass inwards to the brain and produce in us a feeling which we call a **sensation.** We are aware or conscious of the nervous stimulation, so that we may say "*sensations are states of consciousness produced in the brain by stimulations of nerve endings.*" We commonly refer sensations to certain external causes, and locate them at the places where the sensory nerves are usually stimulated, and not in the brain, where the sensation arises. It is through sensations that we gain our knowledge of the external world, including that of our own body.

Sensations are of various kinds, and there is a fundamental difference between a sight and a sound, or between a sight and a smell. Five fundamentally different kinds of sensations are well known—sensations of **touch, taste, smell, hearing,** and **sight.** But this enumeration of the sensations is not complete. Besides the five special sensations just mentioned, there is a large class of sensations called *common* or *general sensations*, produced by the state of the internal organs and the blood. Such general sensations are the sensations of *pain*, *fatigue*, *hunger*, and *thirst*. Further, there are special sensations connected with the action and condition of the muscles as well as special sensations of cold and heat connected with the surface of the skin. There is thus a **muscular sense** and a **temperature sense.** Muscular sensations appear to proceed from the muscles by afferent fibres to the nerve centres. Nerve fibres from the articular surfaces of the joints also probably enter into what is called the muscular sense. The muscular sensations enable us to judge of the degree of contraction of muscles, and so to discriminate different positions of the limbs, different kinds of movement, and differences of weight, even when the eyes are closed.

**157. Sense Organs.**—A sense organ is a part of the body specially adapted to receive some form of energy from the external world, and to transform this energy into nervous impulses. Each of the five special senses has its own special sense organ, the essential part of which consists of special kinds of epithelial cells to which afferent or sensory nerve fibres are connected. The stimulation, or exciting cause, arousing a sensation is not applied to the nerve ending itself, but only to the specially modified epithelial cells in or around which the sensory nerve fibres end. The special end-organs for the sense of touch are found in the skin, and consist of certain small corpuscles in the dermis and some fine nerve fibrils among the deeper cells of the epidermis ; the special end-organ for the sense of taste are the peculiar nerve endings in cells in the papillæ on the tongue ; for the sense of smell they are in nerve endings and cell connections in the mucous membrane of certain parts of the nostrils ; for the sense of sight the real end-organ is in the retina at the back of the eyeball ; and for the sense of hearing the end-organ is a special structure in the inner ear called the **organ of Corti.**

The eye and the ear are the most specialized sense organs, each having, besides the peculiar end-organ just mentioned, certain accessory parts that aid in bringing the stimulus to the real or essential part. Thus, in the eye we find structures that serve to focus the light rays that are to act on the real end-organ in the retina, and in the ear there are special parts to conduct the waves of sound to the auditory cells connected with the auditory nerve.

Each end-organ of the special senses can only be thrown into action by a particular form of energy, that is, by certain kinds of stimuli for which alone it is adapted. Thus the retina can be stimulated by waves of light, but not by waves of sound. Further, the nerves in connection with each end-organ only convey those impulses which give rise to their own peculiar sensations. Thus the retina, however irritated, only gives rise to sensations of light. Pressure on the eyeball, for example, acting on the retina, causes us to see rings of light. So it is with the other sense organs and their nerves.

**158. Touch.**—The sensations of touch or contact are caused by stimulation of nerve endings in the skin and certain parts of the mucous membrane in the mouth and nose (for structure of skin and mucous membrane, see pars. 16 and 131). Touch is the most widely diffused of the special senses, but in no case does the body, touched directly, meet the sensory nerve, epithelial cells of some form coming between the agent and the nerve. The sensory nerve endings concerned in touch sensations are of various forms.

In many of the papillæ of the dermis are microscopic oval bodies called **touch corpuscles**, or **tactile corpuscles** (Fig. 142). A touch corpuscle is a mass of connective tissue round which a nerve fibre winds, terminating within near the summit. Touch corpuscles are most abundant where the sense of touch is most acute. In the deeper part of the dermis, or in the subcutaneous tissue, larger corpuscles are found, termed **Pacinian corpuscles.** They also appear to be concerned in touch sensation. In addition to the nerve endings in the corpuscles just mentioned, very fine nerve fibrils pass from nerves in the dermis into the deeper layers of the epidermis, but not into the outer horny part.

The sense of touch is most acute and delicate at the tip of the tongue, and next at the tips of the fingers, probably owing to the thinness of the epithelial cells and the abundant supply of nerve fibrils to these parts. The lower lip and tip of the nose are also very sensitive to pressure sensations.

A mode of estimating the delicacy of the sense of touch is to use a pair of divider compasses, so blunted that they do not prick and give rise to pain when applied to the skin or mucous membrane. The nearer the two points can be separately and distinctly felt, the more acute is the sense of touch in that part. Thus, on the tip of the finger, the two points are

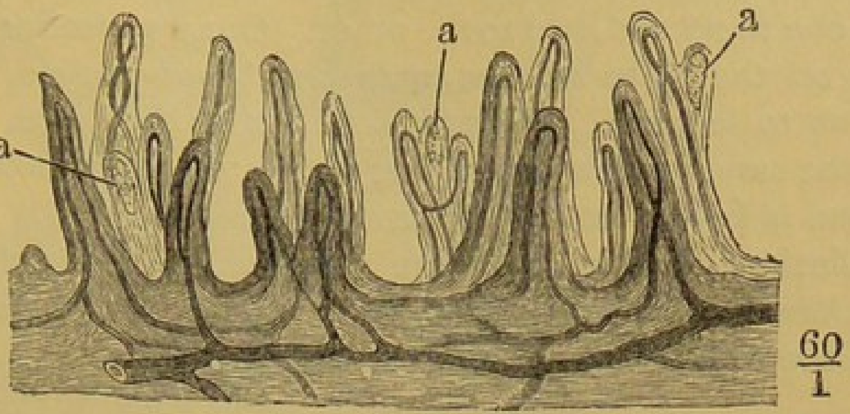



FIG. 142.—Section of portion of dermis from which the epidermis has been removed, showing rows of papillæ with blood-vessels passing in and out. In three or four papillæ touch-corpuscles, *a*, are seen.

distinctly recognized, with the eyes closed, at a distance of $\frac{1}{12}$ of an inch apart, while, on the palm of the hand, the two points placed on the surface together, are only felt as one at this distance. They must be nearly $\frac{1}{2}$ an inch apart to be felt separately on the palm of the hand. On the back of the hand the distance is 1 inch, and, at the back of the neck, much more.

**159. The Temperature Sense.**—The skin, with the mucous membrane of the mouth and some other parts, is not only sensitive to contact and pressure variations (tactile sensations proper), but sensations of warmth and cold are very largely skin sensations, and these sensations are quite different from those of pressure. Small areas of the parts mentioned seem specially sensitive to heat, and other small areas specially sensitive to cold. Such sensitive areas of temperature are on the palms of the hands, on the cheeks, and on certain parts of the tongue. It is probable that there are special nerve endings for these temperature sensations.

The chief facts regarding the temperature sensations of the skin are—

(*a*) Bodies of the same temperature as the part of the skin to which they are applied give rise to no thermal sensations.

N 2

(*b*) The parts of the body having the sense of temperature most acute are, in order, the tip of the tongue, the eyelids, the cheeks, the lips, and the hands.

(*c*) Though the power of the skin to recognize changes of temperature is very great, yet our power of estimating the real or absolute temperature by skin sensation is small. If one hand be placed in a basin of hot water, and the other in a basin of cold water, and both hands then plunged in a basin of tepid water, the water will seem warm to one hand and cold to the other. Our own feeling of warmth depends on the state of the cutaneous blood-vessels, full vessels leading us to feel hot, and empty vessels to feel cold. Hence a body of the same temperature gives a different sensation according as the skin is full or empty of warm blood.

(*d*) Illusions in this sense are common, a cold weight feeling heavier than a warm one, a good conductor like metal feeling colder than a piece of wood of the same temperature, etc.

**160. The Tongue and Taste.**—The end organs of taste are situated chiefly in the upper surface of the tongue and the under surface of the soft palate. The tongue is a fleshy, movable organ found in the mouth. It is composed of a close mass of muscular fibres running in several directions, and it is covered by a peculiar mucous membrane. Behind, the tongue is attached to the **hyoid bone**, a **V**-shaped bone connected to the skull by two long ligaments. Folds of mucous membrane also pass from the base of the tongue to the epiglottis, and from the sides of the base to the soft palate as it passes into the pharynx. Beneath, a fold of membrane, termed the **frenum**, or bridle of the tongue, attaches the hinder part of the under surface to the lower jaw. But these attachments leave the upper surface, borders, and the front third of the lower surface free.

The tongue receives a rich supply of blood, and also an abundant nerve supply. The nerve fibres are derived from the fifth, ninth, and twelfth cerebral nerves (see par. 147). The first two are sensory nerves, and the last is the motor nerve of the tongue.

The mucous membrane of the tongue consists of an outer layer of epithelial cells, and of a vascular dermis rising up into processes or papillæ like the dermis of the skin. But the papillæ of the tongue are much larger and more distinct than in the skin, the epithelium covering them follows their outline and serves to throw them up. (Examine the upper surface of a friend's tongue with a lens.)

The papillæ of the tongue are of three kinds. (1) At the

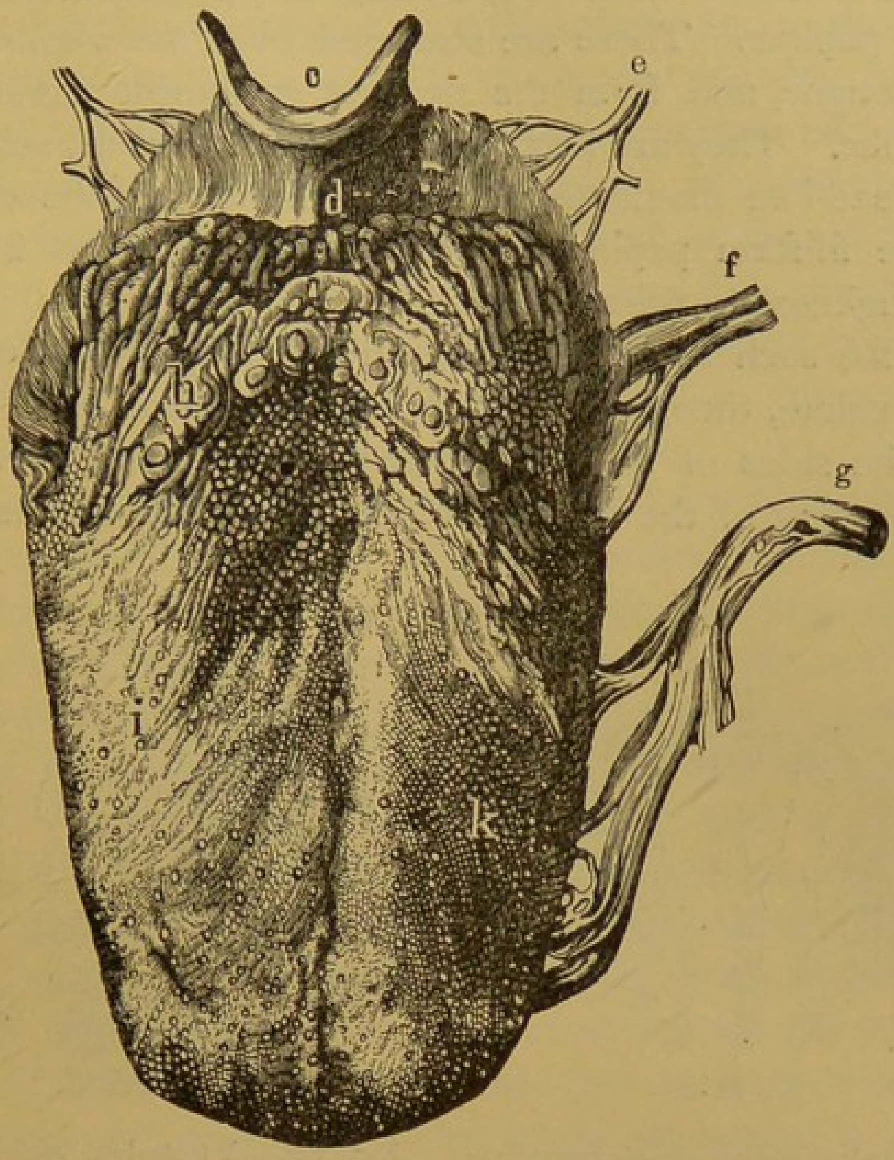



FIG. 143.—Upper surface of tongue. *d*, root of tongue passing to hyoid bone, *c*; *e*, branch of ninth cranial nerve (glossopharyngeal nerve); *f*, branch of twelfth cranial nerve to muscles of the tongue; *g*, branch of fifth cranial nerve (taste); *h*, circumvallate papillæ; *i*, fungiform papillæ; *k*, filiform papillæ.

back of the tongue are ten or twelve **circumvallate papillæ**, arranged in two rows in the form of a **V** with the point backward. These are the largest papillæ, $\frac{1}{15}$ to $\frac{1}{20}$ of an inch wide. Each circumvallate papilla is a roundish projection with a trench and wall (*vallum*) around it. The dermis part of it is formed of dense connective tissue supplied with blood-vessels and nerves, and this is covered above and around by stratified epithelium. (2) **Fungiform papillæ** are the second kind of papillæ. These are smaller than the circumvallate papillæ, are scattered over the surface of the tongue, but occur chiefly at the sides and towards the front. They are the shape of a puff-fungus, or club with a narrow base. (3) **Filiform papillæ** are the third kind of papillæ. These are scattered over the whole surface of the tongue, and form the smallest and most numerous of the papillæ. They are tiny, long, conical processes, sometimes with thread-like filaments. In such animals as the dog and cat these filiform papillæ are long recurved spines that give great roughness to the tongue.

Papillæ such as those found on the tongue also occur on the soft palate, though they are not so prominent.

At the sides of all the circumvallate papillæ, and at the sides of many of the fungiform papillæ, small bodies, called

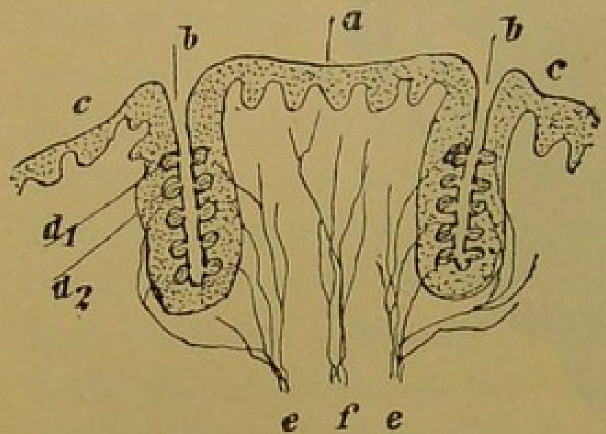



FIG. 144.—Vertical section of a circumvallate papilla and of taste-buds. *a*, the epithelial surface (dermis beneath is left plain); *b*, the surrounding trench; *c*, part of wall surrounding the papilla; $d_1$, $d_2$, taste-buds; *e*, *e*, nerves of taste proceeding to taste-buds; *f*, nerves of touch.

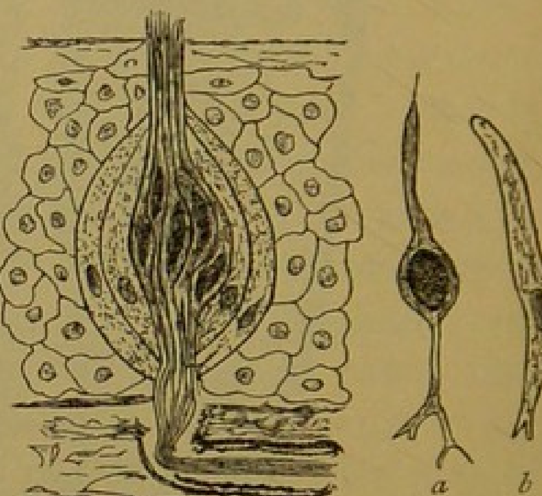



FIG. 145.—A taste-bud highly magnified. *a*, supporting cell; *b*, gustatory cell of same. (*From Gray's "Anatomy."*)

from their form and structure, **taste-buds**, are lodged in the epithelium. A few taste-buds are also found in the papillæ of the soft palate. Fig. 144 shows a section of a circumvallate papilla with the taste-buds in the epithelium of the trench round the papilla. The dense connective tissue of the dermis of the papilla is not indicated, but nerve fibres are shown, with branches proceeding to the taste-buds and branches towards the upper surface. The taste-buds are the parts specially concerned in the sensations of taste. When magnified, each taste-bud is seen to be a flask-shaped body composed of a number of cells arranged somewhat like the leaves of a bud, the cells being of two kinds, supporting cells outside and gustatory cells inside. The gustatory cells have slender hair-like processes that project into the trench around the papilla, and thus become exposed to the fluids in the mouth. To each inner cell of a taste-bud a fine filament from a branch of the ninth cranial nerve can be traced. The branch of the fifth cranial nerve passes chiefly to the front of the tongue, and, as taste sensations are here rather acute, this nerve and its terminals must also be concerned in the sense of taste.

The sensation of taste is brought about by vibrations of the molecules of substances in solution exciting the inner sense cells of a taste-bud, and this stimulation, transformed into a nervous impulse, is carried by nerve fibres to cells in the brain. The stimulation of these brain cells gives rise to the taste sensation, the sensation being referred to the part of the tongue affected. Taste sensations may be mixed with tactile sensations, as, when a sweet substance also feels rough. Only substances that will dissolve can be tasted — sugar, not sand; quinine, not powdered gypsum. Dry the tongue and put on its tip a little sugar. No sensation arises till the sugar dissolves. Properly speaking, there are only four kinds of taste— *bitter*, *sweet*, *salt*, and *acid*. The tip of the tongue is the most sensitive to sweets, the back to bitters. To show the delicacy of the sense, it is sufficient to say that 1 part of saccharine (sweet) can be tasted in 100,000 parts of water, that one part of quinine (bitter) can be tasted in 30,000 parts of water, and 1 part of sulphuric acid in 1000 parts of water.

Many sensations called tastes are mostly sensations of smell. The flavours of fruit, wine, meat, and other foods are really smells. Particles, or vapours, from these pass into the nostrils or into the pharynx, and from thence into the nose, where they are smelt.

Hence a bad cold in the nose destroys our enjoyment of the flavours of these articles, as well as the sensations of smell obtained through the outer nostrils, for the odorous particles cannot then reach the olfactory cells of the mucous membrane in the upper part of the nose owing to the thick mucus that covers it.

**161. The Nose and Smell.**—The organ of the sense of smell is the mucous membrane lining the upper part of the cavities of the nose, or, more accurately, certain cells lying in the mucous membrane of this part of the nasal cavities.

Each outer nostril leads into a large cavity or chamber above the roof of the mouth, the two nasal chambers being separated by a thin partition, which is formed, in front, of cartilage, and behind by the vomer bone that runs backward over the roof of the mouth. In front the nasal chambers ascend high between the orbits of the eye, and then, descending, terminate behind by two openings, called the **posterior nares.** These lead into the pharynx at the back of the mouth (Fig. 85). Below, each nasal chamber is separated from the mouth by the bony palate towards the front, and the soft palate behind. Above, each nasal chamber rises into a vault, which is separated from the bony cranium or brain-case by the perforated part towards the front, called the *cribriform plate* of the ethmoid bone. The whole internal surface of the nasal chambers is lined by mucous membrane, and, upon the outer wall of each chamber, the mucous membrane is spread over three delicate spongy bones arranged in scrolls one above another, the **inferior, middle,** and **superior** turbinal bones. (A sheep's head, sawn in half, shows most of the features of the nose described above.)

The mucous membrane of the *lower* part of the nasal chambers is covered by ciliated epithelial cells, as in other parts of the respiratory track. This mucous membrane is not connected with the sense of smell. Branches of the fifth cranial nerve pass from this part of the nasal mucous membrane.

The mucous membrane over the upper and middle turbinal bones, and on each side of the middle partition of the nose opposite to these bones, is the real olfactory mucous membrane.

It differs from the mucous membrane in the lower part of the nose, as it is thicker, and the outer walls are not ciliated. It receives nerve fibres from the first cranial nerve through the cribriform plate. These nerve fibres pass from the olfactory bulb (Fig. 136) as it rests on this plate, and their

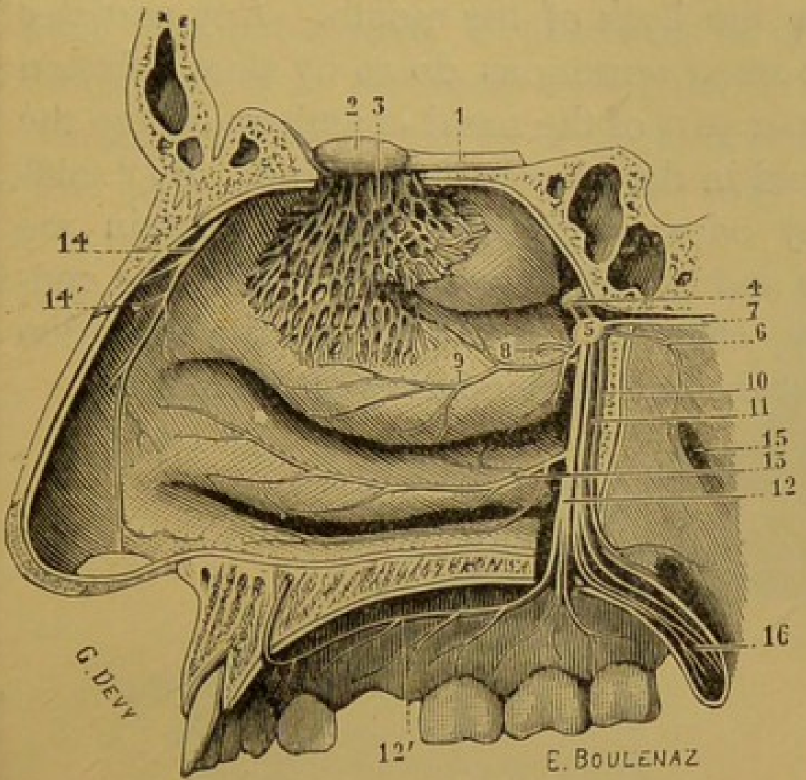



Fig. 146.—Wall of outer nasal cavity, showing the three turbinated bones covered by mucous membrane. 1, olfactory nerve in cranium; 2, olfactory bulb upon cribriform plate; 3, branches of olfactory nerve in nasal cavity; 5, a nerve ganglion with branches of the fifth cranial nerve below proceeding to lower part of nose and palate. Figures 8 and 9 on middle turbinated bone. (*From Testut's "Anatomie."*)

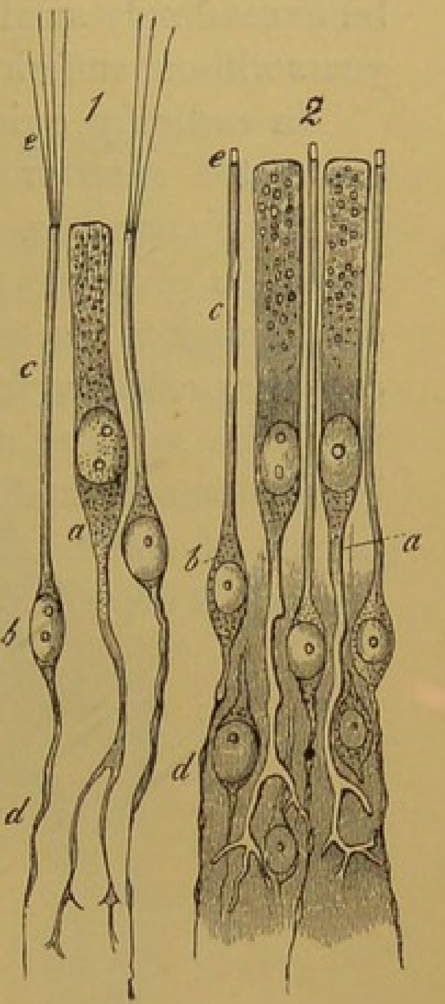



Fig. 147.—Cells and terminal nerve fibres of the olfactory region. (M. Schultze.) Highly magnified. 1, from the frog; 2, from man; *a*, epithelial cell, extending deeply into a ramified process; *b*, olfactory cells; *c*, their peripheral rods; *e*, their extremities, seen in 1 to be prolonged into fine hairs; *d*, their central filaments. (*From Quain's "Anatomy."*)

finest fibrils end in peculiar rod-shaped bipolar cells of the olfactory mucous membrane. These *olfactory* sense cells lie interposed between the columnar epithelial cells of the olfactory mucous membrane (Fig. 147). They are excited by the molecules of vapours, and this excitation causes a nerve impulse to pass on to the brain. All scents and smells are believed to be due to vapours, the odoriferous molecules of which must reach the olfactory cells in order to arouse a sensation. Substances which do not give off any vapour have no smell. The particles given off by many odorous [illegible]st be exceedingly small. A piece of musk will scent a roo[illegible] for years without suffering any loss of weight that can be estimated.

In ordinary quiet breathing, with the mouth shut, the air enters the anterior nares, and passes along the lower part of the nasal chambers to the back of the mouth. Any particles that then give rise to smell sensations do so by slow diffusion of the air into the upper part of the nasal chambers, where the olfactory cells are found in the mucous membrane. By "sniffing," the air and any odorous particles it may contain are brought more readily and speedily into contact with the end-organs of smell. The effect of a bad cold on the sensation of smell is described at the end of the preceding paragraph.

# CHAPTER XX.

## *THE EYE AND THE SENSE OF SIGHT.*

**162. Position and Protection of Eye.**—The eye lies in a bony cavity of the skull called the **orbit**, and is connected behind with the brain by a stalk, termed the **optic nerve.** The interior of the orbit is padded with fat, and its bony walls

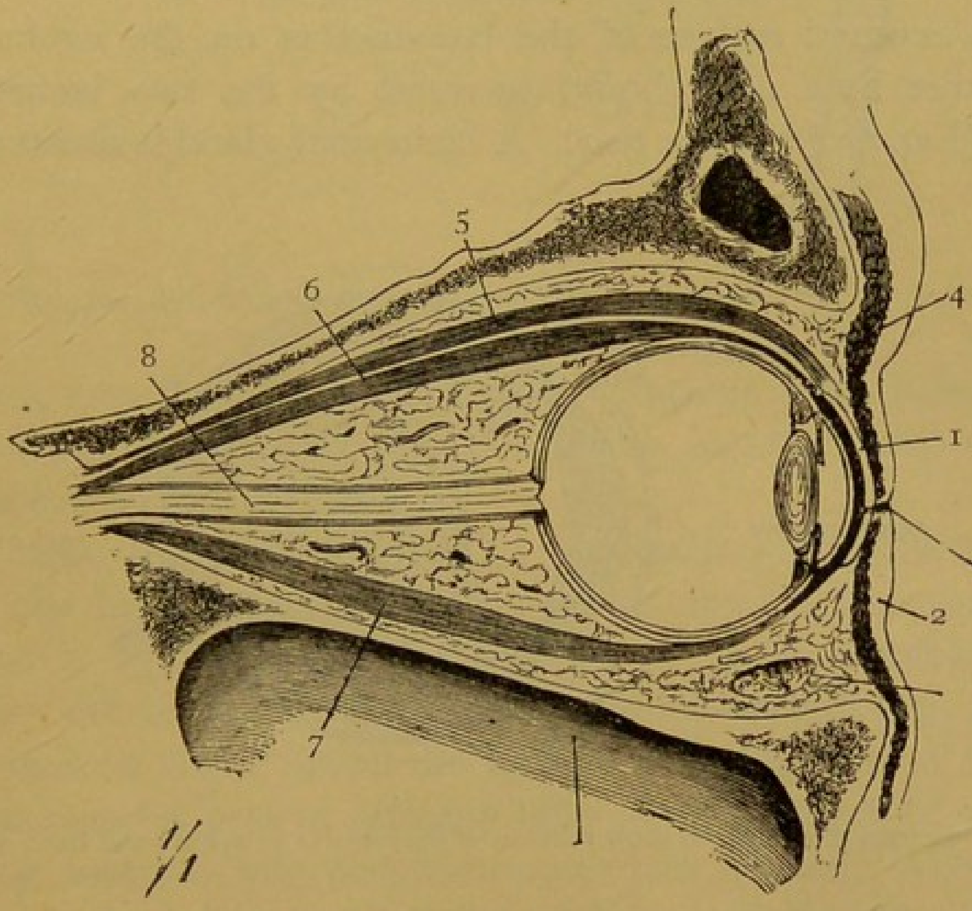



FIG. 148.—Section through the orbit of the eye and its contents. 1, upper eyelid; 2, lower eyelid; 3, chink between eyelids; 4, the orbicular muscle; 5, elevator muscle of upper lid; 6, superior rectus muscle of eyeball; 7, inferior rectus muscle; 8, optic nerve.

afford protection to the eyeball, except in front. The front of the eye is protected by the eyelids, which consist of fibrous and muscular tissue, covered outside by ordinary skin and internally by a moist mucous membrane, called the **conjunctiva.** Along the free edge of the lids are curved hairs called eyelashes, and these are kept moist by an oily secretion from tiny glands at the edge of the lids. Imbedded in the eyelids are circular muscular fibres, forming the **orbicular muscle**, that close the lids in sleep or on the approach of an object. A muscle in the upper lid raises it. Internally, the eyelids are lined with the conjunctiva, and at the back of the lids this is reflected on to the eyeball, and becoming attached to it forms a delicate transparent membrane over the front surface. The passage of the conjunctiva from lid to eyeball can be seen on pressing down the lower lid as far as possible. The conjunctival membrane is supplied with blood-vessels and nerves, so that it is very sensitive, as is learnt when a speck of dust falls upon it.

The exposed surface of the conjunctiva on the eyeball is kept moist by a salty liquid secreted by the two lachrymal glands (Lat. *lachryma*, a tear). A lachrymal gland is situated on

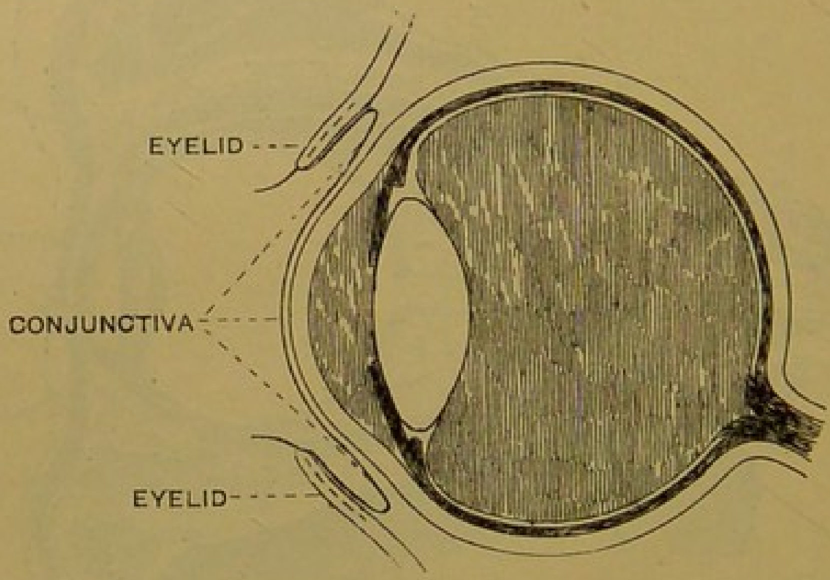



FIG. 149.—Section of eyeball to show relation of conjunctiva to eyelids and front of eye.

the outer side of each bony orbit, and this gland pours out its salty secretion through fine ducts on the inner surface of the upper lid, so that it spreads over the outer conjunctival surface of the eyeball. The chief function of this secretion is to wash and keep warm the front of the eye, and in this it is aided by the automatic blinking of the eye every few seconds. The water collects in the inner corner of each eye and passes thence into two small openings, the **puncta lachrymalia**, that lead into two short canals and then along a bony tube, the **nasal**

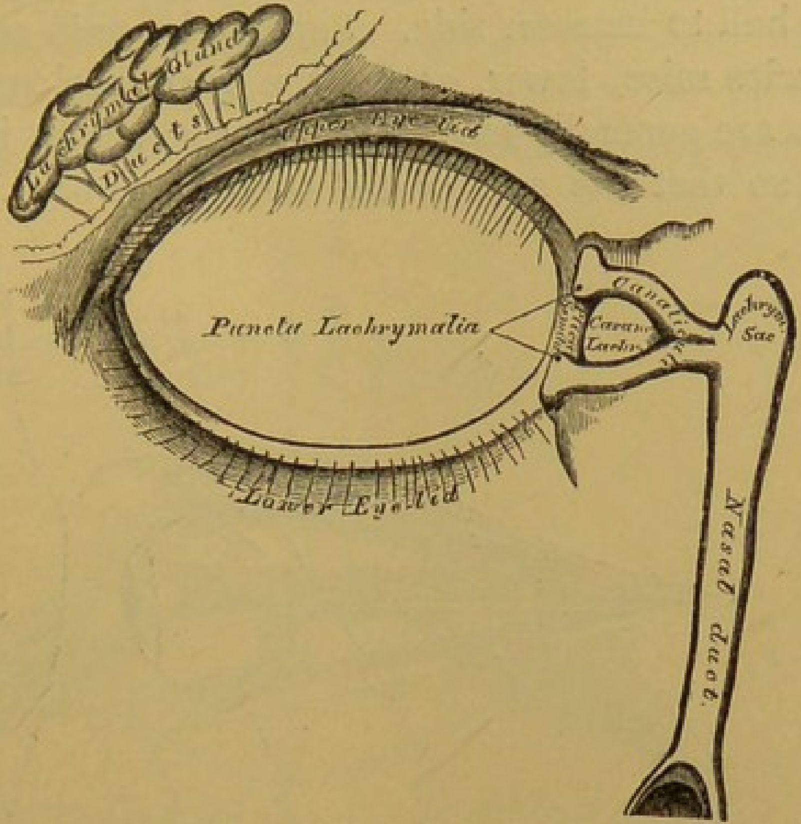



FIG. 150.—The lachrymal apparatus, right side. (*From Gray's "Anatomy."*)

**duct,** into the nostril (Fig. 85). Various sensations lead to an increased quantity of liquid being secreted, and this may overflow as tears.

**163. Movements of the Eyeball.**—With the head still we can by moving the eyeballs look upward, downward, and towards all sides. These movements of the eyeball in its socket are brought about by the separate or combined action of six muscles that connect the eyeball with the walls of the orbit. Four muscles pass in straight lines from the back of the orbit to be inserted into the front outer part of each eyeball—one above, one below, one on the outside and one on the inside, These four muscles being straight are termed **rectus muscles.** and are named, respectively, the superior rectus, the inferior rectus, the exterior rectus, and the interior rectus. The other two muscles of the eye bend in their course. and are called **oblique muscles.** The superior oblique muscle, arising behind, passes over the eye towards the front and forms a tendon that passes over a pulley and then turns backward to be attached to the outer side of the ball. The inferior oblique muscle springs from the lower part of the inner angle and passes below the ball to its outer side. Separately, or in combination, these muscles raise, lower, or turn the eye in various directions. Both eyes are generally moved at the same time in the same direction, so that the axes of the eyeballs remain parallel to

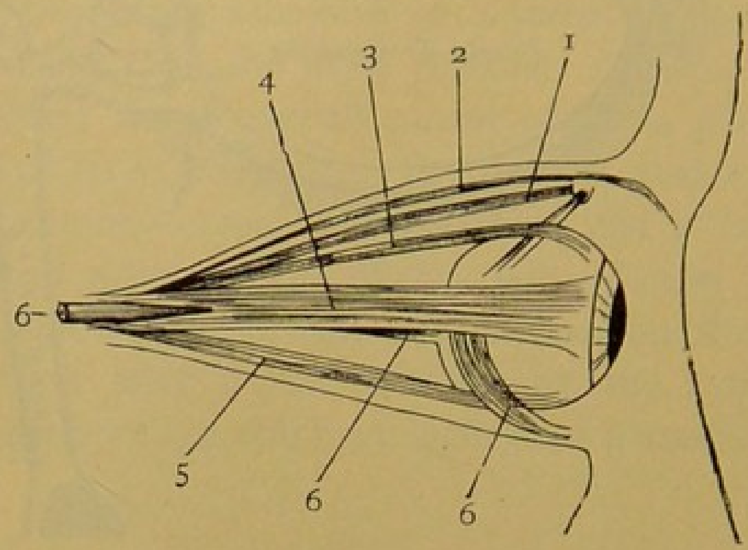



FIG. 151.—The muscles of the eye, diagrammatic. 1, the superior oblique muscle passing through a pulley to its insertion; 2, the elevator muscle of the eyelid; 3, the superior rectus muscle; 4, external rectus side muscle (the internal rectus not seen); 5, inferior rectus muscle, 6, 6, optic nerve.

each other, and when the object is near, the eyeballs are turned inwards to keep them steadily upon it. If the eye muscles are not properly balanced and co-ordinated in their action, *squinting* results, and an object appears double.

**164. Structure of the Eyeball.**—The eyeball when removed from the socket is seen to be a globe or sphere in general shape, but the front portion bulges and curves more strongly than the rest. When a section of the eyeball is made it is seen to be composed of three coats or tunics that lie over one another. These coats enclose two spaces or chambers that are occupied by transparent substances that fill up the eyeball.

**Coats of the Eye.**—The three coats of the eye from without inwards are—

(1) The sclerotic and cornea.
(2) The choroid, ciliary body, and iris.
(3) The retina.

The **sclerotic** is the dense fibrous coat that covers the hinder five-sixths of the globe, and appears as "the white of the eye." It is pierced behind by the optic nerve, while in front it is changed into a circular transparent portion that projects forward

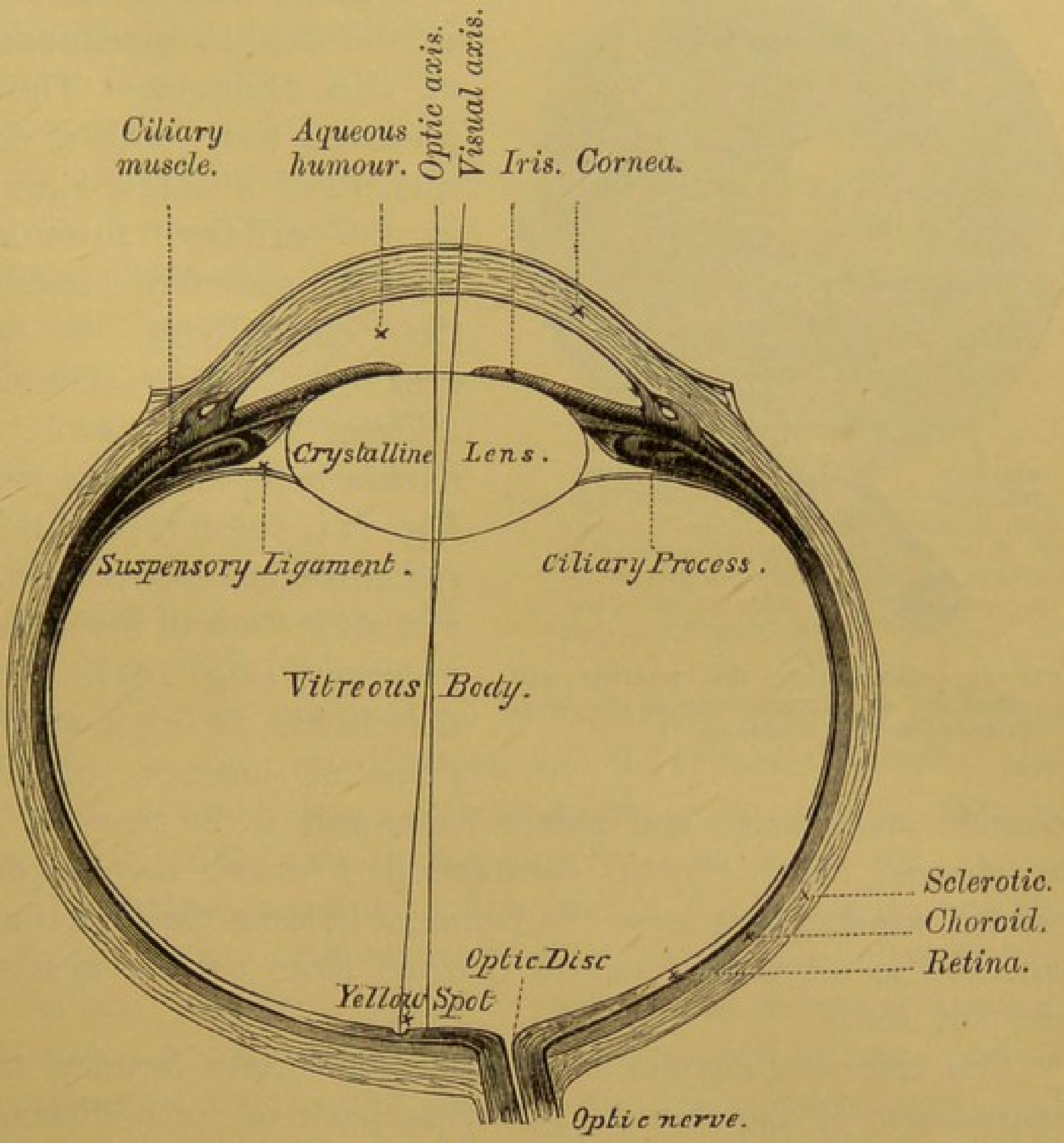



FIG. 152.—Horizontal section of the left eyeball. (*From Waller's "Human Physiology."*)

and is called the **cornea**. As already stated, the inner transparent membrane of the eyelid, the **conjunctiva**, is reflected over the cornea at the front surface of the eye.

The **choroid** is the second coat of the eye, and lines the inner surface of the sclerotic up to the edge of the cornea, where it leaves the outer coat and passes across the eye at some distance from the cornea to form the circular coloured curtain called the **iris.** The choroid is a dense structure of connective tissue, fine blood-vessels, and cells containing dark pigment. Just before passing into the iris in front its inner surface is thrown all round into a number of radiating folds or plaits. This fringe of folds is known as the **ciliary processes of the choroid.** These processes form, with a circular band of muscle known as the **ciliary muscle,** what is sometimes called the "ciliary body" of the eye. This ciliary muscle, thickest in front, forms a narrow band of muscle (see Fig. 153, where it is seen in section) that runs round the eyeball in front of the ciliary processes (Fig. 154). The muscle has its origin at the point of junction of the sclerotic and cornea, and passes backwards to be inserted in the choroid coat. By its contraction it draws the choroid forward, renders less tense the ligament holding the crystalline lens, and so allow this lens to become more convex in front (see par. 168).

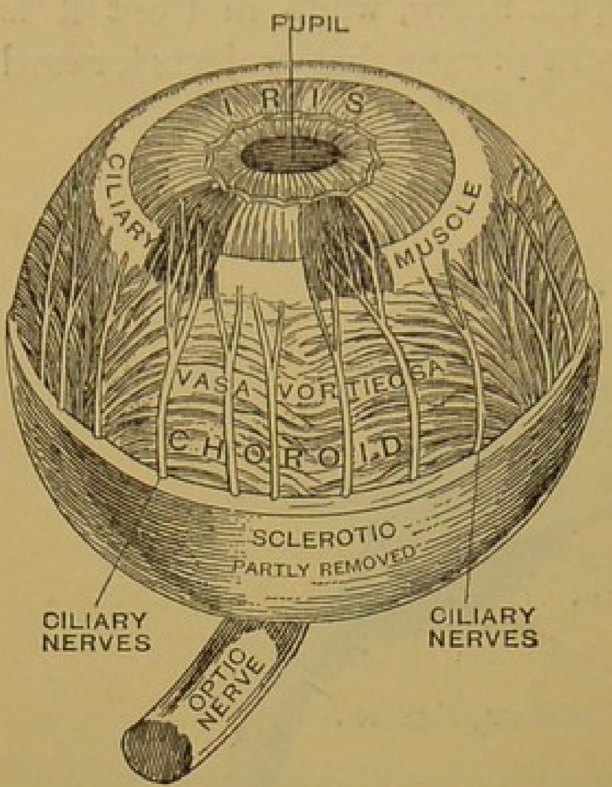



FIG. 153.—Illustrating the position and structure of certain parts of the eye. (*From Gray's "Anatomy."*)

The **iris** is a circular contractile flat curtain forming the continuation of the choroid, but lying back at some distance from the cornea. In the middle it is pierced with a round hole, called the **pupil,** for the admission of light. At its inner edge it is united to the choroid coat. Its tissues consist in part of unstriped muscular fibres. One set of these muscular fibres is arranged circularly round the pupil, so that contraction of these makes the pupil smaller and relaxation makes it larger. (Muscular fibres arranged in a ring form what is called a sphincter muscle.) Another set of fibres radiate from within outwards, and by their contraction aid in dilating the pupil. The iris has thus the function of a "stop," or diaphragm, placed before the lens in a photographer's camera, which regulates the amount of light admitted through the opening. The iris contains pigment cells, the amount and nature of the pigment determining the "colour of the eye." The iris is supplied richly with blood-vessels and nerves (the ciliary nerves, Fig. 153), but its action under light, by which the size of the pupil is diminished in a strong light and increased in a dim light, is not due to voluntary impulses. This action is a **reflex** action (par. 154). On standing in a dark corner with the eyes turned from the light, the pupils will be seen enlarged when examined in a hand mirror. If now the eyes be brought into a bright light, the sphincter of the iris contracts, the iris expands inwards, and the pupil becomes less. A strong light is dazzling at first, as it requires a little time for the muscles of the iris to act.

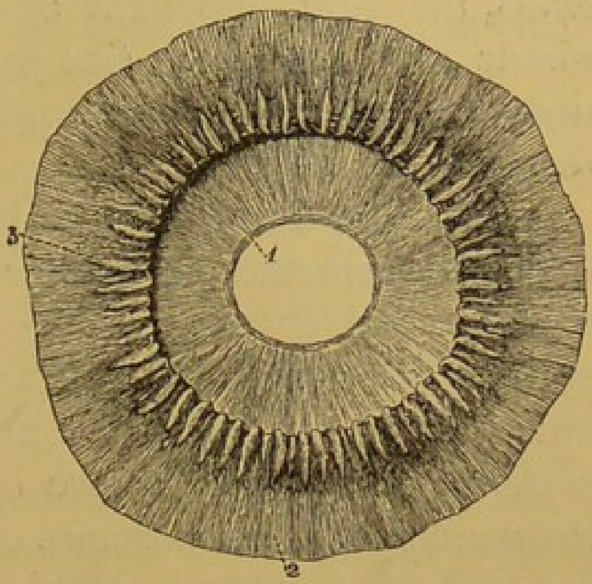



FIG. 154.—Ciliary processes and iris as seen from behind. Twice the natural size. 1, posterior surface of the iris, with the sphincter muscle of the pupil; 2, anterior part of the choroid coat; 3, ciliary processes. (*From Quain's "Anatomy."*)

The **retina** forms the inner coat of the eye lying on the choroid, but only reaching forward as far as the beginning of the ciliary processes, where it ends in an irregular border, termed the **ora serrata.** It may be regarded in great part as an expansion of the optic nerve which pierces the sclerotic and choroid coats at the back of the eyeball a little to the nasal side of the middle of the ball, the point of entrance being termed the **optic disc.** The retina is the most important part of the eye, as it receives the rays of light that pass through certain transparent media in front before they form upon it the images of outside objects in a way shortly to be explained. To the naked eye it appears as a whitish pulpy sheet, extending from the optic nerve nearly two-thirds forward. Exactly in the centre at the back, corresponding to the axis of the eye, is an oval area called the **yellow spot** of the retina, and in the centre of this there is a small depression. Though the retina is only about $\frac{1}{50}$ of an inch thick, yet in a microscopical section it can be seen to consist of several distinct but related layers, the most important of which is the layer containing minute rods and cones (see par. 159). A small artery passes along the centre of the optic nerve to form a network of blood-vessels in the retina.

**165. The Chambers of the Eye and their Contents.**—The iris separates the interior of the eyeball into two unequal spaces called chambers. The small anterior chamber of the eye lies between the cornea and the iris, and is filled with a little watery liquid called the **aqueous humour.** The large posterior chamber of the eye behind the iris is occupied by a transparent jelly-like substance enclosed in a delicate membrane, the hyaloid membrane, called the **vitreous humour.** The vitreous humour thus lies for the most part against the retina, but it is hollowed out in front to receive a double convex lens, termed the **crystalline lens** of the eye. The crystalline lens thus lies opposite to and behind the iris and its pupil, and its hinder surface fits into the depression of the vitreous humour just mentioned.

The crystalline lens is a soft, solid, transparent, and elastic body, enclosed in a transparent elastic capsule. It has two surfaces of unequal curvature, being flatter in front than behind. At the edge of the lens the delicate hyaloid membrane comes forward, splits into two layers, one of which passes behind the lens, and the other in front to fuse with the capsule of the lens (see Fig. 158). The anterior layer is known as the **suspensory ligament** of the lens. The suspensory ligament of the lens is thus a section of the hyaline membrane of the vitreous body, and passes on to the front of the lens, where, owing to its usual tense condition, it keeps the lens flattened by the pressure it exerts upon it.

**166. Dissection of the Eye.**—Obtain from the butcher two or three fresh bullock's or sheep's eyes. The eye of the bullock, being larger, is most suited for the ordinary student. Cut away the fat from one of the eyes, and notice the short stalk left behind. This is the optic nerve. Notice also what looks like a nearly complete sheath of muscle. It can be separated into six distinct muscles. They were cut short when the eye was removed from its orbit. Each is attached by a short tendon to the outer coat of the eye towards the front. Note the transparent cornea in front and its continuation behind into the white sclerotic.

With a sharp razor cut an eye into front and back halves. A large quantity of a jelly-like substance, the vitreous humour, escapes. Note in the back half the greyish-white pulpy inner lining that forms the inner coat of the great part of the eye. It peels off readily, except where it is united with the optic nerve. Peel off the retina, and notice the choroid forming the dark lining of the eye. The light passing in at the cornea through the crystalline lens, vitreous humour, and retina, is absorbed by the dark pigment in the choroid, so that reflection is prevented. Peel away the choroid, and note the strong sclerotic. Take the front half, and notice the ciliary processes and the lens in its capsule. Remove the lens, and note its form and elasticity. In front of the lens lies the circular curtain called the iris, which we thus see from behind.

Take another eye, and push the point of a pair of sharp scissors through the edge of the cornea. Then cut round the edge of the cornea and remove it, noting the few drops of aqueous humour that escape. Examine the cornea, and note its transparency. Now look at the iris with its pupil from the front. In the ox's eye the pupil is a slit, and not a round hole as in man. Light passes through the pupil to the crystalline lens, but the pigment in the iris prevents any reaching the lens at the sides. From the pupil make two cuts inwards a little distance apart in the iris, and turn the narrow strip back. You will thus see that the iris is a continuation of the choroid coat, joining with it where the outer sclerotic passes into the cornea. Find also the black fringe of ciliary processes behind the outer edge of the lens and the transparent suspensory ligament passing from the edge of the processes to be attached to the front of the lens. Cut through the suspensory ligament on each side, and gently squeeze what is left of the eye. The lens passes out, leaving the impression of its form on the vitreous humour that remains. Notice the shape and transparency of the lens, its greater convexity behind than in front, and its magnifying effect on some print over which it is held. With a penknife raise the sclerotic where it joins the cornea, and then cut loose a flap about half an inch wide and a little longer. Turn it back, and note a narrow, pale band lying on the black choroid. This is the ciliary muscle (see Fig. 153). The vitreous humour may now be turned out, and the retina separated from the choroid, except at the point where the nerve enters the eye. The choroid may then be separated from the sclerotic as before.

**167. Formation of Images by Lenses and by the Eye.**—A double convex lens is a curved body of glass or other transparent substance, with its faces regularly curved out so as to be thickest in the middle and thinnest at its circumference. Its appearance when seen in section is shown in Fig. 155. In a

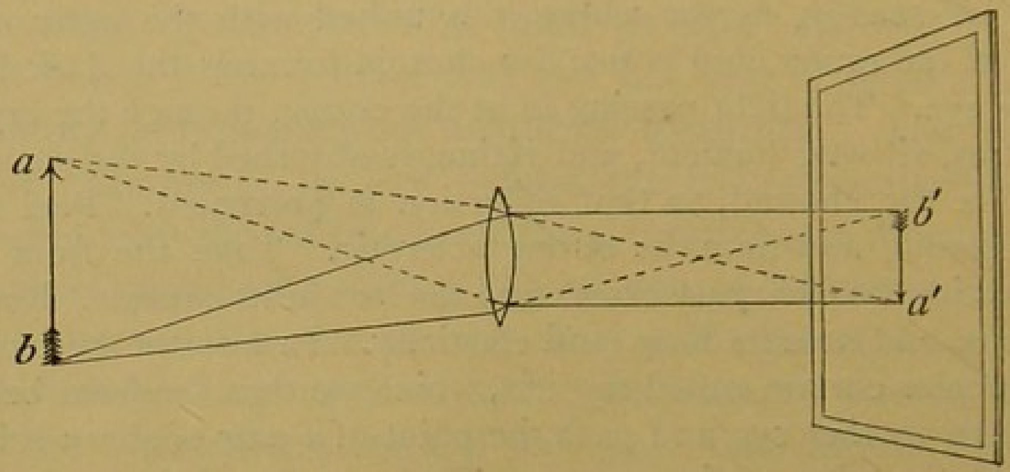



FIG. 155.—Illustrating the formation of an inverted image by a convex lens. Only two rays from each end of the object are represented, for the sake of simplifying the illustration.

dark room hold a lighted candle a few feet in front of a double convex lens, and on the other side place a sheet of paper or ground-glass to form a screen, then at some short distance behind a clear inverted image of the flame will be seen on the screen. Lines of light, called rays, from each and every point of the candle-flame are then said to be brought to a conjugate point or focus on the screen. The inversion of the image is due to the refraction or bending of the rays by the lens, so that they cross before the image is formed. Bring the candle-flame nearer to the lens and the image on the screen becomes indistinct. A clear image, larger than the first, however, will be obtained by moving the screen further from the lens. Now move the candle-flame further from the lens, and it will be found that to get a clear image the screen must be nearer to the lens than at first. In this case, too, the image will be smaller. We thus learn that—

(1) *A convex lens will form an inverted image of a luminous object;* (2) *the nearer an object is to a lens, the greater must be the distance of the screen to receive a clear image, and vice versâ.*

Now, obtain a convex lens of the same size, but thicker in the middle, *i.e.* with more convex surfaces. Repeat the above experiments, and notice that the distance behind the lens at which the distinct image is formed is less than in the preceding experiments with the same distance of the candle. This is because such a lens is stronger than one whose convexity is less, that is, it exerts a greater bending or refractive power on the light rays. We may thus learn that—the more convex a lens is, the shorter is the distance behind at which the sharp image of an object is produced.

In daylight, rays of light are reflected from every point of an object in all directions, for each object in the light is illuminated by receiving, either directly or indirectly, sunlight upon it. An arrow or pencil, for example, gives off such reflected rays, but we

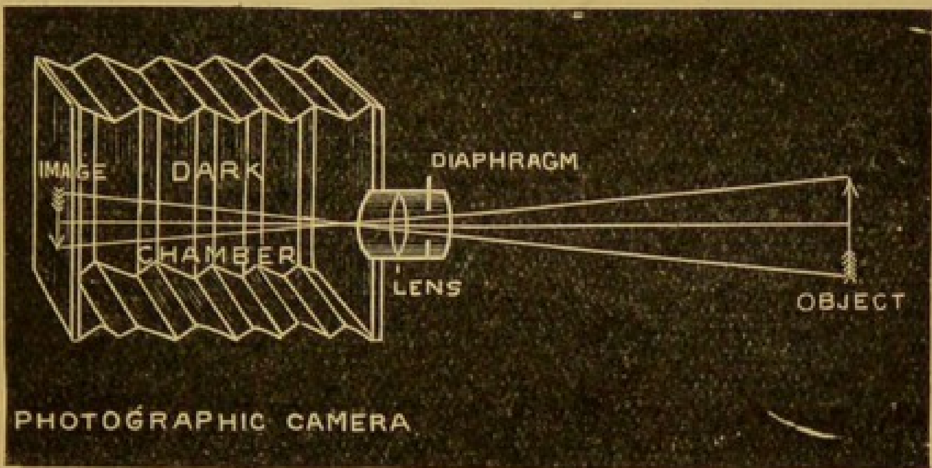



FIG. 156.—Formation of an inverted image on the screen at the back of the dark chamber of a camera. (*From Paul's "Domestic Economy."*)

cannot see the image formed by a lens of such an object, if the screen itself is in the light. We can arrange, however, to have the screen in a **camera obscura**, or dark chamber. This is the principle of a photographer's camera. It consists essentially of a box blackened inside, fitted with a convex lens placed in a movable tube in front, and having a movable ground-glass screen behind. A diaphragm, or stop, in front of the lens cuts off the side rays so that only those passing through the centre of the lens pass on.

If an object is placed in front, and the distance of the screen from the lens properly adjusted, a real inverted image of the object is formed on the screen. When this image is properly focussed the photographer replaces the screen by a sensitive plate, and then allows the sunlight reflected from the object to imprint a picture of it on the plate.

It will now be understood how the eye forms inverted images of external objects on the retina as a screen, and how the retinal screen is at the back of a darkened chamber just as the screen of the photographer. The image is formed by the refractive action

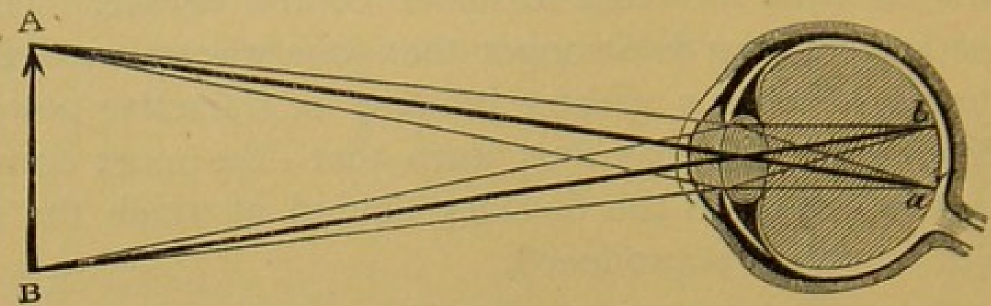



FIG. 157.—Formation of the image of external objects by the crystalline lens on the retina. (*From Ganot's "Physics."*)

of the crystalline lens, and, to some extent, by the cornea and the humours of the eye. If we remove the hinder part of the sclerotic from a fresh bullock's eye, and then fix the eye in a tube blackened inside, we shall be able to see, on directing the cornea to a window, inverted pictures of external objects.

In the eye, too, the iris plays the part of the "stop" of the photographer; thus regulating the amount of light entering the eye. The rays passing through the edge of a lens do not come exactly to the same focus as those passing through the centre, and the nearer the object is the more of these side rays may be cut off to get the image clearest. Watch another person's pupil. Get him to look at a distant object, and then at a near one, and notice the pupil becomes smaller as the near object is viewed. Shade the eye of a person with your hands, and notice the size of the pupil. Remove the hands, and let a strong light fall on the eye, when the pupil again becomes smaller. The pupil, therefore, becomes small (1) when the eye is directed to a near object, (2) when the light is strong. The pupil dilates (1) when the eye is directed to a distant object, (2) when the light is feeble. The change in the size of the pupil is brought about by the double set of muscle fibres in the iris (par. 164).

There remains the question of how the eye forms images of both near and distant objects. The photographer can alter the distance between the screen and the refracting lens, but this cannot occur in the eyeball. There must, however, be some means of adjusting the eye for vision at different distances.

**168. Accommodation.**—The power by which the eye is enabled to form distinct images on the retina of both distant and near objects is called "the power of accommodation." The **need** for accommodation is evident when we consider the mode in which images of objects at various distances are formed, and when we remember that we cannot see distinctly both a near and a distant object at the same time. In the normal eye at rest it is accommodated for distant objects, the rays from which are sensibly parallel. This is proved by the fact that such objects are seen without any effort quite clearly. But for distances less than seventy yards, an effort of accommodation is needed. How is this accommodation effected? It is not by altering the position of the retina, as the globe of the eye has been proved not to alter its shape. It is not by altering the curvature of the cornea, as was once thought, for the eye can be accommodated under water, which has practically the same refractive power as the cornea. It has been definitely proved that the anterior surface of the crystalline lens undergoes a change of curvature when looking at near objects, the increased curvature being necessarily accompanied by increased refractive power.

The change in the anterior surface of the crystalline lens is brought about by the action of the ciliary muscle. When the eye is in the condition of rest or relaxed accommodation, the lens is kept somewhat flattened in front by the tension of the suspensory ligament or zonule of Zinn, which passes forward all round from the ciliary processes of the choroid to its attachment to the margin of the lens. The ciliary muscle springs from a fixed point at the junction of the cornea and sclerotic, and its smooth fibres pass back to be inserted upon the ciliary and front part of the choroid, so that its contraction pulls forward the movable ciliary processes and choroid (which is but loosely attached to the sclerotic), and thus slackens the suspensory ligament. This lessens the tension of the ligament on the anterior surface of the lens, so that it then bulges forward and becomes more convex in virtue of its own elasticity.

Various experiments show that this explanation is correct. Thus, if the point of a needle be passed through the sclerotic into the choroid of an eye, it is noticed that when the ciliary muscle is stimulated the eye end of the needle moves backward, and, therefore, the point in the choroid moves forward.

Stimulation of the ciliary nerves, branches from which pass

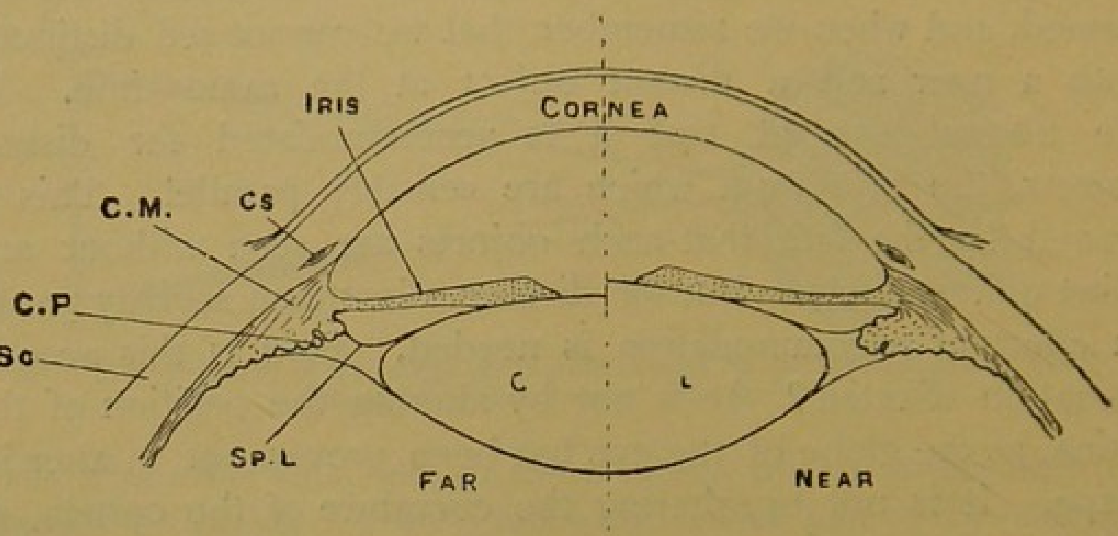



FIG. 158.—Diagram to illustrate accommodation. On one side the form of the lens is shown, when at rest, viewing distant objects; on the other side its form when accommodated for near objects. Sc, sclerotic; C.P., ciliary processes; C.M., ciliary muscle; Cs, canal of Schlemm; SP.L., suspensory ligament; CL, crystalline lens.

to the ciliary muscle, has been observed to lead to forward movement of the choroid and bulging of the lens. Accommodation for near objects is associated with convergence of the eyes upon the object viewed, and with movements of the iris that diminish the size of the pupil.

**169. Structure and Functions of the Retina.**—The retina, as already explained, appears as an expansion of the optic nerve. In a section examined under a high power of the microscope, although it is but $\frac{1}{50}$ of an inch in thickness, ten different layers may be made out in this thin coat (Fig. 160). It consists essentially of the terminal fibres of this nerve, together with various nerve cells, and certain rod-and-cone cells, a kind of connection being formed by interlacing fibrils from one element to another. The layer of nerve fibres is at the inner surface, that is, next to the vitreous humour, while the layer of rods and cones comes next to the choroid coat, from which it is separated by a thin layer of pigment cells. The nervous elements of the retina are bound together for the most part by a supporting framework, composed of what are known as the radiating fibres of Müller.

Various facts and experiments prove that the essential part

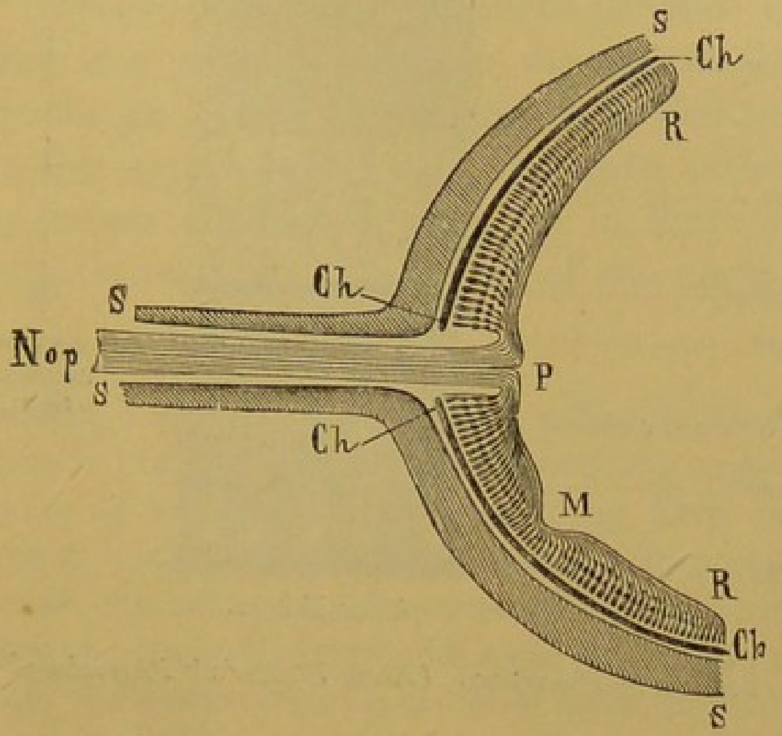



FIG. 159.—Diagrammatic section to show how the retina is formed as a thin expansion of the optic nerve, and how the fibres of the optic nerve pass backwards to be connected with the rods and cones of the retina that lie next the choroid coat. *Ch*, choroid; S, sclerotic; R, retina; *Nop*, optic nerve; P, point of entrance of optic nerve, blind spot; M, yellow spot of retina.

of the retina is the layer of rod-and-cone cells near the choroid, as the sensation of light cannot be excited without these. The rods are the more numerous, and consist of two different parts, and each has a fine process tapering inwards. The cones are flasked-shaped cells, with the narrow end pointing to the choroid.

Two parts of the retina need special notice, owing to the differences of structure at these parts. The fibres of the optic nerve enter through the sclerotic and choroid coats, not in the middle of the eye, but a little to the inner or nasal side, and then spread out in a thin layer next to the vitreous humour. At this point, the **optic disc** (Figs. 152 and 159), there can be no rods and cones. Light falling on this spot fails to arouse any sensation. It is, therefore, called the **blind spot** of the eye. We are not usually aware of this spot as the eyes are in

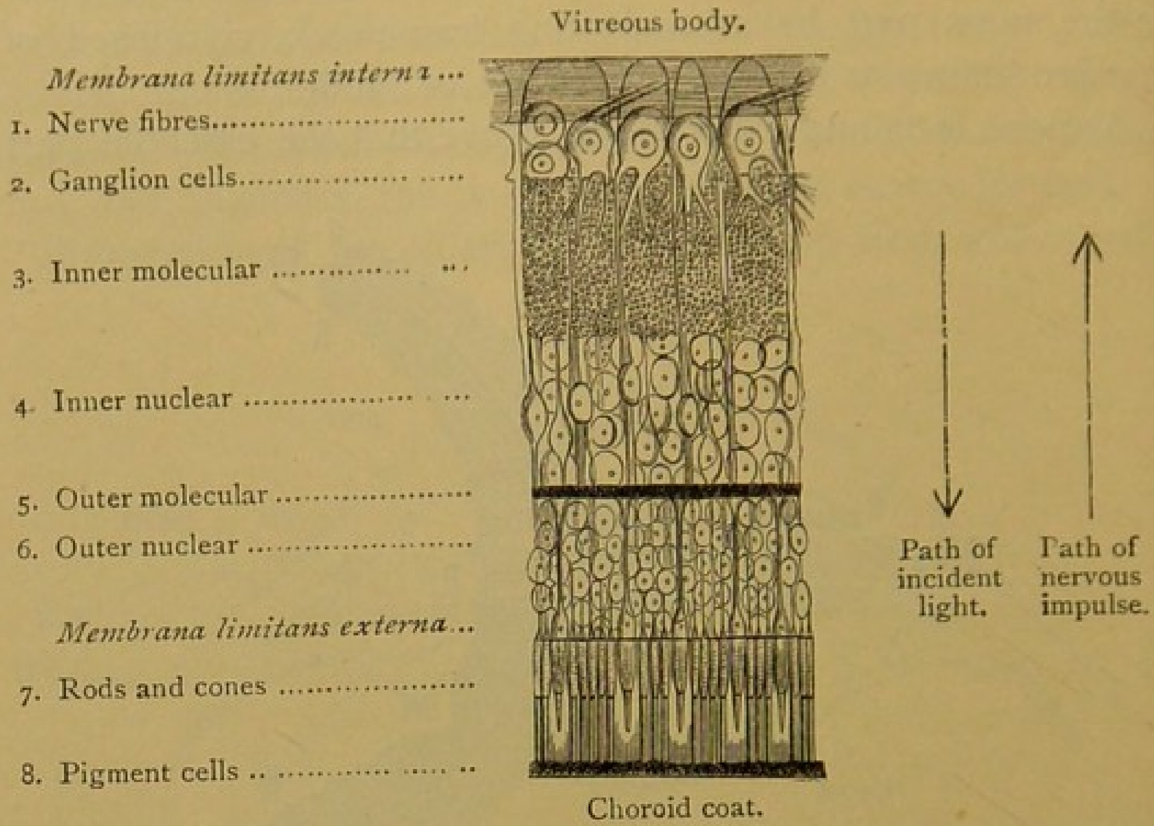



FIG. 160.—The retina. (*From Waller's "Physiology."*)

almost constant motion, but a simple experiment will show its existence.

Make two letters, or a spot and a cross, on a sheet of paper about $2\frac{1}{2}$ inches apart, and then hold it about 10 or 12 inches from the face. Close the left eye and look steadfastly

at the dot. The cross will also be seen. Now move the paper towards the face, and, at a certain distance, the cross disappears. On moving closer it reappears. It can be shown that in the position where the cross disappears its image falls on the area where the optic nerve enters. The fibres of the optic nerve are not, therefore, acted on directly by light.

The **yellow spot (fovea centralis)** is a small oval pit in the retina at the centre of the back of the eye. Here all the layers of the retina except the rods and cones are greatly thinned down, cones being the most numerous. At the very centre of this spot cones only are present. At the yellow spot vision is most distinct, and we are constantly moving the eyes to bring objects on this spot, and thus get the clearest image. It thus appears that, although the light first meets the nerve fibres in the retina, it is the rods and cones, and in man the cones in particular, that are the parts stimulated by light, and these then affect the fibres of the optic nerve, so that afferent impulses are set up that travel to the brain, and there produce visual sensations. Something similar occurs in the organs of sense and smell, where we have rod-shaped cells with delicate processes that receive the impressions set up, and then transmit them to the sensory nerves concerned, although in these sense-organs the rod-like cells are at the outer end of the nerve fibres, as it were.

**170. Some Visual Sensations.**—The duration of a luminous sensation is greater than that of the exciting cause or stimulus. The impression of an instantaneous lightning flash remains after the flash is past. It has been found that an impression remains about one-tenth of a second. Hence an ascending rocket produces the impression of a trail of light; and if a glowing rope-end be rapidly whirled we get the sensation of a circle of light, provided the circle is completed in less than one-tenth of a second. If a succession of pictures be shown upon a screen at such a rate that the image of a new one appears while that of the preceding one remains without interruption, objects will appear to go through various consecutive motions. We may thus see a boat-race or firemen extinguishing a conflagration true to life. This is the principle of the well-known *cinematograph*.

If one looks at a bright light after being in the dark a short time, and then closes the eyes, a **positive after image** of the light persists for a short time. On looking steadily at a black object on a white sheet for a short time, and then turning the eye to a white wall, we see a white patch on a greyish ground. This is a **negative after image,** due to the quicker excitability of the parts of the retina previously rested. Other instances of similar phenomena may be easily found, and they are most noticeable after rising in the morning. Especially interesting are certain **colour after images,** all of which are due to the fatigue of the retina for one portion of white light. It will be remembered that white light can be shown by a prism to consists of seven colours—red, orange, yellow, green, blue, indigo, and violet. Look intently at a bright-red wafer or piece of red paper lying on a white sheet until the eyes feel tired. Then remove the wafer, or look away at some other white surface. A green spot of the same shape as the red one appears. The explanation is that the retina became fatigued to red rays, and when this colour was removed the red rays from the white surface were not perceived by the fatigued part of the retina. The mixture of other colours in the white light were perceived, and produced the sensation of bluish green. **Green** and **red** are said to be complementary colours, and together they produce the sensation of white. Yellow and blue, green and purple, are other complementary colours. When the retina is fatigued for any of these, the colour of the after image will always be its complementary colour.

Some people are more or less incapable of properly distinguishing between certain colours, so that they are said to be more or less **colour blind.** Thus some people cannot distinguish between red and green. In other cases violet and yellow appear the same. In a few cases there is inability to perceive any kind of colour differences in objects—only differences of light and shade.

We have learnt that the images formed on the retina are inverted and that the right and left sides are transposed. But we see objects in their proper position. Our earliest experiences, and perhaps hereditary disposition, teach us to refer impressions on the upper part of the retina to the lower parts of visible objects and *vice versâ*, while impressions received on the right side of the retina are referred to the left side of objects and *vice versâ*.

**171. Distance of Distinct Vision—Short Sight and Long Sight.**—When an object is placed nearer to an ordinary eye than 5 inches it is too near for accommodation, for the rays of light are too divergent to be brought to a focus on the retina. Hence, in a normal eye accommodation occurs between an infinite distance, the remote point, and 4 or 5 inches, the near point. As age advances the near point gets further away, owing to the power of accommodating becoming less in consequence of the lens growing less elastic and the ciliary muscle becoming weaker. Near objects are then seen less distinctly, a book being held further and further from the eye. This defect in old people is called **presbyopia.** This kind of long-sighted eye must be distinguished from that due to the eyeball being unusually short.

The luminous rays from all objects beyond 70 yards' distance are virtually parallel. In a normal eye parallel rays are focussed on the retina without any effort. In viewing nearer objects we become conscious of an effort, especially after the distance becomes less than 20 feet, due to the contraction of the ciliary muscle in accommodating. A normal eye is said to be **emmetropic**, or in measure.

In a **myopic** eye distant objects are indistinctly seen, and objects nearer than 5 inches are plainly visible. Such persons are said to be "short-sighted." The eyeball is too long—its accommodation being normal—so that distant objects are brought to a

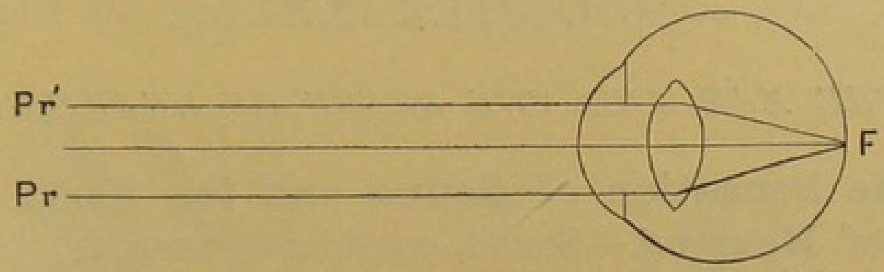



FIG. 161.—Emmetropic or normal eye. Parallel rays focussed on retina.

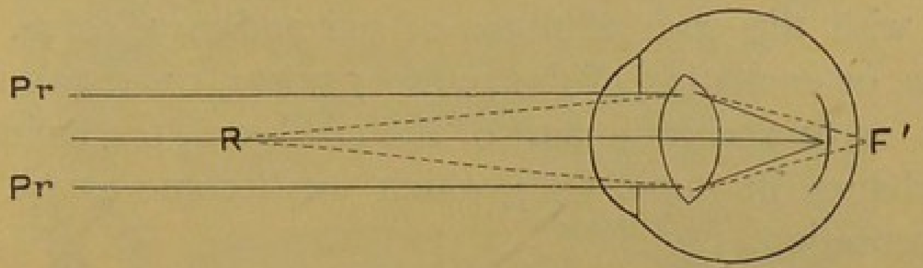



FIG. 162.—Myopic or short-sighted eye. Parallel rays focussed in front of retina. R, remote point of distinct vision, from which divergent rays are focussed on the retina.

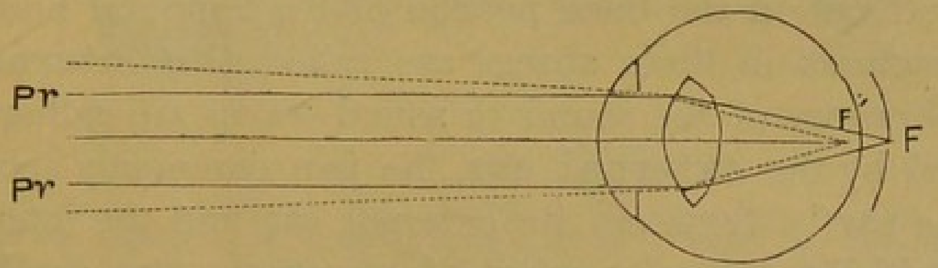



FIG. 163.—Hypermetropic or long-sighted eye. Parallel rays focussed behind the retina. Convergent rays focussed on retina.

focus in front of the retina. In a **hypermetropic** eye the eyeball is too short, near objects cannot be distinctly seen, and the rays from distant objects are brought to a focus behind the retina unless accommodation is used. Such persons are said to be "long-sighted." Spectacles with scattering or diverging lenses (biconcave) are used to remedy **myopia**, or short-sight; converging or convex lenses are used to remedy **hypermetropia**, or long-sight.

# CHAPTER XXI.

## *THE EAR AND THE SENSE OF HEARING.*

**172. The Sensation of Sound and the Parts of the Organ of Hearing.**—Sound, considered apart from the ear, consists of vibrations of air, and such vibrations of the air, if not too rapid nor too slow, may reach certain cells connected with the ends of fibres of the auditory nerve. This stimulus, or excitation of the auditory nerve, causes an impulse to pass on to a certain part of the cerebrum, producing there a disturbance in nerve cells, which we become aware of as a sound sensation.

The sensory cells connected with the auditory nerve endings lie away from the surface of the body in spaces hollowed out in the thick portion of the temporal bones, and the structures in these spaces are called **the internal ear**. The vibrations of the sound or sound waves are gathered and received by the **external ear**, the part commonly spoken of as "the ear." Between the external ear and the internal ear is a **middle ear**, a number of structures that conduct the sound to the **internal ear.** We, therefore, distinguish three parts of the organ of hearing, the external ear, the middle ear, and the internal ear.

**173. The External Ear.**—The external ear consists of an irregular plate of cartilage covered by skin, and of a passage about 1¼ inch long, called the **auditory canal**, or **external auditory meatus.** This canal (meatus) has, in its outer part, a number of modified sweat glands, the **ceruminous glands**, that secrete cerumen or wax. Across the inner end of the auditory canal there lies a membranous partition called the tympanic membrane, or ear-drum.

**174. The Middle Ear, or Tympanum.**—The middle ear, or tympanum, is a cavity, lined by mucous membrane, in the dense portion of the temporal bone of the skull. As just stated, it is separated from the outer ear by the tympanic membrane. This is an almost circular fibrous membrane, about $\frac{1}{3}$ inch in diameter, which is attached at its circumference round the end of the external auditory canal. Above,

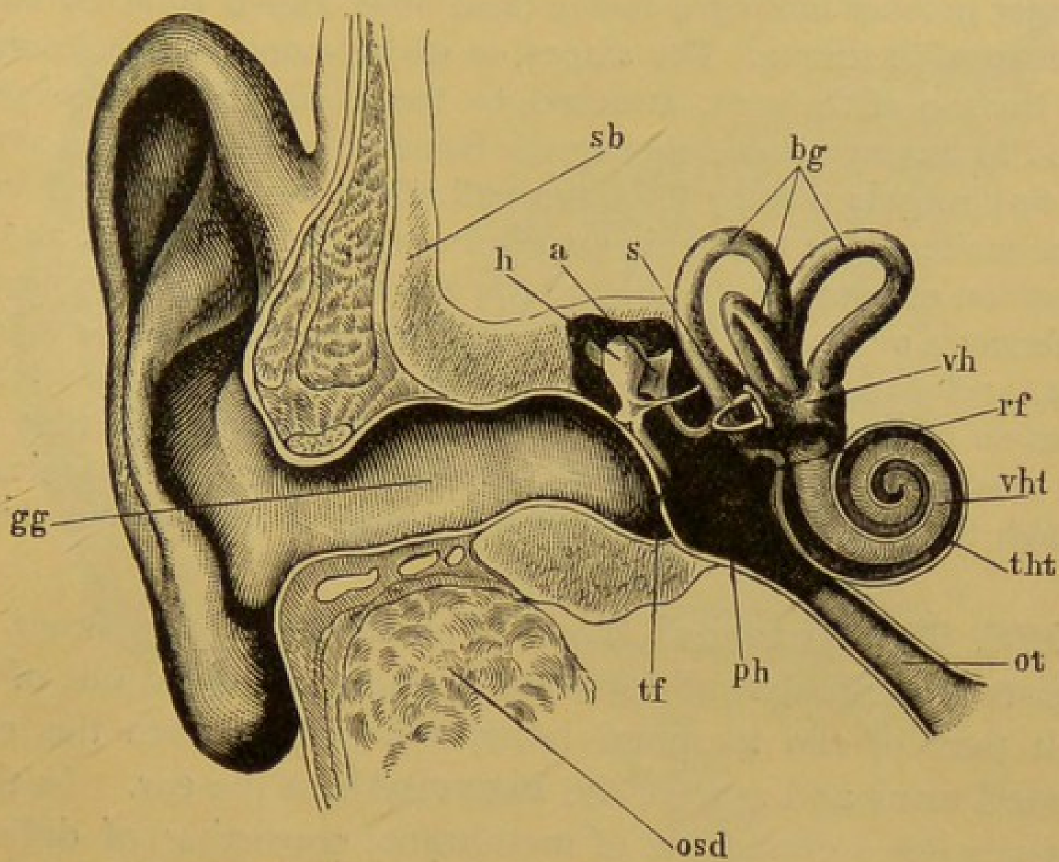



FIG. 164.—Outer ear, middle ear, and parts of the inner ear. *gg*, external auditory meatus; *tf*, membrane of tympanum; *ph*, cavity of middle ear or tympanum; *h*, hammer; *a*, anvil; *s*, stirrup with foot-plate against fenestra ovalis; *bg*, bony semicircular canals; *vh*, vestibule; *vht*, scala vestibuli of cochlea; *tht*, scala tympani of cochlea; *rf*, fenestra rotunda; *ot*, Eustachian tube; *osd*, bone in section.

the tympanic cavity is separated from the brain by a thin piece of bone; below, on the inner side, is a tube about $1\frac{1}{2}$ inch long, called the **Eustachian tube.** This tube leads into the pharynx, and in this way the tympanic cavity or cavity of the middle ear is kept in communication with the air. On the inner wall of the cavity of the tympanum are two small openings, closed by membrane, which communicate with the internal ear. The upper opening is called the **fenestra ovalis** (oval window), and the lower opening is the **fenestra rotunda** (round window) (Fig. 165).

Stretching across the cavity of the middle ear is a chain of three small bones, called the **ossicles of the ear** (*h*, *a*, *s*, Fig. 164). The first of these is called the **malleus**, or hammer, owing to its shape. The part like the handle of the hammer is fixed to the inner surface of the tympanic membrane, while the rounded head of the malleus is jointed to the second bone, called the **incus**, or anvil. The incus, or anvil-bone, has a body and two processes—a short process attaching it to the walls of the tympanic cavity, and a longer process uniting it to the third bone, called from its shape the **stapes**, or stirrup. The stapes, or stirrup-bone, lies horizontally with the top of the arch, attached to the incus and the foot-plate joined to the membrane closing the fenestra ovalis. By the action of a tiny muscle passing from the wall of the cavity to the handle of the malleus, the tympanic membrane can be tightened, and by the action of another attached to the stapes the membrane closing the fenestra ovalis can be tightened. The three ossicles—malleus, incus, and stapes—are so united as to move as one lever. Any vibration of air passing down the outer auditory canal that sets the tympanic membrane in vibration is then communicated through the chain of bones to the membrane of the fenestra ovalis.

**175. The Internal Ear.**—The cavity of the inner ear consists of a number of tortuous passages hollowed out of the thick part of the temporal bone, and called, from the complicated turns and spaces, the **labyrinth** of the ear. In these passages lies a closed sac of membrane, consisting of different parts, corresponding to the hollows and passages in the bone. We thus get (*a*) an **osseous, or bony labyrinth**, and (*b*) a **membranous labyrinth.** The tubes and sacs forming the membranous labyrinth contain a fluid called the **endolymph**, and around the membranous labyrinth, in the space between it and the bony wall, is a fluid called the **perilymph**, so that the membranous labyrinth, with its fluid, floats, as it were, in the fluid in the bony labyrinth. Although the structure of the inner ear is complex, careful attention to the description and frequent reference to the figures will enable the reader to get clear ideas of its various parts and connections.

**176. The Osseous Labyrinth.**—The osseous labyrinth consists of (1) a central oval cavity behind the fenestra ovalis, called the **vestibule** (*vh*, Fig. 164); (2) three arching bony tubes, the **osseous semicircular canals**, which arise from the upper and back part of the vestibule (*bg*, Fig. 164). (These three bony canals are so placed that, in the upright position, one lies horizontally and the other two vertically, but at right angles to one another, one vertical canal lying across from side to side, and one running from front to back.) (3) A

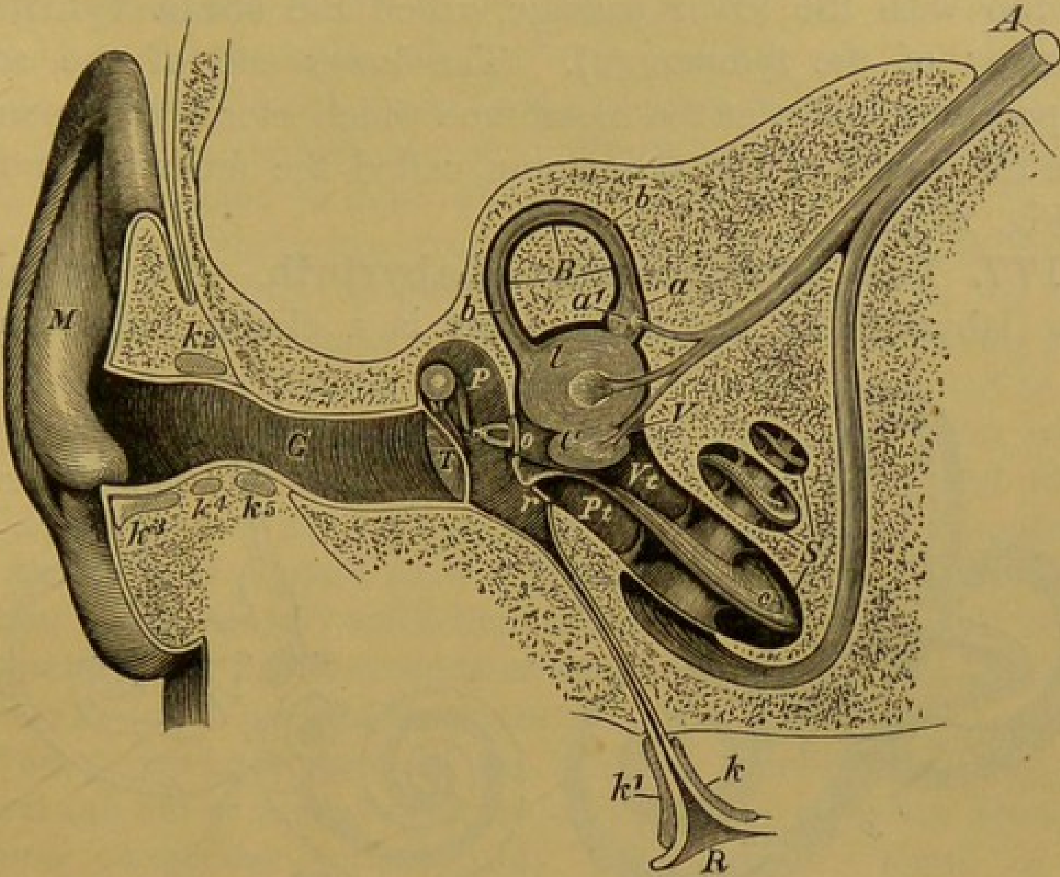



FIG. 165.—Semi-diagrammatic section through the right ear. (Czermak.) M, concha of external ear: G, external auditory meatus; T, tympanic membrane; P, tympanic cavity in which the auditory ossicles, the malleus, incus, and stapes are placed; *Rr*, Eustachian tube leading from pharynx into tympanic cavity; O, oval window or fenestra ovalis with stapes fitting into it; *r*, round window or fenestra rotunda; *Vt*, scala vestibuli of cochlea; *Pt*, scala tympani of cochlea; S, coils of cochlea; *b*, one of the membranous semicircular canals lying in its bony canal, B; *a'*, ampulla of semicircular canal with branch of vestibular nerve passing in; *l*, utricle; C, saccule; A, auditory nerve passing through internal auditory meatus and dividing into two main branches.

bony structure below and in front of the vestibule resembling a tiny spiral shell, and called the **cochlea** (Gk. *kochlias*, a snail). The cochlea consists of a bony canal, or tube, which winds in a spiral of two and a half turns round a central column or **modiolus**, and the tube is divided into an upper and lower passage by a plate or partition, the **lamina spiralis** projecting from the central column, but not quite across (see Fig. 165, which shows the two and a half coils of the cochlea, and where *Vt* is at the beginning of the upper passage, and *Pt* at the end of the lower passage, *c* being the lamina spiralis).

In the inner ear, the lamina spiralis is completed across by membrane, shortly to be described. The upper passage of the cochlea, starting from the vestibule, is called the **scala vestibuli** (stairway of the vestibule), and communicates at the top with the lower passage, called the **scala tympani** (stairway of the tympanum). The lower end of the scala tympani terminates at the membrane which closes the opening from the cavity of the tympanum, called the fenestra rotunda (*r*, Fig. 165).

**177. The Membranous Labyrinth.**—The membranous labyrinth of the internal ear is a closed membranous

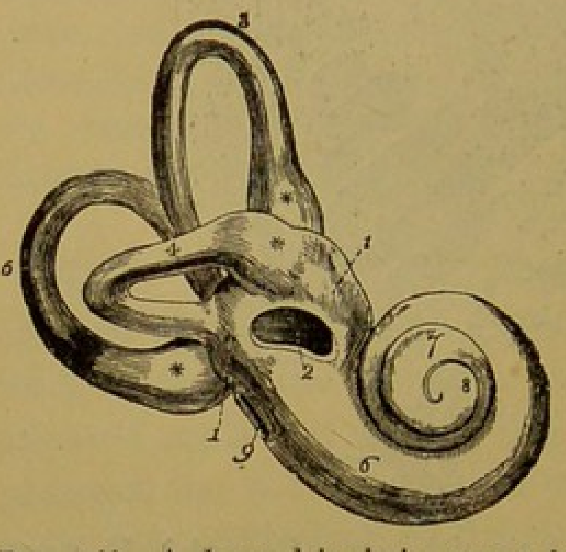



FIG. 166.—A bony labyrinth removed from the dorsal bone in which it lies. 1, the vestibule; 2, fenestra ovalis; 3, 4, 5, the semicircular bony canals; 6, first turn of cochlea; 7, second turn; 8, apex; 9, fenestra rotunda (2½ times natural size). (*From Quain's "Anatomy."*)

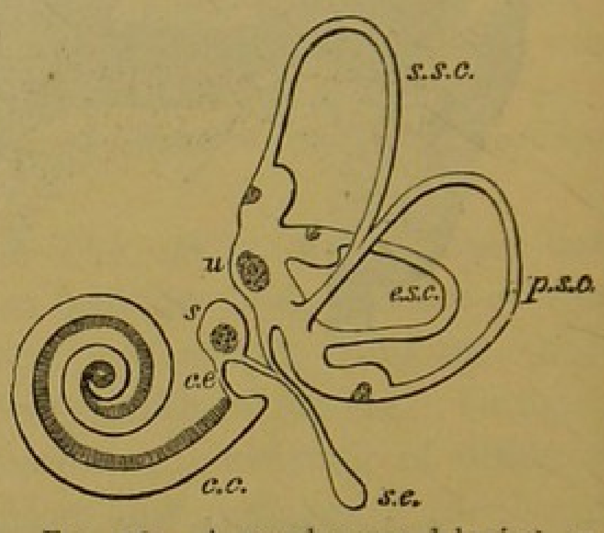



FIG. 167.—A membranous labyrinth removed out of a bony labyrinth, showing utricle, *u*, and three membranous semicircular canals; *s*, saccule; *s.e.*, a sac; *c.e.*, uniting canal; *c.c.*, cochlea. The shaded parts indicate parts to which auditory nerve is distributed (*From Quain's "Anatomy."*)

tube of several parts, lying within the bony labyrinth just described. In the bony vestibule and bony semicircular canals, the membranous structures are very similar in form to the cavities in which they lie, except that the one bony vestibule contains two connected membranous sacs, the **utricle** and the **saccule** (see Fig. 165, *l* and C; also Fig. 167).

The membranous semicircular canals, three in number, lie within the bony canals, being attached along one side

(Figs. 164 and 166). Each has, at one end, a swelling or expansion, called an **ampulla.** A membranous tube, united to the saccule, also runs in a coil of two and a half turns in the bony tube of the cochlea. It will be more fully described directly.

**178. The Auditory Nerve.**—The auditory nerve from the brain, the eighth cranial nerve (par. 147), divides into two main branches, one branch going to the vestibule and semicircular canals, and one branch going to the cochlea, as shown in Fig. 165. The vestibular portion of the auditory nerves divides into five portions, one going to each ampulla, and one to the utricle and saccule. Here these five strands end in connection with special sense cells developed on elevated spots (as indicated in Fig. 167) within these membranous sacs, the special sense cells having hair-like processes projecting into the endolymph contained in the membranous sacs. It is doubtful whether the nerve fibres which come from the vestibular branch of the auditory nerve, and which are connected with the sensory cells in the utricle and ampullæ of the semicircular canals, have anything to do with the sense of hearing. The sensory epithelium of the semicircular canals serves when stimulated by movements of the endolymph to give us *knowledge of our position and movements in space.*

The cochlear portion of the auditory nerve passes up the central column or modiolus of the cochlea, and gives off fibres to become connected with sensory cells that are found in the membranous canal of the cochlea all along one of its walls, as will be explained in par. 181.

**179. The Cochlea.**—We have already described the bony part of the cochlea, and seen how the bony tube that coils round the central column is almost divided into two passages by the bony plate, called the **lamina spiralis**, that starts below between the fenestra ovalis and the fenestra rotunda (Fig. 165). Passing from the edge of the lamina spiralis to the outer wall of the bony tube of the cochlea is a piece of membrane called the **basilar membrane.** This completes the division of the tube into two passages, the **scala vestibuli** above and the **scala tympani** below. Now, passing from the upper edge of the lamina spiralis is another membrane, the membrane of Reissner. This runs obliquely upwards and outwards to the outer wall of the bony tube, and so cuts off, in the bony tube, a triangular canal, **the canal of the Cochlea.** All the three spiral channels of the cochlea are seen in section in Fig. 168, the small triangular one being the membranous canal of the cochlea. This membranous canal, or the cochlea,

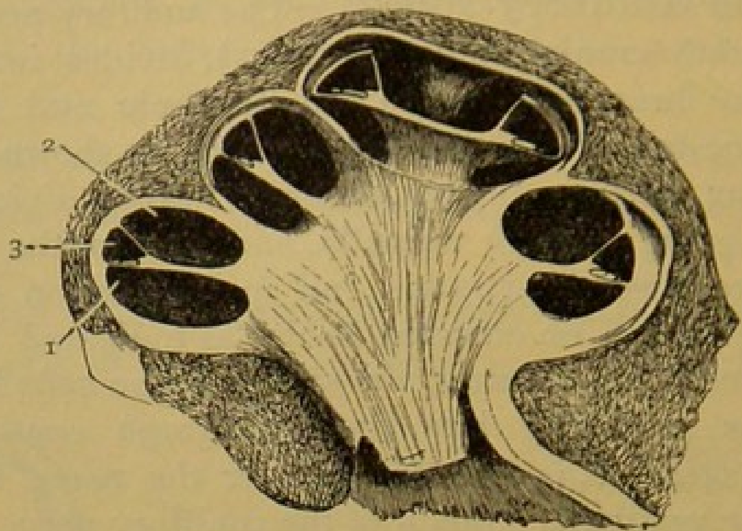



FIG. 168.—Vertical section of the cochlea of a calf. (Kölliker.) Showing the two scalæ with the intermediate canal of the cochlea, and the lamina spiralis. 1, scala tympani; 2, scala vestibuli; 3, scala media or canal of cochlea. (*From Quain's "Anatomy."*)

starts from the saccule in the vestibule, and has a blind end at the top of the cochlea, terminating just before the scala vestibuli passes over at the top into the scala tympani.

**180. The Organ of Corti.**—On the inner part of the basilar membrane that forms the floor of the triangular canal of the cochlea lies the true terminal apparatus of the sense of hearing. This is called, after an Italian anatomist, the **organ of Corti.** This organ comprises several structures, the chief of which are—(1) **Corti's rods,** or pillars, (2) **hair cells** (inner and outer), (3) the **membrana tectoria,** or roofing membrane (Fig. 169).

Fig. 169 shows somewhat diagrammatically a **section** through the three canals in the bony tube of the cochlea about the middle of the coil. The figure 1 is placed in the scala vestibuli, 2 in the scala tympani, and 3 in the canal of the cochlea. *Sch* points to the osseous wall. The organ of Corti is the structure that rests on *Gm*, the basilar membrane. This membrane passes from the bony lamina spiralis to the outer wall of the bony tube of the cochlea. B indicates a pair of Corti's rods, the broad bases of which rest on the basilar membrane, while the heads meet together. A pair of

Corti's rods thus form an arch, and as the pairs occur one after another on the membrane throughout the length of the canal of the cochlea (4000 to 5000 pairs in all), they form a triangular tunnel, the tunnel of Corti, in the canal of the cochlea. On the inner side of the rods of Corti nearest the bony lamina spiralis is a single row of hair cells one after another ; and on the outer side of the rods of Corti are three or four rows of hair cells. These hair

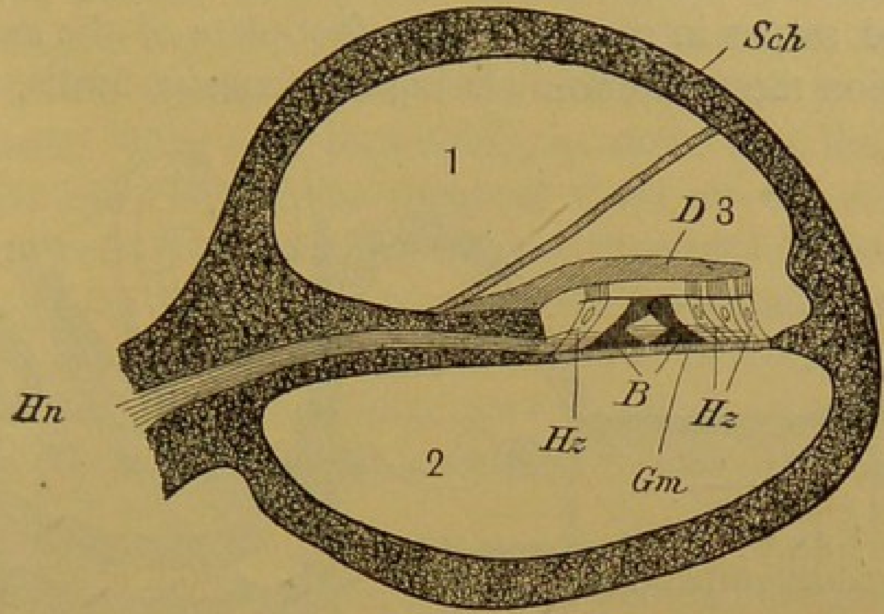



FIG. 169.—Diagrammatic section of a turn of the cochlea. *Sch*, the bony wall of the cochlea ; 1, scala vestibuli ; 2, scala tympani ; 3, canal of cochlea. Reissner's membrane is between 1 and 3. *Gm*, basilar membrane ; B, rods of Corti ; *Hz*, hair cells ; D, membrana tectoria arising from edge of lamina spiralis ; *Hn*, filaments of auditory nerves passing through lamina spiralis to hair cells on basilar membrane.

cells (*Hz*, Fig. 169) are oval nucleated cells having a number of fine hair-like processes at their free upper end. The inner hair cells are said to number 3000, and the outer hair cells 12,000. Outside the hair cells are other cells, termed **supporting cells,** not indicated in Fig. 169. The **membrana tectoria,** or roofing membrane, is an elastic membrane (D, Fig. 169) attached by its inner end to the lamina spiralis, from which it projects over the hair cells and rods of Corti.

Fibres of the cochlear branch of the auditory nerve pass from the column of the cochlea into the lamina spiralis, and from the outer edge of this they continue as naked axis cylinders, some to be connected with the inner row of hair cells, and some passing on across the tunnel of Corti to the outer hair cells, as indicated in Fig. 169.

**181. How Waves of Sound reach the End-organ of Hearing.**—Sound waves are produced in the air by vibrating bodies, and these air waves move on at the rate of 1100 feet per second. On reaching the external ear, the air waves pass along the external meatus or auditory canal, striking, at its inner end, against the elastic membrane of the tympanum, and setting this membrane into vibrations of corresponding rate and intensity. The vibrations of the tympanic membrane set the malleus swinging with it, and the malleus then sets the incus and stapes in motion. The foot-plate of the stapes sets in vibration the membrane closing the fenestra ovalis, and this

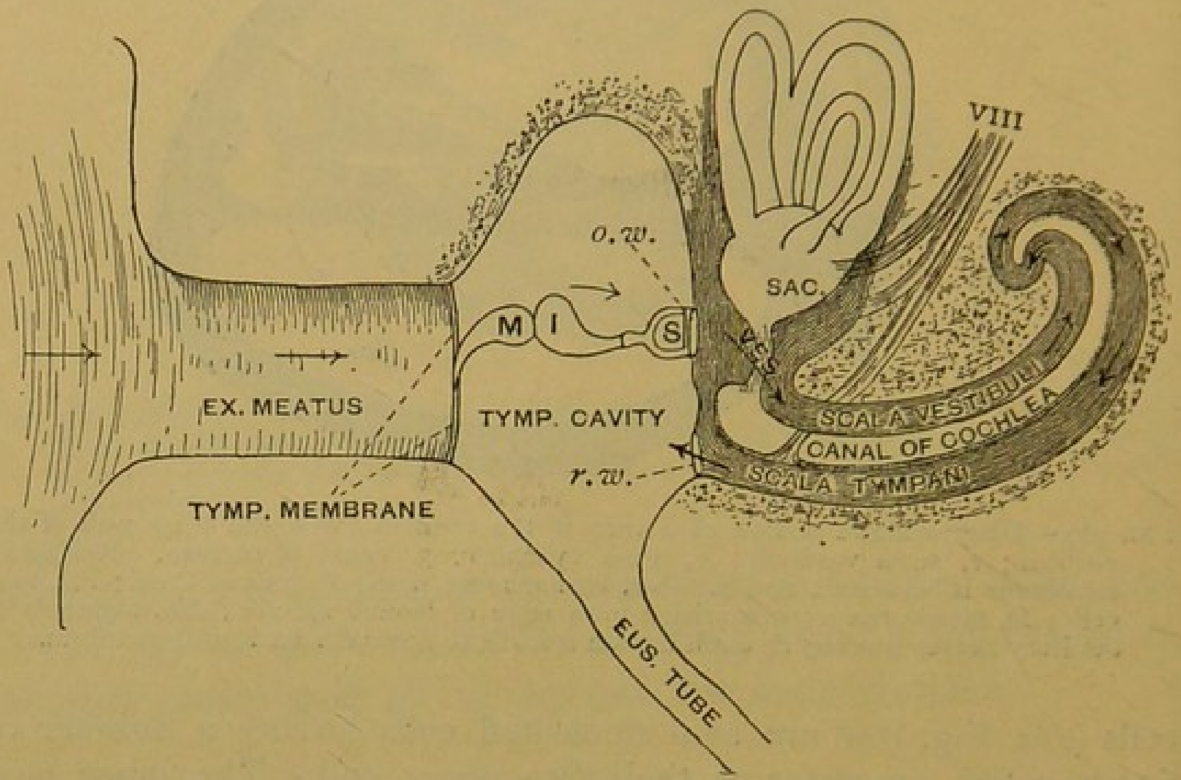



FIG. 170.—Diagrammatic figure showing how sound waves reach the endolymph in the canal of the cochlea and affect the filaments of the auditory nerve in the organ of Corti, resting on the basilar membrane of the cochlear canal, and how the vibrations pass on to the fenestra rotunda. Compare Figs. 165, 167, and 169. M, malleus; I, incus; S, stapes; *o.w.*, oval window or fenestra ovalis; VES, vestibule; *sac*, utricle and saccule; VIII, the eighth cranial nerve (auditory nerve), one branch of which passes to organ of Corti in canal of cochlea. The arrows indicate the direction of the sound waves across the tympanic cavity and through the cochlea to *r.w.*, the sound window or fenestra rotunda.

vibrating fenestra sets up tiny waves in the liquid perilymph contained in the various parts of the bony labyrinth of the inner ear. These waves travel from the perilymph in the vestibule to the perilymph in the bony semicircular canals on the one hand, and to the perilymph in the upper spiral canal, or scali vestibuli of the cochlea, on the other hand (see Fig. 165).

Going up the coiling scala vestibuli, the vibrations pass on at the top, above where the canal of the cochlea ends, into the scala tympani, or lower spiral canal of the cochlea, to end on the membrane of the fenestra rotunda.

The vibrations, on their way through the perilymph of the bony labyrinth, communicate themselves to the endolymph in the various parts of the membraneous labyrinth. Thus, as the vibrations pass up the scala vestibuli of the cochlea, they are transmitted across the membrane of Reissner to the endolymph in the central canal of the cochlea, and to its basilar membrane. They will thus affect, in some way, the auditory epithelial hair cells of the organ of Corti on this membrane. But these cells are in connection with filaments of the cochlear branch of the auditory nerve, so that the stimulation of the hair cells of the organ of Corti give rise to nervous impulses in the filaments of the auditory nerve, and these impulses, on reaching the brain, produce in us the sensation of sound.

**Deafness,** or inability to perceive sound, may arise from several causes. The meatus or outer passage may be blocked by wax secreted by the ceruminous glands, so that the sound waves cannot reach the tympanic membrane. The tympanic membrane may be ruptured or the ossicles of the middle ear may become so stiffly bound together that they fail to conduct the sound waves across to the inner ear. Stoppage of the Eustachian tube at its lower end in the pharynx interferes with the adjustment of the air in the tympanic cavity, and then hinders the transmission of sound to the inner ear. Lastly, there may be some defect or disorganization in the inner ear itself.

# CHAPTER XXII.

## *THE LARYNX, VOICE, AND SPEECH.*

**182. Position, Form, and General Structure of the Larynx.**—The larynx, or organ of voice, is a kind of short tube or box which lies in front of the neck beneath the hyoid bone at the root of the tongue. It forms the enlarged and modified upper end of the trachea. Its relation to the tongue, pharynx, gullet, and other neighbouring parts may be learnt from Figs. 85 and 175. Its upper opening leads into the throat, or pharynx. At the lower end is the trachea, or windpipe, with which it is continuous. Behind it is the gullet, or œsophagus, to which it is adherent. All air passing to and from the lungs must pass through the larynx.

The larynx consists of a framework of cartilages, partly united by joints and partly bound together by ligaments and membranes. Various muscles also serve to connect the cartilages, as well as to move them with reference to one another. The inside of this organ is lined by mucous membrane continuous with that of the pharynx and mouth above, and with that of the trachea below.

On examining a larynx stripped of its outer muscles, we find that the chief cartilages of which its framework is composed are five in number; viz. the **thyroid cartilage**, the **epiglottis**, the **cricoid cartilage**, and two **arytenoid cartilages**.

The **thyroid cartilage** forms the greater part of the front and sides of the larynx. It consists of two curving side plates, or wings (*alæ*), which unite at an angle in front. The prominent ridge of the thyroid thus formed is known as "Adam's apple." Each *ala* or wing of the thyroid curves round the side for some distance, but a wide space is left between them behind, which is occupied by other structures. A projection at the upper hinder corner of each wing of the thyroid, known as the *superior horn*, or *cornu*, of each wing, is connected by a ligament to the hyoid bone above, while the whole upper edge of the thyroid is united to the hyoid bone by the thyro-hyoid membrane. The hyoid, or tongue bone, is a U-shaped bone lying horizontally and embedded in the muscles at the root of the tongue, with its convexity forward. This bone is not articulated with any other bones, but is suspended from the skull by two long ligaments passing from the temporal bones. Besides giving attachment to muscles of the tongue, muscles connect it with the thyroid and sternum. At the lower and hinder part of the thyroid, an inferior horn or cornu on each side articulates this cartilage with the sides of the cricoid cartilage.

The **epiglottis** is the leaf-shaped plate of cartilage which

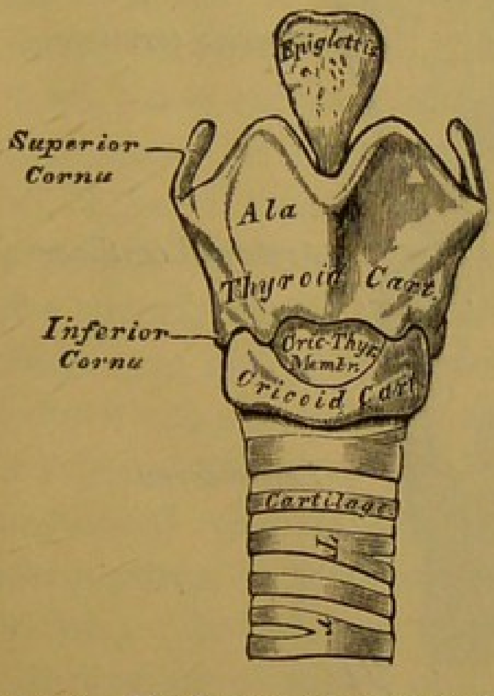



FIG. 171.—The larynx and upper portion of trachea from the front. (*From Gray's "Anatomy."*)

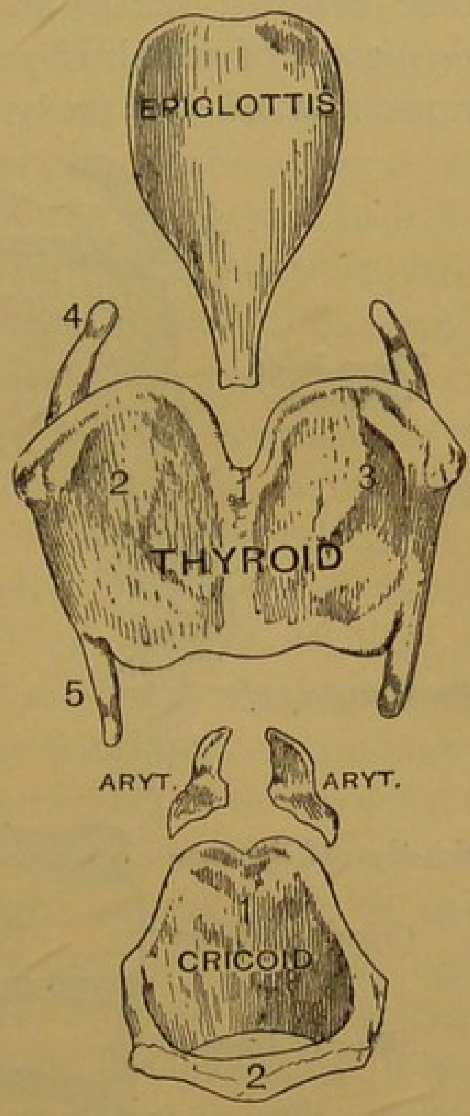



FIG. 172.—Cartilages of larynx separated and seen from before. 1, ridge of thyroid; 2, 3, wings of thyroid; 4, 5, cornua of thyroid. 1, hinder surface of cricoid; 2, front portion of cricoid.

forms the upper anterior portion of the larynx. Its lower narrow base is attached in front to the inner angle of the upper part of the thyroid, and an elevation on its inner part is spoken of as the *cushion* of the epiglottis. Above, the epiglottis is broad and round, and its free top border may be seen at the back of the tongue if the mouth is opened widely and the back of the tongue pressed forward and down. Ligaments connect the upper part of the epiglottis just below its free broad end with the hyoid bone and the back of the tongue. In ordinary conditions the epiglottis stands upright, but during swallowing muscles attached to its sides draw it down, so that it forms a valve or lid over the entrance into the larynx, thus preventing food and drink going the wrong way (par. 112, Fig. 105).

The **cricoid cartilage** is a complete ring of cartilage, the lower margin of which is parallel to the first incomplete cartilaginous ring of the trachea, the two parts being united by

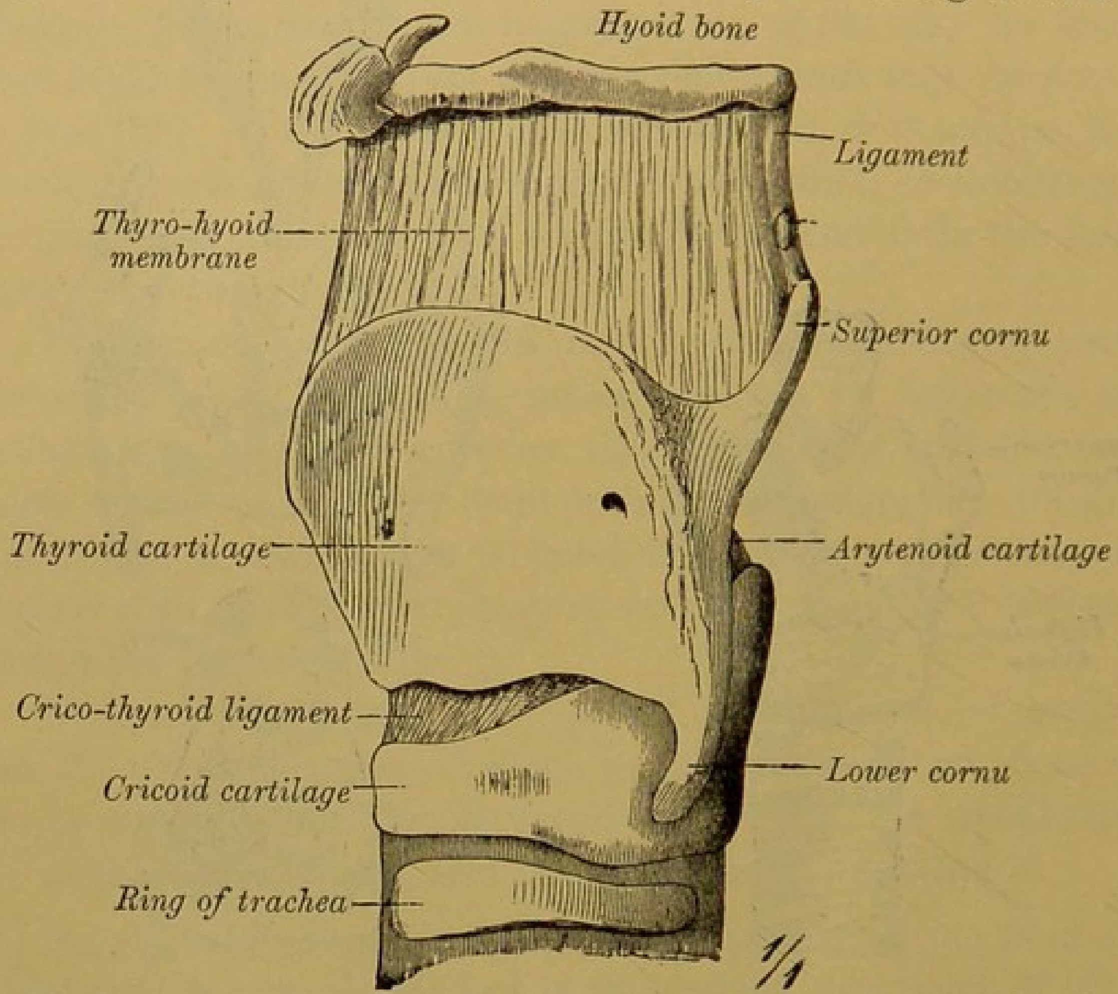



FIG. 173.—Side view of larynx (natural size).

fibrous membrane. In front the cricoid is narrow, and a small space between it and the thyroid is occupied by the crico-thyroid membrane. Behind, the cricoid is broad, the broad part projecting upwards into the space between the back edges of the thyroid.

The **arytenoid cartilages** lie at the back of the larynx, seated on the top of the hinder part of each side of the cricoid cartilage. Each arytenoid is somewhat like a triangular pyramid; that is, it has three surfaces, a base with three angles, and an apex. The bases are so jointed with the cricoid as to be movable upon it by the action of certain muscles. From the tip of each arytenoid a fold of mucous membrane, the aryteno-epiglottic fold, passes to the sides of the epiglottis, thus forming the hinder and lateral boundaries of the opening into the larynx from above (Fig. 175), as the epiglottis itself forms the front boundary of this entrance. As the arytenoid cartilages are jointed to the top of the hinder part of the cricoid and connected with it by ligaments, any movement of the cricoid will also affect the arytenoids and the vocal cords attached to them.

**183. The Interior of the Larynx.**—The cavity or interior of the larynx is wider than that of the trachea. In it we find on each side two ridges, formed of folds of tissue covered by mucous membrane, and passing from behind to the front, one ridge below the other on each side. The lower ridge or fold on each side of the interior of the larynx is termed the **vocal cord**, because **voice** is due to the vibrations of the edges of these lower ridges in the larynx. The vocal cords are, in fact, two bands of elastic tissue covered with mucous membrane which run forwards from the anterior angle of the base of the arytenoid cartilages to be attached in front to the inner surface of the thyroid cartilage where the two wings of this cartilage unite (Figs. 174 and 175). Between the two edges of the vocal cords (which are not quite horizontal, but incline upwards a little) is a narrow fissure or chink, prolonged behind between the two arytenoid cartilages. This fissure between the right and left vocal cords is termed the **glottis**, or *rima glottidis* (chink of glottis). In ordinary quiet breathing the glottis is **V** shaped, the opening of the **V** being backwards; but in order to produce voice, the cords are brought close to one another and their edges made to vibrate by a blast of air sent through the narrow glottis from the lungs. Above, the true vocal cords are two other folds of tissue, one on each side, passing within the larynx from behind to the front, but as these take no active part in the production of sound they are spoken of as the **false vocal cords.** Two recesses in the larynx, one between each true vocal cord and the false vocal cord above it, are termed the

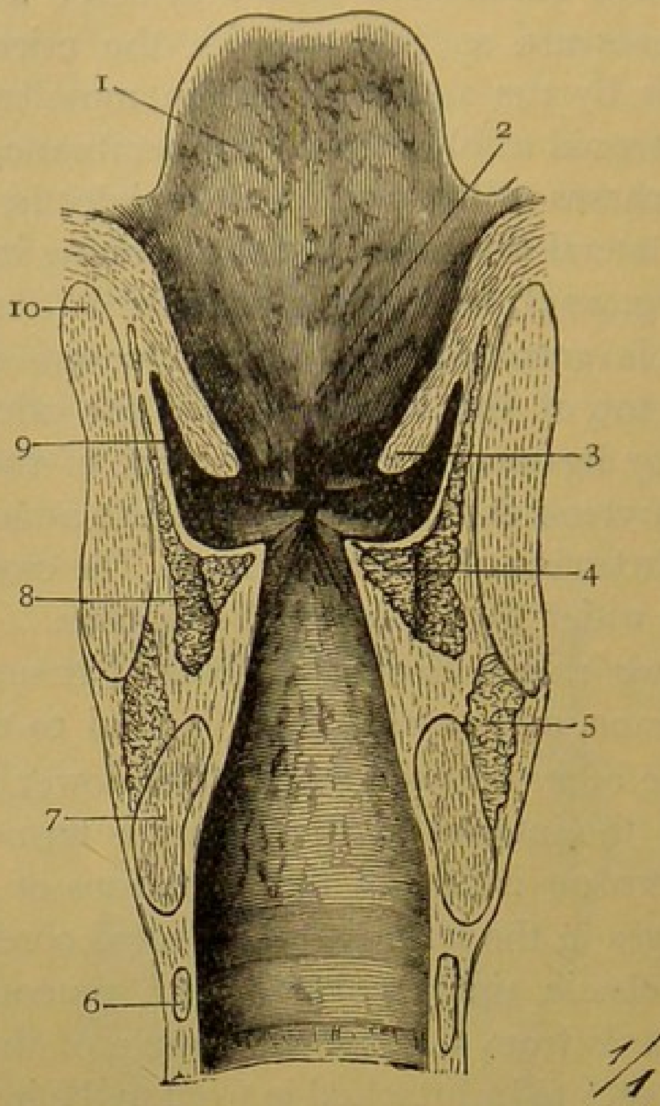



FIG. 174.—Interior of larynx seen from behind, the hinder wall being removed. 1, epiglottis; 2, cushion of epiglottis; 3, superior or false vocal cord; 4, inferior or true vocal cord running forward to thyroid cartilage in front, the glottis lying between the two cords; 5, cut surface of crico-thyroid muscle; 6, cut end of a cartilaginous ring of the trachea; 7, cut surface of cricoid cartilage; 8, thyro-arytenoid muscle; 9, ventricle of larynx between false and true vocal cords; 10, cut surface of thyroid cartilage.

*ventricles of the larynx.* The false vocal cords are sometimes spoken of as the **superior vocal cords,** and the true vocal cords as the **inferior vocal cords.**

If the student will obtain from a butcher a sheep's tongue with the larynx, windpipe, and gullet attached, he will be able, on clearing off the muscles and fat from the front and sides, to find the various cartilages mentioned. The smooth mucous membrane lining the interior of the larynx may also be noted. Near the middle will be seen the chink of the glottis, guarded on each side by the vocal chords and the arytenoid cartilages. The cords are not strings, but folds of tissue such as might be pinched up from the skin of the hand.

By the aid of a suitable arrangement of mirrors we get an instrument called the *laryngoscope*, which enables us, through the upper opening of the larynx, to see its interior. This upper opening is triangular in shape, and slopes backwards. It is wide in front, where it is bounded by the epiglottis, narrow behind, where it is limited by the membrane covering the tips of the arytenoids. Its sides are formed by the aryteno-epiglottic folds of membrane (small cartilages in this fold forming little projections) which pass

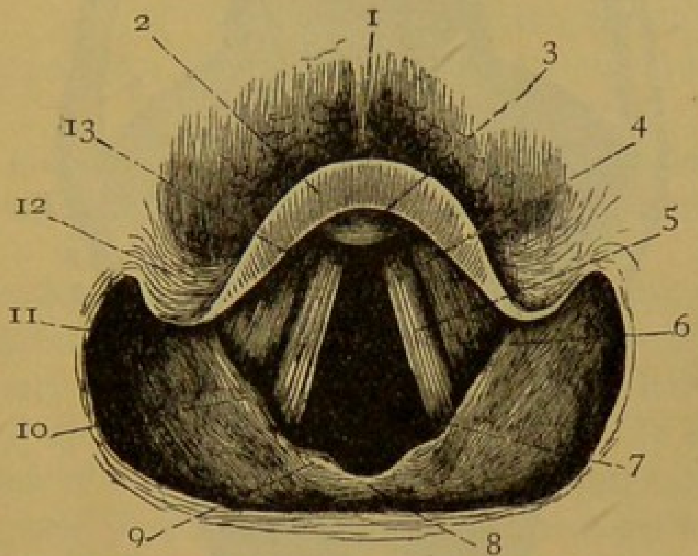



FIG. 175.—View from above through the upper opening of the larynx into its interior; natural size during quiet breathing. 1, hinder part of tongue; 2, upper edge of epiglottis; 3, cushion of epiglottis; 4, superior or false vocal cords; 5, inferior or true vocal cord; 6, side of aryteno-epiglottic fold forming side boundary of upper entrance into larynx; 7, the V-shaped glottis between the true vocal cords; 8, points to a fold between the two arytenoid cartilages below; 9 and 10, small cartilages in aryteno-epiglottic fold; 11, a small recess between the fold and the side of the epiglottis; 12, fold in pharynx; 13, points to the ventricle between true vocal cord and false vocal cord.

upwards from the arytenoids to the sides of the epiglottis. Below this opening the cavity is seen to narrow to a triangular chink—the glottis—on the sides of which the true vocal cords are seen. On making a deep inspiration the cords are seen to move further apart, and the glottis becomes so wide that the observer can see down the trachea for some distance. On sounding a note the vocal cords can be seen to pass inwards, and the glottis become a mere slit. Thus examined, the true vocal cords are seen in the middle line as white, shining bands when in a healthy condition. At a higher level, on each side of the true vocal cords, the pinker, false vocal cords are seen.

The average length of the vocal cords in men is $\frac{7}{12}$ of an inch, and in women $\frac{5}{12}$ of an inch, while the space between the cords, called the glottis, is about $\frac{1}{2}$ of an inch in width when wide open. In youth there is no difference between the larynx of the male and the female; but at a certain age a boy's larynx enlarges, and the voice "breaks," or becomes deeper in pitch, with the increase in length of the vocal cords.

**184. Muscles of the Larynx.**—The muscles of the larynx are arranged in two sets, called extrinsic and intrinsic. The first set

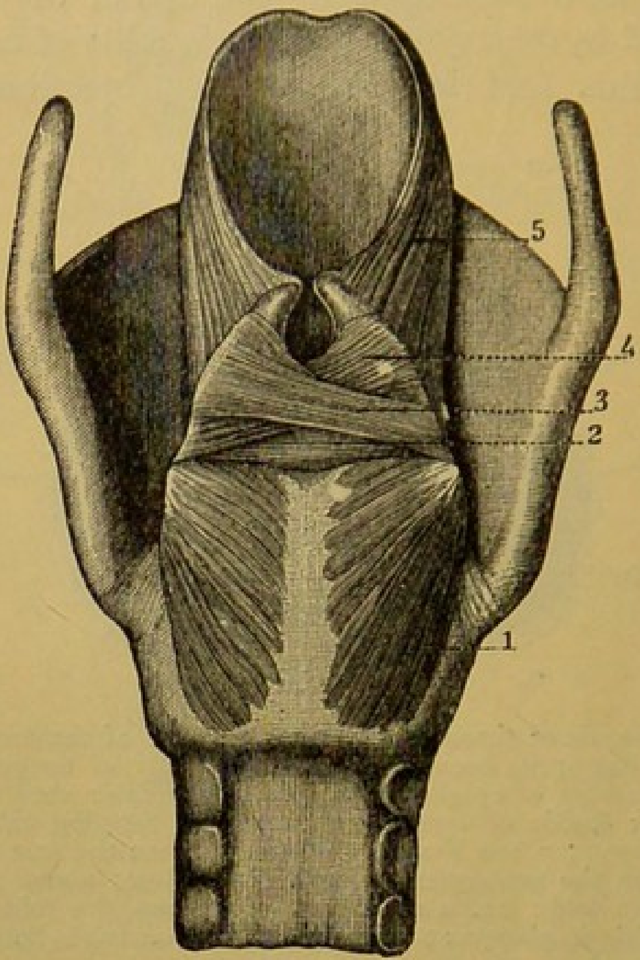



FIG. 176.—Posterior muscles of the larynx. 1, posterior crico-arytenoid; 2, arytenoid; 3, 4, oblique fibres passing round the edge of the arytenoid cartilages to form 5, the muscles which connect these cartilages with the epiglottis. (*From Quain's "Anatomy."*)

seems mainly to elevate or depress the whole organ. At the instant of swallowing, for instance, the larynx is drawn upwards and forwards under the root of the tongue, just as the epiglottis is made to fall down and close the entrance to it. The intrinsic muscles serve mainly to move the cartilages, and so to regulate the position and tension of the vocal cords. These muscles are named according to their positions and connections, and are for the most part in pairs. Thus, a **crico-thyroid muscle** arises on each side from the fore part of the external surface of the cricoid, and passes up and backwards to the thyroid. When these muscles contract they cause a backward movement of the hinder part of the cricoid, and of the arytenoid cartilages seated upon it, and thus increases the width of the larynx from back to front. As a result the vocal cords attached to the arytenoids are made more tense. A single muscle, the arytenoid muscle, passes behind from one arytenoid cartilage to another, and by its contraction draws them together, and so narrows the glottis. Other muscles also aid in this latter action. We may summarize and describe the action of the various muscles thus—

| | |
|---|---|
| Tensor of vocal cords ... | Crico-thyroid muscle. |
| Constrictors of the glottis | Lateral crico-arytenoid muscles,<br>Thyro-arytenoid muscles,<br>Arytenoid muscle. |
| Dilator of glottis ... | Posterior crico-arytenoid muscles. |
| Depressor of epiglottis ... | Aryteno-epiglottic muscle. |

**185. Voice and Speech.**—Voice, as defined by physiologists, is the sound produced in the larynx by the vibration of the vocal cords. During ordinary respiration the glottis is about half open, but with a forced inspiration it becomes widely dilated. In order to produce voice the chink of the glottis must be rendered narrow by the free edges of the vocal cords being brought close together and rendered parallel. The cords must also be made more or less tense. As already explained, both the width of the glottis and the tension of the vocal cords are regulated by the action of muscles which move the thyroid and arytenoid cartilages to which the vocal cords are attached. With the cords close together and tense, an expiratory blast of air from the lungs causes the thin membranous cords to vibrate, and these vibrations are then communicated to the air in the larynx and air passages above. The air waves on reaching the ear produces the sensation of sound.

The *pitch* of the voice depends upon—(1) The length of the vocal cords, for the longer a cord is the more slowly it vibrates, and the lower is the note produced, and *vice versâ*. The vocal cords of women and children are about one-third shorter than those of men, and hence their voice is of higher pitch. (2) The tension of the cords, for the tighter the cords are the higher the pitch, and *vice versâ*.

**Speech** is voice modified by alterations and additions made in the pharynx, mouth, and nose, and by articulating together the sounds into syllables and words. Speech sounds are divided into **vowels** and **consonants.** A **vowel** is the sound produced by the vibrating cords when the upward passage of the air is quite free. It is easy to learn that the different vowel sounds are mainly produced by altering the shape of the mouth—an alteration made by changing the position of the tongue, lips, and lower jaw. Sing (or say) **a** (ah), and without altering the note change the sound to **o** (oh), and then to **oo.** Notice the change made in the cavity of the mouth. A **consonant** is the sound produced by the vocal cords when the escaping air is checked or stopped in its passage

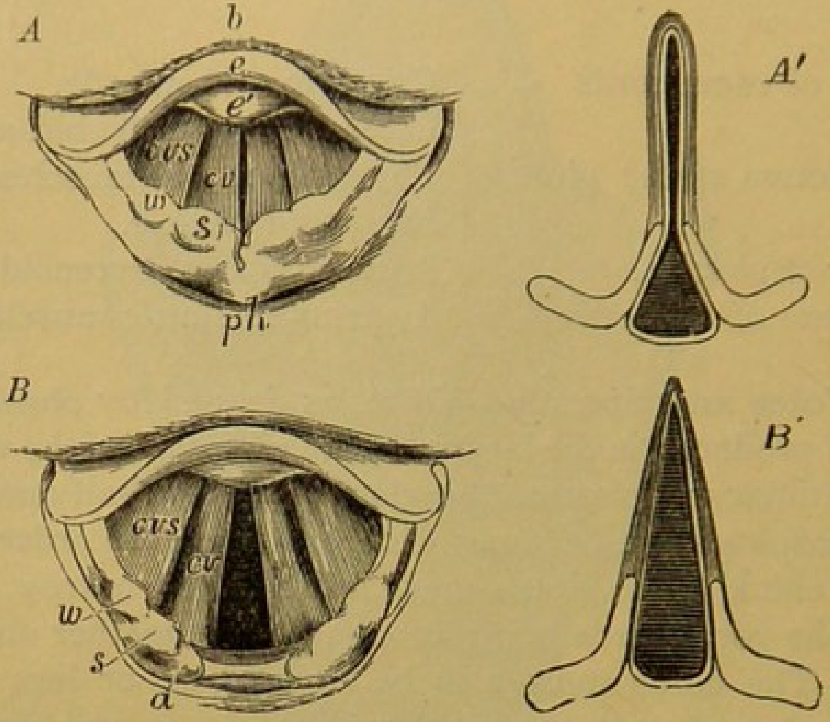



FIG. 177.—Two views of the larynx as seen from above by the laryngoscope. (Czermak.) A, the condition when voice is being produced, as in singing a high note. The cords are parallel and tense, and the glottis between them a narrow chink; B, the condition of easy breathing, when no voice is being produced; *b*, base of tongue; *e*, the upper free part of epiglottis; *e'*, cushion of epiglottis; *cvs*, the upper or false vocal cords; *cv*, true vocal cords; *s* and *w*, elevation in fold of membrane; *a*, position of arytenoid cartilage; *ph*, front wall of pharynx; A' and B', diagrams of the arytenoid cartilages and vocal cords in the two positions with the glottis (dark) between. (*From Quain's "Anatomy."*)

through the mouth. It is also usually preceded (f, l, r) or followed (b, d, k) by a vowel sound. If the interruption of the outgoing current of air is made by the lips, as in pronouncing p, b, f, v, the letters are called **labials** (Lat. *labium*, a lip). Letters, the sound of which are made with the tip of the tongue near the teeth, are called **dentals,** as t, d, th. **Gutturals,** as k, g (hard), are made by a check at the top of the throat.

**Whispering** is speech without voice, that is, there is no vibration of the voice cords, but the feeble air currents are moulded into faint speech by movements of the tongue and lips.

# GLOSSARY

The pronunciation of each word is indicated in a bracket immediately after the word, the mark ′ indicating the accented syllable and the mark ¯ a long vowel. The derivation of the word is then generally given within a second bracket. The student should note the frequent use of the diminutive endings *-cule*, *-cle*, *-ule*, *e.g.* molecule (Lat. *moles*, a mass), a little mass ; saccule, a little sac or pouch ; particle, corpuscle, a little body (Lat. *corpus*, a body), globule, lobule, etc.

**Abdomen** (ab-dō′-men) [Lat. *abdo*, to hide]. The cavity of the trunk extending from the diaphragm to the pelvis.

**Abductor** (ab-dukt′-or) [Lat. *ab*, from ; *duco*, *ductum*, to lead]. A muscle which draws a part away from the axis or central line of a limb or the body, *e.g.* the abductor of the thumb.

**Absorption** (ab-sorp′-shon) [Lat. *ab*, from ; *sorbeo*, to suck up]. The process by which materials are taken up by blood-vessels or lymphatics.

**Accommodation** (ak-kom′-o-da-shon) [Lat. *ad*, to ; *commodare*, to fit, adapt]. The function of the ciliary muscle and crystalline lens which accommodates or adjusts the eye for the clear vision of objects at different distances.

**Acetabulum** (as-ē-tab′-ū-lum) [Lat. *acetabulum*, a vinegar cup]. The cup-shaped cavity in the innominate bone that receives the rounded head of the femur.

**Acid** (as′-id) [Lat. *acidus*, sour]. Acids are compound substances that have a sour taste, that turn blue litmus red (the acid reaction), and that neutralize alkalies. They are compounds of hydrogen with other elements, often with oxygen in addition.

**Adductor** (ad-dukt′-or) [Lat. *ad*, to ; *duco*, *ductum*, to lead]. An adductor muscle is one which draws a part inwards *to* a centre or *to* the median line of the body ; the opposite of *abductor*.

**Adenoid** (ad′-en-oid) [Gk. *adēn*, a gland, *eidos*, form]. Adenoid tissue is tissue resembling gland tissue.

**Adipose** (ad′-i-pōz) [Lat. *adeps*, *adipis*, fat]. Consisting of fat, as adipose tissue.

**Albumen**, or Albumin (al-bū′-men) [Lat. *albus*, white]. A class of proteid bodies which are soluble in water and which coagulate on being heated. They are complex nitrogenous compounds composed of the elements carbon, nitrogen, hydrogen, oxygen, and sulphur. Egg albumen (white of egg) and serum albumen found in blood are examples.

**Aliment** (al′-i-ment) [Lat. *alo*, to nourish]. Food, nutriment.

**Alkali** (al′-ka-li) [Ar. *al*, *kali*, the soda plant]. Alkalies are substances that turn red litmus blue (alkaline reaction), and have other properties in contrast with those of acids. Soda, potash, and ammonia are common alkalies. An alkali forms a soap when united with oil or fat.

**Alkaline** (al′-ka-līn). Having the properties of an alkali.

**Alveolus** (al-vē′-o-lus) [Lat. diminutive of *alveus*, a hollow, a cavity], p. *alveoli*. A word used to denote the small cavities found in many parts, as the air-cells or alveoli of the lungs.

**Amylolytic** (am-ī-lō-līt′-ik) [Gk. *amulon*, starch ; *lutikos*, loosening]. Having the power to change starch into sugar.

**Antiseptic** (an-ti-sept′-ik) [Gk. *anti*, against; *sepein*, to rot, putrefy]. Having the power to prevent putrefaction.

**Arterial** (ar-ter′-i-al). A term applied to the bright red blood that has been oxygenated in the lungs; opposed to *venous*, which is applied to the dark blood that has given up oxygen in the tissues. The pulmonary arteries contain venous blood—all others arterial blood.

**Artery** (ar′-ter-i) [Gk. *aer*, air; *tero*, to contain]. A vessel by which blood is conveyed away from the heart. The arteries are usually empty after death, and were supposed by the ancients to contain air, hence the name.

**Articular** (ar-tik′-u-lar) [Lat. *articulus*, a joint]. Pertaining to the articulations or joints.

**Asphyxia** (as-fik′-si-a) [Gk. *a*, not; *sphyxis*, a throb, a pulse]. Literally stoppage of the pulse, but now used to mean suffocation from interruption of the respiratory movements, and extreme deficiency of oxygen in the blood. It is produced by strangulation, drowning, inhalation of coal-gas, etc.

**Assimilation** (as-sim-il-ā′-shon) [Lat. *ad*, to; *similis*, like]. The act or process by which living organisms absorb and incorporate digested food so that it becomes part of the living tissues.

**Auriculo-ventricular** (aw-rik′-u-lo, ven-trik′-u-lar). Relating to both auricle and ventricle, as the auriculo-ventricular orifice.

**Axon** (ak′-son) [Lat. *axis*, axle]. The central strand or core of a nerve fibre, called also the axis cylinder of the fibre. It is the essential conducting part of the fibre, and arises as a process of a nerve cell.

**Bacteria** (bak-tē′-ri-a) [Gk. *bakterion*, pl. *bakteria*, a rod]. Very minute vegetable organisms, consisting of colourless protoplasmic cells without nucleus, and of a globular, rod-like, or comma-shaped form. They are also known as microbes, or micro-organisms. Their origin and the part they play in putrefaction, disease, and fermentation is discussed in works on Bacteriology.

**Biceps** (bī′-seps) [Lat. *bi*, two; *caput*, *capitis*, head]. Having two heads. The biceps muscle on the front of the upper arm has two tendinous heads. A biceps muscle is also found in the thigh.

**Bicuspid** (bī-kus′-pid) [Lat. *bi*, two; *cuspis*, a point]. Having two points or cusps. The fourth and fifth teeth from the middle upon each side of each jaw are the bicuspid teeth. The mitral valve between the left auricle and left ventricle has two cusps, and is also known as the bicuspid valve. The corresponding opening on the right side is guarded by the tricuspid valve.

**Bifurcate** (bī-fur′-kāt) [Lat. *bi*, two; *furca*, a fork]. Forked, dividing into two branches.

**Bolus** (bō′-lus) [Lat. *bolus*, a clod]. A mass of masticated food ready for swallowing.

**Brachial** (brak′-i-al) [Lat. *brachium*, the arm]. Relating to the arm.

**Bronchi** (brong′-kī) [Gk. *brongchos*, the windpipe]. The two branches of the trachea.

**Bronchial** (brong′-ki-al). Relating to the bronchi or to their branches.

**Cæcum** (sē′-kum( [Lat. *cæcus*, blind]. The blind or closed end of the large intestine to which the vermiform appendix is attached. The small intestine opens into the inner side of the large intestine a little more than an inch from its end (Fig. 103).

**Calyx** (kāl′-iks) [Lat. *calyx*, pl. *calyces*, a cup]. A subdivision of the pelvis of the kidney, one of the recesses into which a pyramid of the kidney projects.

**Cancellated**, or Cancellous (kan′-se-lā-ted) [Lat. *cancelli*, a lattice or grating]. Formed of minute cross-bars; as the cancellated or cancellous tissue forming the loose, spongy part of bone.

**Canine** (ka-nīn′) [Lat. *canis*, a dog]. The sharp, tearing teeth placed between the incisors and molars; very prominent in dogs.

**Capillary** (kap′-il-a-ri) [Lat. *capillus*, a hair]. Capillaries are minute blood-vessels, finer than a hair, connecting the smallest arteries with the smallest veins.

**Capsule** (kap′-sūl) [Lat. *capsa*, a case]. A fibrous or membranous covering, as the capsule of the kidney; the ligamentous structure enveloping a joint, called the capsule or capsular ligament of the joint.

**Carbohydrate** (kar-bo-hī′-drāt). Carbohydrates are organic bodies containing six atoms of carbon or some multiple of six, and hydrogen and oxygen in the same proportion as in water. The hydrogen and oxygen, however, do not form water, but are combined with the carbon. Starches and the different kinds of sugar are carbohydrates.

**Carbonic acid** (kar-bón-ic as′-id). A gaseous compound of carbon and oxygen ($CO_2$), formed by the oxidation of the element carbon, more properly called carbon dioxide.

**Cardiac** (kar′-di-ak) [Gk. *kardia*, the heart]. Pertaining to the heart.

**Carotid** (ka-rot′-id) [Lat. *carotis*, from Gk. *caros*, sleep]. The great arteries of the neck. They were supposed by the ancients to give origin to sleep.

**Casein** (kā′-sē-in) [Lat. *caseum*, cheese]. The chief proteid of milk and of cheese.

**Cell** (sel) [Lat. *cella*, a small cavity]. One of the minute masses of protoplasm of which tissues are composed.

**Cellular.** Composed of cells.

**Cellulose** (sel′-ū-lōs). An indigestible carbohydrate which forms most of the framework of vegetable tissues.

**Cerebral** (ser′-ē-bral) [Lat. *cerebrum*, the brain]. Belonging to, situated in, or affecting the brain or cerebrum.

**Cervical** (ser′-vi-kal) [Lat. *cervix*, *cervicus*, the neck]. Belonging to or pertaining to the neck.

**Chorda** (kor′-da) [Lat. *chorda*, a cord]. The chordæ tendinæ are tendinous cords connecting the fleshy masses termed papillary muscles on the inner side of the ventricles of the heart to the auriculo-ventricular valves—sometimes called the "heart-strings" (Fig. 68).

**Chyle** (kīl) [Gk. *chulos*, juice]. (1) The liquid contents of the small intestine after digestion; (2) the milky fluid consisting of emulsified fat and lymph found in the lacteals during digestion and absorption.

**Chyme** (kīm) [Gk. *chumos*, juice]. The partly digested contents of the stomach as they enter the intestine.

**Cilia** (sil′-i-a) [Lat. *cilium*, pl. *cilia*, eyelid]. (1) The hairs growing from the eyelids, the eyelashes; (2) the microscopic hair-like vibratile processes of cells. The adjective *ciliary* means belonging to the eyelids or some other part of the eye, while the adjective *ciliated* refers to cells or other parts provided with the microscopic hair-like processes. Ciliated epithelial cells line the respiratory track, etc., and the cilia are in constant movement, sweeping outward mucus and foreign particles (Fig. 4).

**Clinical** (klin′-ik-al) [Gk. *kline*, a bed]. Relating to treatment of disease at the bedside of the patient.

**Coagulation** (kō-ag-ū-lā′-shon) [Lat. *coagulare*, to curdle]. To change from a fluid into a thickened or curd-like mass; to congeal; to clot; to become solid. Thus blood, lymph, muscle plasma, and milk coagulate owing to the change of a soluble proteid in them into an insoluble proteid.

**Condyle** (kon′-dil) [Gk. *condulos*, a knuckle]. A rounded knob or eminence, as those at the lower end of the humerus and femur.

**Convolutions** (kon-vō-lū′-shons) [Lat. *con*, together; *volvo*, to roll]. The folds or coils on the outer surface of the brain.

**Co-ordination** (kō-or-di-nā′-shon). [Lat. *co*, together, and *ordo*, *ordinis*, order]. The capacity of parts to work together in proper strength and order to fulfil some purpose in the body. Thus the nerve centres co-ordinate incoming impulses with outgoing impulses that produce definite movement.

**Corpuscle** (kor′-pus-l) [Lat. *corpusculum*, a little body, diminutive of *corpus*, a body]. A word applied to certain cells and other anatomical elements of the body, as blood-corpuscles, lymph-corpuscles, tactile corpuscles, etc.

**Costal** (kos′tal) [Lat. *costa*, a rib]. Pertaining to the ribs as costal cartilage.

**Cranial** (krā′-ni-al) [Lat. *cranium*, the skull]. Pertaining to or connected with the skull.

**Cribriform** (krib′-ri-form) [Lat.

*cribrum*, a sieve]. Sieve-like; perforated like a sieve; as the cribriform plate of the ethmoid bone through which the nerve fibrils of the olfactory nerve pass.

**Cricoid** (krī′-koid) [Gk. *krikos*, a ring]. Ring-shaped.

**Cutaneous** (kū-tā′-nē-us) [Lat. *cutis*, the skin]. Relating to or pertaining to the skin.

**Cuticle** (kū′-ti-kl). The epidermis, or outer skin.

**Cutis** (kū′-tis). The true skin beneath the epidermis; called also the cutis vera, the corium, and the derma.

**Death**. Cessation of life. We distinguish *general death* and *local death*. *General death* is the total and permanent cessation of the vital actions of the body owing to the stoppage of the functions of the brain, lungs, and heart. The death of the body as a whole is followed after an interval by the death of the tissues (par. 41). *Local death* is the cessation of life in a part of the body—a piece of skin, bone, or a finger—owing to injury and failure of nutrition. Local death of cells is continually going on, as they are continually wasting and being replaced.

**Decalcify** (de-kal′-si-fī), [Lat. *de* down, from; *calx*, *calcis*, lime; *facio*, to make.] To deprive of lime and other mineral matter. A decalcified bone is one from which the mineral matter is removed.

**Decussate** (de-kus′-āt) [Lat. *decusso*, to divide crosswise]. To cross over; applied especially to the crossing of nerve fibres.

**Defæcation** (dē-fē-ka′-shun) [Lat. *de*, down, and *fæces*, the fæces]. The act of expelling the fæces from the bowel.

**Deglutition** (deg-lōō-tish′-un) [Lat. *de*, down, and *glutio*, I swallow]. The act or process of swallowing.

**Dendron** (den′-dron) [Gk. *dendron*, a tree, a branch]. A dendrite or branch of a nerve cell.

**Diagram** (dī′-a-gram) [Gk. *dia*, through; *grapho*, to describe]. A more or less simplified drawing; an illustrative figure giving only the general scheme (not an exact representation) of an object.

**Dialysis** (dī-al′-i-sis) [Gk. *dia*, through; *lusis*, a loosening]. The diffusion of soluble substances termed crystalloids through animal membranes or parchment. Colloids do not suffer dialysis.

**Diastole** (dī-as′-to-lē) [Gk. *dia*, through; *stello*, I place]. The expansion or relaxation of the cavities of the heart, during which they become filled with blood.

**Diffusion** (di-fū′-zhon) [Lat. *diffusis*, a spreading]. The act of spreading and mixing; the act of passing through membranes.

**Digestion** (di-jes′-tyon) [Lat. *dis*, apart; *gero*, *gestum*, to carry]. The process by which the food taken into the body is changed into such forms that it can be absorbed into the blood and made part of the tissues.

**Dorsal** (dor′-sal) [Lat. *dorsum*, the back]. Relating to the back or to the posterior part of any organ.

**Duct** (dukt) [Lat. *duco*, *ductum*, to lead]. A tube, especially any tube which conducts a secretion away from a gland.

**Duodenum** (dū-o-dē′-num) [Lat. *duodeni*, twelve]. The first part of the small intestine, beginning at the pylorus, for the length of about twelve finger breadths.

**Efferent** (ef′-e-rent) [Lat. *ex*, out of; *fero*, I carry]. Carrying out of. Efferent nerves convey impulses out from a nerve centre. Efferent vessels are those that lead from an organ.

**Emulsion** (e-mul′-shun) [Lat. *emulgeo*, I milk out]. A liquid rendered milky looking by the suspension in it of fine particles of oil or fat.

**Endocardium** (en-do-kar′-di-um) [Gk. *endon*, within; *kardia*, the heart]. The lining membrane of the interior of the heart.

**Energy** (en′-er-ji). Power to do work, *i.e.* to overcome resistance and produce motion of any kind. The energy of the body is derived from the oxidation processes that go on in the tissues.

**Epidermis** (ep-i-der′-mis) [Gk. *epi*, upon; *dermis*, the skin]. The outer layer of the skin, called also the cuticle, or scarf skin.

**Epithelium** (ep-i-thē′-li-um) [Gk. *epi*, upon; *thele*, a teat, or papilla]. The superficial layer or layers of cells covering the skin and mucous membranes lining ducts and serous membranes, etc. Epithelial tissue contains no blood-vessels, *i.e.* is non-vascular, but the cells are nourished by imbibing the plasma or lymph that passes out from the underlying blood-vessels.

**Eustachian tube** (ū-stā′-ki-an). The passage by which the pharynx communicates with the middle ear or cavity of the tympanum. The passage is named after an Italian anatomist, Eustachio (sixteenth century).

**Excretion** (eks-krē′-shon) [Lat. *ex*, out; *cerno, cretum*, to sift, to separate]. (1) The separation from the blood of the waste matter of the body; (2) the substance or material excreted.

**Extensor** (eks-ten′-sor) [Lat. *ex*, out; *tendo, tensum*, to draw]. An extensor muscle is one that straightens a limb after flexion.

**Fascia** (fash′-i-a) [Lat. *fascia*, a band]. The fibrous covering of muscles and other organs.

**Fauces** (faw′-sēz) [Lat. *fauces*, the throat]. The back part of the mouth leading into the pharynx, *i.e.* the space surrounded by the palate, tonsils, and uvula.

**Fenestra** (fe-nes′-tra) [Lat. *fenestra*, a window]. An opening between the middle and internal ear.

**Fibrinogen** (fī′-bri-nō-jen) [fibrin and Gk. *gennao*, to produce]. The proteid substance dissolved in blood plasma, which gives rise to the solid fibrin threads when blood clots.

**Filiform** (fil′-i-form) [Lat. *filum*, a thread]. Slender like a thread.

**Filtration** (fil-trā′-shun) [Lat. *filtrum*, felt]. The process of straining a liquid through porous paper or other substance. The liquid and any matter dissolved passes through, but insoluble solid particles are kept back.

**Flexor** (fleks′-or) [Lat. *flexo*, to bend]. A muscle that bends a limb or part.

**Follicle** (fol′-i-kl) [Lat. *folliculus*, a diminutive of *follis*, a bellows, bag, or sac]. A small tubular or sac-like depression, usually with a secretory function, *e.g.* the gastric follicles.

**Foramen** (fo-rā′-men), pl. foramina. A hole or perforation.

**Fulcrum** (ful′-krum) [Lat. *fulcrum*, a prop]. The fixed support on which a lever turns.

**Fungiform** (fun-ji-form) [Lat. *fungus*, a mushroom]. Having the shape of a mushroom, as certain papillæ of the tongue.

**Fusiform** (fū′-si-form) [Lat. *fusus*, a spindle]. Tapering both ways like a spindle; spindle-shaped.

**Ganglion** (gang′-gli-on) [Gk. *ganglion*, pl. *ganglia*, a swelling]. A knot-like mass or aggregation of grey nervous matter, consisting of nerve cells with nerve fibres running to and from them.

**Gastric** (gas′-trik) [Gk. *gaster*, the stomach]. Pertaining to the stomach.

**Gelatin** (jel′-a-tin) [Fr. *gélatine*, jelly]. A nitrogenous food-stuff containing the same elements as proteid in nearly similar proportions. It differs from a true proteid, as it can only in small part make good the nitrogenous waste of the body. White fibrous tissue yields gelatin on boiling. Pure gelatin is a transparent brittle solid that dissolves in hot water and forms a jelly on cooling. Glue is an impure kind of gelatin.

**Glenoid** (glē′-noid) [Gk. *glene*, a socket]. Socket-like, as the glenoid cavity in the scapula for articulation with the humerus; the glenoid fossa in the temporal bone for articulation with the lower jaw.

**Globule** (glob′-ūl) [Lat. *globus*, a globe or sphere]. A little sphere, as the fat globules seen under the microscope in milk.

**Globulin** (glob′-ū-lin). A proteid substance closely allied to albumin.

**Glomerulus** (glō-mer′-o-lus) [Lat. diminutive of *glomus*, a ball of yarn]. A cluster of capillary vessels, such as those forming part of the Malpighian bodies of the kidney.

**Glycogen** (glī′-kō-jen). A carbohydrate known as animal starch. It is formed by the liver cells out of the digested starch and sugar in the blood.

**Gustatory** (gus′-tā-tō-ri) [Lat. *gustus*, taste]. Pertaining to the sense of taste.

**Hæmoglobin** (hē-mo-glō-bin) [Gk. *haima*, the blood]. The substance found in the red corpuscles of the blood that has the power of carrying oxygen. It is a complex compound containing carbon, nitrogen, oxygen, and iron; it gives the corpuscles and the blood the red colour; it combines loosely with oxygen, which it carries to the tissues, the fully oxidized condition being called *oxyhæmoglobin*.

**Haversian canal** (hav-er′-si-an). One of the numerous small channels in the substance of bone for the capillary blood-vessels. The channels are named after Havers, an English anatomist (seventeenth century).

**Hepatic** (hē-pat′-ik) [Gk. *hepar*, *hepatos*, the liver]. Pertaining to the liver.

**Hyaline** (hī′-a-lin) [Gk. *hualos*, glass). Like glass, clear.

**Ileum** (il′-e-um) [Gk. *eilein*, to twist]. The lower three-fifths of the small intestine (the word must not be confused with *ilium*).

**Ileo-cæcal** (il-ē-ō-se′-kal). Relating to the ileum and cæcum, as the ileo-cæcal valve (Fig. 113).

**Iliac** (il′-i-ak). Pertaining to or near the ilium or flank-bone.

**Ilium** (il′-i-um) [Lat. *ilium*, the flank]. The upper bone of the pelvis.

**Incisor** (in-sīz′-or) [Lat. *incido*, to cut into]. The chisel-shaped front teeth.

**Infundibulum** (in-fun-dib′-ū-lum) [Lat. *infundibulum*, a funnel]. A name applied to one of the air spaces into which the minute bronchial tubes expand and which consist of a number of alveoli or air cells.

**Inhibition** (in-hi′-bish-on) [Lat. *inhibeo*, I hold in]. A restraining or checking upon the action of some organ by the nervous system, as the inhibitory or restraining action of the pneumogastric on the heart.

**Innominate** (i-nom′-i-nāt) [Lat. *in*, not, *nominatus*, named]. A term applied to several parts of the body to which no definite name has been given, as the innominate bone, the innominate artery, etc.

**Intercostal** (in-ter-kost′-al) [Lat. *inter*, between, and *costa*, a rib]. Between or connecting the ribs.

**Jejunum** (je-jōōn′-um) [Lat. *jejunus*, empty]. The middle portion of the small intestine, about eight feet long—often found empty after death.

**Jugular** (jug′-ū-lar) [Lat. *jugulum*, the throat]. A term applied to the large veins situated in the neck and returning the blood from the head.

**Labyrinth** (lab′-i-rinth) [Gk. *laburinthos*, a maze]. An intricate arrangement of passages, as in the inner ear.

**Lachrymal** (lak′-ri-mal) [Lat. *lachryma*, a tear]. Relating to tears which are secreted and discharged by the lachrymal glands.

**Lacteals** (lak′-te-al) [Lat. *lac*, *lactis*, milk]. The fine lymphatic tubes of the intestines which take up the fatty matter during digestion.

**Lacuna** (la-kū′-na) [Lat. *lacuna*, pl. *lacunæ*, a hollow]. A hole or cavity, as the small spaces in bony tissue occupied during life by the bone cells.

**Lamina** (lam′-i-na) [Lat. *lamina*, a thin plate, diminutive *lamella*]. A thin plate or layer, as the laminar bony plates.

**Lateral** (lat′-er-al) [Lat. *latus*, *lateris*, the side]. Situated on one side, as the lateral columns of the spinal cord.

**Lens** (lenz) [Lat. *lens*, a lentil]. A transparent substance having curved surfaces and the power of changing the direction of rays of light.

**Lesion** (le′-zhun) [Lat. *læsis*, from *lædo*, I injure]. Injury, harm, or damage, whether visible or not; any change impairing the function of a part.

**Leucocytes** (lū-kō-sīt) [Gk. *leukos*, white, and *kulos*, a hollow vessel or cell]. A term applied to white blood-corpuscles, lymph corpuscles, lymph cells, and the wandering cells of connective tissue.

**Ligament** (lig′-a-ment) [Lat. *ligare*, to bind]. The fibrous bands of connective tissue which bind bones together at the joints.

**Lobe** (lōb) [Lat. *lobus*, a rounded mass]. A rounded or prominent portion of an organ separated from other parts, as the lobes of the liver and of the brain.

**Lobule** (lob′ūl) [Lat. *lobulus*, a little lobe, diminutive of *lobus*, a lobe]. One of the lesser divisions of the cerebrum; one of the small elementary structures that go to form a lobe of an entire organ, as in the liver, lung, and various glands.

**Loins**. The lateral and back part of the body between the hinder part of the lower ribs and the pelvis.

**Lumbar** (lum′-bar) [Lat. *lumbus*, the loin]. Situated in the loins, as the lumbar vertebræ, the lumbar muscles, etc.

**Lymph** (limf) [Lat. *lympha*, a spring of water]. The fluid consisting of plasma and white corpuscles which has left the capillaries to nourish the cells of the body.

**Lymphatics** (lim-fat′-ik). The tubes which convey lymph back to the great veins.

**Malar** (mā′-lar) [Lat. *mala*, the cheek]. Relating to the cheek, the cheek-bone.

**Malpighian** (mal-pig′-i-an) body or corpuscle. One of the numerous small structures found in the cortical substance of the kidney, each consisting of the dilated extremity of a urineriferous tubule enclosing a tuft or glomerulus of minute blood-vessels. The bodies are named after Malpighi, an Italian anatomist (seventeenth century).

**Mastication** (mas-ti-kā′-shon) [Lat. *mastico*, I chew]. The act of chewing, produced by the movements of the lower jaw.

**Matrix** (mā′-triks) [Lat. *matrix*, from *mater*, mother]. That which encloses anything; the groundwork in which the cells of a tissue are embedded; the portion of corium or true skin lying beneath the root of a nail.

**Maxillary** (maks′-il-ar-i) [Lat. *maxilla*, jawbone, diminutive of *mala*, cheek-bone]. Referring to the jaw, as the superior and inferior maxillary bones.

**Maximum** (maks′-i-mum). A Latin superlative signifying greatest or highest. Minimum signifies least or lowest.

**Meatus** (mē-ā′-tus) [Lat. *meare*, to pass]. A passage.

**Medulla** (me-dul′-a) [Lat. *medulla*, pith or marrow]. Any soft substance resembling marrow in structure or position.

**Medulla oblongata**. The part of the brain just above the spinal cord, called also the **spinal bulb**.

**Membrane** (mem′-brān) [Lat. *membrana*, skin]. Any skin-like part of an organ.

**Mesentery** (mes′-en-ter-i) [Gk. *mesos*, middle, *enteror*, intestine]. The folds of peritoneum which unite parts of the intestines and join them to the posterior abdominal wall.

**Metabolism** (me-tab′-o-lizm) [Gk. *metabole*, a change]. The entire series of changes connected with the manufacture and changes of the protoplasm of the tissues, and divisible into (1) constructive metabolism or *anabolism*, and (2) destructive metabolism or *katabolism*.

**Metatarsal** (met-a-tar′-sal) [Gk. *meta*, after, and *tarsos*, the part of the foot adjoining the ankle-joint]. The five metatarsal bones are the five bones between the tarsus and the toes.

**Mitral** (mī′-tral) [Gk. *mitra*, a head covering]. The mitral or bicuspid valve between the left auricle and ventricle resembles a priest's mitre when closed.

**Molar** (mō′-lar) [Lat. *mola*, a mill]. A tooth having a flat surface for grinding food. The last three teeth on each side of each jaw are molars.

**Mucus** (mū′-kus) [Lat. *mucus*, slime]. The thin slimy fluid produced by the epithelium that lines the organs of respiration and digestion. It consists of water, a proteid substance called mucin, and a small amount of salts.

**Mucous membrane.** The soft skin-like membrane that lines the tubes and cavities which open on the surface of the body.

**Myosin** (mī-ō-sin). The substance formed when muscle plasma coagulates. The substance from which myosin is produced is called mysinogen.

**Nares** (nā′-rēz) [Lat. *naris*, a nostril]. The nostrils; the anterior openings and the posterior openings of the cavities of the nose.

**Nasal** (nā′-zal) [Lat. *nasus*, nose]. Relating to or situated in the nose.

**Neural** (nū′-ral) [Gk. *neuron*, a nerve]. Relating to the nerves or nervous tissue.

**Neurone** (nū′-ron). A nerve unit (see par. 144).

**Nucleus** (nū′-klē-us). The central and essential part of a cell.

**Occipital** (ok-sip′-i-tal) [Lat. *ob*, against; *caput*, the head]. Pertaining to the occiput or back part of the head.

**Ocular** (ok′-ū-lar) [Lat. *oculus*, an eye.] Pertaining to the eye.

**Odontoid** (o-don′-tōid) [Gk. *odous*, *odontos*, a tooth; and *eidos*, form]. Resembling a tooth; the tooth-like peg or process of the axis round which the atlas turns.

**Olecranon** (ō-lē-krā′-non) [Gk. *olene*, elbow; *kranion*, head]. A process or projection of the ulna forming the bony prominence at the back of the elbow.

**Olfactory** (ol-fak′-tor-i) [Lat. *oleo*, to smell, and *facio*, to make]. Pertaining to the sense of smell.

**Optic** (op′-tik) [Gk. *ops*, eye]. Relating to the eye or the sense of sight.

**Orbit** (or′-bit) (Lat. *orbis*, a socket]. The bony socket or cavity in which the eyeball is situated.

**Os** [Lat. *ŏs*, *ossis*, a bone]. Bone. The adjective *osseous* means bony, or composed of bone. The os innominatum, innominate or nameless bone, is so-called as it bears no resemblance to any known object. Each os innominatum consists of ilium, ischium, and pubes.

**Osmosis** (os-mō′-sis) [Gk. *osmos*, an impulse.]. The diffusion of a liquid or of substances in solution through membranes or porous partitions.

**Oxidation** (ok-si-dā′-shon). The process of uniting with oxygen.

**Oxyhæmoglobin** (ok-si-hem-ō-glō′-bin). Hæmoglobin loosely combined with oxygen as it exists in the red corpuscles of arterial blood. It is a substance of a bright red colour, and can be obtained crystalized in rhombic prisms from the blood.

**Papilla**, pl. papillæ (pa-pil′-a) [Lat. *papilla*, nipple]. A teat, or something like a nipple; a small conical elevation as a papillary process, often very small, as the papillæ of the tongue, the papillæ of the true skin, in which nerves terminate.

**Paralysis** (pa-ral′-i-sis) [Gk. *para*, beside, and *lusis*, a loosening]. Failure of action of a part due to interference with its nerve supply; loss of sensation or voluntary motion, or both.

**Parietal** (pa-rī′-et-al) [Lat. *paries*, *parietis*, a wall]. Forming or situated upon the side walls of a cavity.

**Parotid** (par-ot′-id) [Gk. *para*, besides; *ous*, *otis*, the ear]. Lying alongside the ear, as the parotid glands.

**Pectoral** (pek′-to-ral) [Lat. *pectus*, *pectoris*, the breast]. Relating to the chest.

**Pelvis** (pel-vis) [Lat. *pelvis*, a basin]. (1) The bony basin at the bottom of the trunk; (2) the cavity of the kidney into which its pyramids project, and which forms the expanded upper end of the ureter.

**Peptone** (pep′-tōn) [Gk. *pepto*, to digest]. A substance formed by the digestion of a proteid.

**Pericardium** (per-i-kar′-di-um) [Gk. *peri*, around; *kardia*, the heart]. The closed membranous covering that envelops the heart.

**Periosteum** (per-i-os′-tē-um) [Gk. *peri*, around; *os*, a bone]. The thin fibrous and vascular membrane that invests the surfaces of bones, except on the articular surfaces.

**Periphery** (pe-rif′-er-i) [Gk. *peri*, around; *phero*, I carry]. The outside, the parts away from the centre, the superficial portions.

**Peristaltic** (per-i-stalt′-ik) [Gk.

*peri*, around; *stalsis*, a constriction]. Peristaltic muscular action, seen in the alimentary canal and other tubes provided with both circular and longitudinal fibres, is the rhythmic wave of contraction passing from above downwards, and due to the successive contractions of the circular and longitudinal fibres, whereby the contents of the tube are driven onwards.

**Peritoneum** (per-i-tō-nē′-um) [Gk. *peri*, around; *teino*, to stretch]. The serous membrane lining the abdominal cavity and surrounding the enclosed viscera.

**Petrous** (pet′-rus) [Gk. *petra*, a rock]. The dense portion of the temporal bone in which the inner ear is situated is termed petrous owing to its hardness.

**Phagocyte** (fag′-o-sīt) [Gk. *phago*, I eat; *kutos*, a cell]. A leucocyte or cell that ingests and destroys or renders harmless injurious foreign particles, such as bacteria, etc.

**Phalanges** (fā′-lan-jēs), pl. of phalanx. A row of bones in the fingers or toes.

**Phrenic** (fren′-ic) [Gk. *phrēn*, the diaphragm]. Pertaining to the diaphragm, as the phrenic nerves from the cervical plexus to the diaphragm.

**Pigment** (pig′-ment) [Lat. *pigmentum*, a dye]. Colouring matter, especially that in cells.

**Plasma** (plas′-ma). The liquid part of living blood or lymph as distinguished from the corpuscles; also the juice squeezed out of fresh muscle, called muscle plasma.

**Pleura** (plōō′-ra). The serous membrane which envelops each lung, and which reflects back at the root line to the inner wall of the thorax.

**Plexus** (pleks′-us) [Lat. *placto*, I plait; *plexus*, a plating]. An intricate network, especially of nerves or veins.

**Pneumogastric** (nū-mō-gas′-trik) [Gk. *pneumon*, the lungs, and *gaster*, the stomach]. Pertaining to the stomach and lungs. The pneumogastric or vagus nerve is the tenth cranial nerve (par. 147).

**Pons** [Las. *pons*, a bridge]. A term applied to the nervous structure connecting the medulla and the crura cerebri.

**Portal** (pōrt′-al) [Lat. *porta*, a gate]. Pertaining to the porta or notch of an organ, especially of the liver, as the portal vein.

**Process** (pros′-es) [Lat. *pro*, forward; *cedo*, I go]. A word used to signify any projecting part or prominence; also the method of action or procedure.

**Pronation** (prō-nā′-shun) [Lat. *pronatus*, bent forward, with face downward]. The prone position of the arm is that in which the palm of the hand is turned downwards. The opposite is supination, in which the palm of the hand is upward. In pronation the bones of the forearm are crossed, in supination they lie parallel to each other.

**Proteid** (prō′-tē-id). A proteid substance is a compound of carbon, oxygen, nitrogen, and hydrogen, with sulphur and phosphorus in very small quantities. Proteids cannot be built up in an animal's body from simpler compounds, and must, therefore, be supplied in the food. The proteid food-stuffs are called nitrogenous because they are the only kind containing nitrogen. All proteids that enter the body are in the end broken up to form carbon-dioxide, water, and urea. The general properties and tests for proteids are given in par. 99.

**Proteolytic** (prō-tē-ō-lit′-ik) [Proteid and Gk. *lutikos*, loosening]. Having the power of splitting up proteids and changing them into substances which can be absorbed.

**Protoplasm** (prō′-tō-plazm) [Gk. *protos*, first; *plasma*, form]. The viscid contractile substance that forms the chief portion of cells—living matter. Owing to its presence in all organized beings, protoplasm has been called "the physical basis of life." Chemically it consists of water, proteids, and small quantities of carbohydrates and mineral salts.

**Pulse** (puls) [Lat. *pulso*, to beat]. The rhythmic beating of the elastic arteries due to the passage of blood waves caused by successive contractions of the ventricles of the heart.

**Ptyalin** (ti'-a-lin) [Gk. *ptualon*, saliva]. The ferment found in saliva that has the power of converting starch into a kind of sugar.

**Pulmonary** (pul'-mō-nā-ri) [Lat. *pulmo*, *pulmonis*, lung]. Pertaining to the lungs.

**Pylorus** (pi-lō'-rus) [Gk. *puloros*, a gatekeeper]. The ring-like opening from the stomach into the duodenum.

**Racemose** (ras'-ē-mōs) [Lat. *racemus*, a bunch of grapes]. Resembling a bunch of grapes on its stalk; glands having ducts which divide and subdivide and end in small sacs or acini are called racemose glands, exemplified in the salivary glands and the pancreas.

**Radial** (rā-di-al). Pertaining to the radius, the bone on the outer or thumb side of the forearm, as the radial pulse.

**Ramify** (ram'-i-fī) [Lat. *ramus*, a branch]. To spread out like branches.

**Reflex** (rē'-fleks) [Lat. *re*, back; *flecto*, *flexus*, I bend]. Bending backward. Reflex action implies the existence of a nervous arc composed of (1) an afferent nerve conveying a stimulus from its starting-point in the periphery; (2) a nerve centre composed of ganglion cells and capable of converting this impression into an outgoing impulse; and (3) an efferent nerve leading from the centre to the part put in action.

**Renal** (rē-nal) [Lat. *renes*, the kidneys]. Pertaining to the kidneys, as the renal arteries, etc.

**Rennin** (ren'-nin) [Sax. *rinnin*, to run]. The ferment found in gastric juice that causes the curdling of milk by coagulating the casein.

**Retina** (ret'-i-na) [Lat. *rete*, a net]. The third or internal membrane of the eyeball.

**Rhythm** (rithm) [Gk. *rhythmos*, measured movement]. Any regularly recurring motion, as the rhythmic contraction of the heart.

**Ruga** (rōō'-ga) [Lat. *ruga*, pl. *rugæ*, a fold or wrinkle]. The rugæ are folds of the mucous membrane of the stomach.

**Sac** [Lat. *saccus*, a bag]. A bag, pouch, or receptacle of some kind.

**Saccule**. Diminutive of sac, a very small sac.

**Sacro-sciatic** (sā-krō-sī-at'-ik). Connecting the sacrum and ischium.

**Sacrum** (sā'-krum) [Lat. *sacrum*, sacred]. The somewhat curved triangular bone composed of five united vertebræ wedged in behind between the two iliac bones of the pelvis, regarded as indestructible, and therefore sacred.

**Salts.** Chemical compounds formed from an acid when a part or the whole of the hydrogen of the acid is replaced by a metal.

**Saponify** (sā-pon'-i-fī) [Lat. *sapo*, *saponis*, soap, and *facio*, I make]. To convert into soap by combination with an alkali; to decompose oils or fats into salts of the fatty acid and glycerine.

**Sarcolemma** (sar-kō-lem'-a) [Gk. *sarx*, *sarcos*, and *lemma*, husk or sheath]. The delicate sheath surrounding the fibres of striped muscular tissue.

**Sartorius** (sar-tō'-ri-us) [Lat. *sartor*, a tailor]. A long, flat, narrow muscle, arising from the ilium and passing obliquely across the upper and front part of the thigh from the outer to the inner side, to be inserted into the top of the tibia; brought into action in crossing the legs.

**Scala** (skā'-la) [Lat. *scala*, a ladder]. One of the passages in the cochlea in the inner ear.

**Sciatic** (sī-at'-ik) [Lat. *ischiaticus*, from *ischium*, hip-bone]. The great sciatic, the largest nerve in the body, arises from the sacral plexus, and, running through the back of the thigh, ends in branches for the skin and various muscles of the lower limbs. The disease sciatica is marked by severe neuralgic pains along the course of the sciatic nerve.

**Sclerotic** (sklē-rot'-ik) [Gk. *skleros*, hard]. The tough outer covering of the eye.

**Sebaceous** (sē-bā'-shus) [Lat. *sebum*, suet]. The sebaceous glands of the skin secrete an oily matter.

**Secretion** (sē-krē'-shon) [Lat. *se*, apart; *cretus*, separated]. (1) The act of separating from the blood a substance to be used by or discharged from the body (par. 110). (2) The substance so separated from the blood.

**Semi-lunar** (sem-i-lū′-nar) [Lat. *semi*, half; *luna*, the moon]. Shaped like a half-moon.

**Septum** (sep′-tum) [Lat. *sepio*, to fence in]. A partition, especially a partition between two cavities.

**Serous membrane** (sē′-rus). Serous membranes are thin membranes of connective tissue that line certain cavities of the body, and are reflected over the contained viscera, forming in this way a closed bag or sac. Such sacs contain a small amount of a variety of lymph, called from its appearance serous fluid. The two pleuræ, the pericardium and the peritoneum, are examples of serous membranes.

**Serum** (sē′-rum). The clear liquid portion that separates from blood after coagulation and the formation of clot.

**Solution** (sol-ū′-shun) [Lat. *solutus*, loosened]. A liquid containing particles of a solid, gas, or another liquid uniformly diffused through it, the ingredients being unchanged in essential properties.

**Sphincter** (sfingk′-ter) [Gk. *sphingin*, to bind]. A ring-shaped muscle surrounding a natural orifice of the body, as the pylorus, and the circular muscular fibres of the iris.

**Squamous** (skwā′-mus) [Lat. *squama*, a scale]. Scaly, shaped like a scale.

**Stapes** (stā-pēz) [Lat. *stapes*, a stirrup]. The bone of the middle ear, inserted by its base into the fenestra ovalis.

**Steapsin** (stēp′-sin) [Gk. *stear*, fat]. A ferment in pancreatic juice which saponifies fats.

**Stimulus** (stim′-ū-lus) [Lat. *stimulus*, a goad or spur; pl., *stimuli*]. An agent or excitant which is able to cause reaction in muscular or nervous tissue on which it acts. It may be mechanical (pinching, pricking, etc.), thermal, electrical, or chemical.

**Striated** (strī-āt′-ed) [Lat. *stria*, a furrow or streak]. Striped, provided with striæ.

**Subclavian** (sub-klā′-vi-an) [Lat. *sub*, under]. Lying beneath the clavicle.

**Sublingual** (sub-ling′-gwal) [Lat *sub*, under; *lingua*, the tongue] Situated under the tongue.

**Submaxillary** (sub-mak′-si-lā-ri) [Lat. *sub*, under; *maxilla*, the jawbone]. Situated under the lower jaw.

**Supination** (sū-pi-nā′-shon) [Lat. *supinus*, on the back]. The position in which the hand lies on its back with the palm upwards (see Pronation).

**Suture** (sū′-tur) [Lat. *sutura*, a sewing or seam]. The union of certain bones of the skull by the interlocking of their saw-like edges.

**Synovia** (sin-ō′-vi′-a) [Gk. *syn*, with, and *oon*, an egg]. The viscid secretion of the synovial membrane of joints—resembles white of raw egg. Synovial membrane — the membrane that lines the capsular ligaments of joints, and that secretes synovia.

**Systemic** (sīs-tem′-ic). Belonging to the system or body as a whole.

**Systole** (sis′-tō-lē) [Gk. *syn*, together, and *stello*, I place]. The contraction of the heart.

**Tactile** (tak′-tīl) [Lat. *tactus*, touch]. Pertaining to the touch, or touch sensations.

**Tarsus** (tar′-sus) [Gk. *tarsos*, tarsus]. The part of the foot adjoining the ankle-bone, consisting of seven bones, the first of which, the astragulus, articulates with the tibia and fibula to form the ankle-joint.

**Tendon** (ten′don) [Lat. *tendo*, stretch]. The white fibrous cord of connective tissue into which the fibres of a muscle pass, and which serve to attach the muscle to the periosteum of bone. They are inelastic, and do not stretch. Tendons are also known as sinews.

**Tension** (ten′-shun) [Lat. *tendo*, I stretch]. A state of stretching or tightness; internal pressure, or tendency to expand.

**Tone** [Lat. *tonus*, a sound from; *tendo*, to stretch]. (1) a sound of a certain pitch; (2) a moderate state of tension or contraction, as arterial tone; (3) a state of healthy vigour.

**Triceps** (trī′-seps) [Lat. *tres*, three; *caput*, head]. A muscle having three heads or separate points of origin, as the triceps of the arm that lies along the back of the humerus.

**Tricuspid.** Having three cusps or points, as the tricuspid valve.

**Trypsin** (trip′-sin). The proteolytic ferment in the pancreatic juice.

**Tympanum** (tim′-pan-um) [Gk. *tympanon*, a drum]. (1) The middle ear, or cavity between the tympanic membrane and the inner ear; (2) the membrane or drum of the ear is also spoken of as the tympanum.

**Ulna** (ul′-na). The inner and larger of the two bones of the forearm.

**Ulnar** (ul′-nar). Situated near or in relation to the ulna. The ulnar nerve is a nerve descending on the inner side of the arm to the elbow-joint, and passing thence to the muscles of the palm, little finger, and one side of the ring finger. Its stimulation by a knock (hitting the funny-bone) causes the well-known peculiar numb sensation in the fingers to which it passes.

**Urea** (ū′-rē-a). A nitrogenous compound formed in the liver and other tissues by the decomposition of proteid matter, and carried by the blood to the kidneys, which separate it and pass it off in the urine.

**Uriniferous** (ū-ri-nif′-e-rus) [Lat. *urina*, urine; *fero*, I carry]. Carrying or transporting urine, as the uriniferous tubules in the kidneys.

**Uvula** (ū′-vū-la). The fleshy conical projection hanging from the back of the soft palate over the back of the tongue.

**Vagus** (vā′-gus) [Lat. *vago*, I wander; *vagus*, wandering]. A term applied to the pneumogastric nerve on account of its length and varying distribution.

**Valve** (valv) [Lat. *valva*, a leaf of a folding door]. A device to control the flow of a liquid; a membranous part or fold acting as a valve to control the flow of blood or lymph.

**Valvulæ conniventes.** Transverse fold or puckers in the inner walls of the small intestine.

**Vascular** (vas′-kū-lar) [Lat. *vas*; pl. *vasa*, a vessel]. (1) Pertaining to vessels which contain fluids, as the vascular system (par. 72). (2) Provided with small blood-vessels. Muscle and bone are very vascular tissues, but cartilage and epidermis are non-vascular.

**Vaso** [Lat. *vas*, *vasis*, a vessel]. A prefix meaning "belonging to a vessel."

**Vaso-motor** nerves are nerves regulating the size and tension of the walls cf blood-vessels.

**Vena cava** [Lat. *vena*, a vein; *cava*, hollow; pl., *venæ cavæ*]. The superior or upper vena cava and the inferior or lower vena cava that enter the right auricle of the heart are the largest veins in the body.

**Vestibule** (ves′-ti-būl) [Lat. *vestibulum*, a porch]. The vestibule of the ear is a portion of the inner ear communicating with the cochlea and semicircular canals.

**Villus** (vil′-us) [Lat. *villus*, shaggy hair; pl. *villi*]. The short, fine processes on the inner surface of the small intestine. They absorb fat into their lacteals and other digestive products into the blood-vessels.

**Viscera** (vis′-e-ra) [Lat. *viscus*, pl. *viscera*, the internal organs of the body]. The internal organs of the body in the thorax and abdomen.

**Viscid viscous** (vis′-id) [Lat. *viscum*, bird-lime]. Thick and sticky; glutinous.

**Zygoma** (zī-gō′-ma) [Gk. *zugon*, a yoke, a joining]. The bony arch of the cheek between the malar and temporal bones.

# NUMERICAL DATA CONCERNING THE HUMAN BODY

THE weight of a man of average height and build is about 140 lbs. The muscles and tendons of such a man would weigh about 60 lbs. ; the skeleton about 22 lbs. ; the brain about 3 lbs. ; the liver about 3 lbs. ; the heart about 10 ozs. ; and the two kidneys about 8 ozs. There would be from 8 to 9 lbs. of blood in the various blood-vessels of the body.[1]

The heart beats about 72 times a minute when a person is at rest, sending out at each stroke about $3\frac{1}{2}$ ozs. of blood. In the great arteries the blood moves at the rate of about 1 foot per second ; in the smallest capillaries at the rate of 1 to 2 inches per minute. The pulse wave in the arteries travels at the rate of about 30 feet a second. The time taken by the blood in making a complete circuit is 23 to 25 seconds. The diameter of the aorta, the greatest blood-vessel, is about 1 inch ; the diameter of a capillary about $\frac{1}{3000}$ of an inch.

Respiration takes place about 17 times a minute, a little more than $\frac{1}{2}$ pint of air being inspired and expired at each breath. The air in passing in and out of the lungs loses from 4 to 6 per cent. of its oxygen, and gains 4 to 5 per cent. of carbonic acid. In 24 hours about 15 cubic feet of oxygen are taken in, and about the same quantity of carbon dioxide given off in a day (24 hours). The air cells of the lungs are about $\frac{1}{100}$ of an inch in diameter.

From the *skin* the body throws off each day about a pint (20 ozs.) of water, about 1 oz. of carbonic acid, and a little less than 1 oz. of solid matters.

By the kidneys about 50 ozs., or $2\frac{1}{2}$ pints, of water are excreted daily, this water containing in solution about $1\frac{1}{4}$ oz. of urea and about the same quantity of other solid matters.

The mean temperature of the body in all seasons and climates is about $98{\cdot}6^\circ$ F., or $37^\circ$ C.

A nervous impulse travels at the rate of about 100 feet per second.

The size of certain small structures are—

Red corpuscles, $\frac{1}{3200}$ of an inch in diameter.

White corpuscles, $\frac{1}{2500}$ of an inch in diameter.

Striated muscular fibres (variable), $\frac{1}{400}$ of an inch in breadth ; 1 to 2 inches in length.

Non-striated muscular fibres (variable), $\frac{1}{3000}$ of an inch in breadth, $\frac{1}{400}$ of an inch in length.

Nerve fibres (variable), $\frac{1}{12000}$ to $\frac{1}{2000}$ of an inch in breadth.

Nerve cells (variable), $\frac{1}{500}$ to $\frac{1}{250}$ of an inch in breadth.

Epithelial cells (variable), $\frac{1}{1000}$ to $\frac{1}{3000}$ of an inch in breadth.

Gastric glands, $\frac{1}{400}$ of an inch in diameter to $\frac{1}{30}$ of an inch in length.

Cilia of air passages, about $\frac{1}{3000}$ of an inch in length.

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[1] A fluid ounce is 1 oz. Av. of distilled water : 20 fluid ounces are equal to 1 pint.

# QUESTIONS AND EXERCISES ON ELEMENTARY PHYSIOLOGY

THE following questions are not only intended as tests, but they also serve to indicate important points that should receive special attention. The answers should be illustrated by drawings and diagrams wherever possible, whether asked for or not; and for this purpose the student should practise the making of simple figures from those in the book during his study of the work. Elaborately shaded and finished figures are not expected.

## QUESTIONS ON CHAPTER I.

1. Explain the terms organ, tissue, cell. What is epithelial tissue, and where is it found?
2. Give a short account of the chief kinds of connective tissue.
3. What chemical elements enter into the composition of the human body? What are the properties of the elements oxygen and carbon?
4. What are the differences between organic and inorganic compounds? Mention any inorganic compounds that form part of the body, and indicate their chemical composition.
5. Name the three chief classes of organic compounds that enter into the composition of the body. State the elements found in each class of these substances. Give examples of each class.
6. In what respects does a living body resemble an engine in action? What are the differences between a living body and an engine?

## QUESTIONS ON CHAPTER II.

1. What do you understand by the statement that the body may be regarded as having a double-tube structure? What is found in the dorsal or neural tube?
2. Name the organs found in the thorax. What is the general shape and position of each?
3. What are the structures that form the walls of the abdomen? What would be the appearance of a transverse section?
4. Name the organs found in the abdomen, giving the general form and position of each. Point out the situation of the various parts of the alimentary canal.
5. Name the tissues that enter into the structure of a limb.
6. What is the general structure of the skin and of mucous membrane?
7. What is meant by a gland? Name the different varieties of glands.
8. Give a brief description of the nervous system and its functions.

## Questions on Chapter III.

1. Write out a description of the spinal column. To what extent is movement in the spinal column possible?

2. Describe a typical dorsal vertebra, and then the two topmost vertebræ.

3. Enumerate the bones forming the bony thorax. Explain the modes of attachment of the ribs behind and in front.

4. Name the chief bones of the skull, describing in particular the lower jawbone.

5. Give an account of the teeth. Explain the structure of a typical molar.

6. Compare the bones of the arm and hand with those of the leg and foot.

7. Describe the pelvic girdle and the mode in which the femur is attached to it on each side.

8. Give some account of the internal structure of a long bone such as the humerus or femur.

9. What is the general composition of bone? How would you obtain bone ash and a decalcified bone? Of what salts does bone ash consist?

10. What do you know of the structure and uses of cartilage?

## Questions on Chapter IV.

1. Describe the structures that enter into a freely movable joint.

2. Give some account of the shoulder-joint or of the hip-joint.

3. What bones come together to form the elbow-joint, and what movements can be effected at this joint?

4. What are pronation and supination? How are these two movements produced?

5. Give an account of the bones of the wrist and hand, and of the movements of the various joints between these bones.

6. Write a description of the ankle-joint.

7. Explain suture, capsule, olecranon process, saddle-joint, tarsus, malleolus.

8. Give an account of any two pivot-joints of the body.

9. Write out a classification of joints, stating the nature of the movement in each case and giving examples of each kind.

## Questions on Chapter V.

1. Describe an ordinary skeletal muscle and its appearance to the naked eye.

2. What are the different kinds of muscular tissue, and what is the microscopic appearance of each kind?

3. What changes does a muscle undergo (*a*) when it contracts, (*b*) when it dies?

4. How is the forearm flexed and extended? To which class of lever does the mechanism in each case belong?

5. According to the result of their action muscles are spoken of as flexor, extensor, abductor, and adductor. Give examples of each class.

6. Describe the various movements that may take place at the ankle-joint.

7. How is standing upright brought about? Why does a man fall down on fainting or on receiving a severe blow on the head?

8. Name some of the large muscles of the shoulder and leg. What is the result of the action of those you name?

9. What usually leads to muscular action? What is the structure of (1) a tendon, (2) a fascia, (3) a motor end-plate?

10. State what you know of the blood supply of a skeletal muscle and of a large bone like the humerus.

## Questions on Chapter VI.

1. Of what does blood consist? What is the chemical composition of its solid and liquid parts?

2. How would you examine a drop of blood under the microscope? Describe what you would see in such an examination.

3. Explain what occurs when freshly drawn blood is allowed to stand.

4. How would you obtain separately fibrin, blood plasma, and blood serum? Describe the appearance of each.

5. What are the differences between (1) arterial and venous blood, (2) red corpuscles and white corpuscles, (3) the outside and inside of a blood clot?

## Questions on Chapter VII.

1. State exactly the position, shape, and size of a human heart. Tell what you know of the pericardium.

2. Having given a sheep's heart, how would you distinguish the front from the back, the right side from the left, the aorta from the pulmonary artery?

3. Give some account of what you will see when the right side of a heart is laid open. Compare the structure of the auricle and ventricle.

4. Describe in detail what can be seen on opening the left ventricle, the left auricle, and the commencement of the aorta.

5. Give a careful account of a complete heart-beat or cardiac cycle.

6. How would you listen to the sounds of a person's heart? What sounds would you hear, and what is the nature and cause of each?

7. Describe the various valves connected with the heart. How could you show the action of any of these valves?

8. Give a general account of the circulation of the blood, illustrating your answer by a diagram. In what respects is your diagram deficient?

9. Name the chief branches of the aorta and indicate their positions and the parts of the body that they supply with blood. Name also the chief veins that unite to form the two great venæ cavæ.

10. What evidences have we of the circulation of the blood?

## Questions on Chapter VIII.

1. Compare the structure of the walls of arteries, veins, and capillaries. How would you distinguish a large artery from a vein in the dead body of an animal?

2. What do you understand by the term *blood-pressure?* What causes this pressure? Where is it greatest? Where does it diminish, and why?

3. What do you understand by the *pulse?* Where would you feel it? What is its cause? What is the speed of the pulse wave?

4. Explain how the heart is regulated by nervous impulses that reach it, and also how the calibre of the small arteries is regulated by nervous impulses.

5. Describe, with the aid of drawings, a red corpuscle, the aortic arch, and the valves of a vein. What is the purpose of the venous valves?

## Questions on Chapter IX.

1. What is the source of lymph? Give an account of its composition and properties.

2. How do lymphatic vessels arise? Trace the course of the lymph as it passes from a leg until it gets into the blood stream.

3. State the most important facts you know about (1) lymphatic glands, (2) the thoracic duct.

4. Give an account of (1) the portal circulation, (2) the mode in which the lymphatics of the intestine transfer their contents into the blood stream.

5. Where would you look for the aortic semi-lunar valves? Describe their structure and use. In what vessels of the body are similar valves?

## Questions on Chapter X.

1. Give some account of the composition of the air. What changes does it undergo by being breathed?

2. Describe the passages by means of which the air can reach the lungs. Give a fuller account of the pharynx and the various openings connected with it.

3. Describe the structure of the trachea and of the larger bronchial tubes.

4. What do we call the smallest air tubes into which the bronchial tubes divide? How do these terminate?

5. Give an account of the structure of the alveoli of the lungs, and explain how an interchange of gases takes place between the blood in the pulmonary capillaries and the air in the alveoli.

6. Give an account of the pleuræ of the lungs. Illustrate by a figure. What keeps the two layers of a pleura in contact?

7. Why do the lungs always fill the chest cavity? What is the effect of a puncture through the wall of the thorax on one side?

8. Describe carefully the structure, form, and position of the diaphragm. What is the effect of the contraction of the diaphragm?

9. What muscular movements lead to an increase in the size of the thorax, and what is the consequence of this increase in the volume of the thorax? Show, by diagrams, in what directions the thorax is increased during inspiration.

10. How is ordinary expiration brought about? By what muscular action can the lungs be more than half emptied? Can they be emptied entirely of air?

11. What is meant by *tidal air?* How does the oxygen of the tidal air reach the air cells of the lungs?

12. Explain how the nervous system regulates respiration. What is the respiratory centre?

13. What is meant by *tissue respiration?*

14. Explain why (1) a piece of sheep's lung obtained from the butcher floats when thrown into water; (2) why a person breathes more rapidly during running; (3) why a person cannot choke himself by holding his breath for five minutes?

## Questions on Chapter XI.

1. Why does a living body need food at intervals? What indicates the amount of food needed daily? Define the term "food."

2. What is a food-stuff? Name the five chief classes of food-stuffs, giving examples of each.

3. In what respects do proteid food-stuffs differ from the other classes of food-stuff? What common articles of food contain a comparatively good percentage of proteid matter?

4. What is the chemical composition of carbohydrates? Mention a few common carbohydrates. How do fats differ from carbohydrates?

5. What purposes does water serve in the body? How much is needed daily? Why must certain inorganic salts be taken in the food?

6. What is the composition of milk, bread, and lean meat? What is the appearance of milk under the microscope? How could you show that bread contain starch and a proteid? (To answer the latter part describe the tests for starch and a proteid.)

7. State the requisites of a suitable diet and explain why a diet should be a mixed one.

8. What is an emulsion? How would you emulsify olive oil?

9. What do you understand by a *ferment?* What ferment is present in saliva? How would you show its action?

10. Explain the nature of the processes called *diffusion, filtration,* and *osmosis.*

11. Describe (1) a test for dextrose or grape sugar; (2) a method of showing that organic substances contain carbon; (3) the effect of rennet on milk.

12. State why some proteid in the daily food is a necessity, and why a diet of all proteid food would be a serious disadvantage.

13. Why is milk considered a perfect food for the young? Why does a man in active work require more food than a bookkeeper of the same weight?

14. What do you know of the difference between (*a*) gelatin and a true proteid, (*b*) hæmoglobin and oxyhæmoglobin, (*c*) local death and general death?

## Questions on Chapter XII.

1. Trace the alimentary canal from the mouth through the body, giving the names and positions of its various parts. Add a drawing to illustrate your answer.

2. Give an account of the salivary glands. What do these glands secrete? What do you mean by a *secretion?* How is a secretion distinguished from an excretion?

3. Explain the process of swallowing. What happens if a morsel of food goes the "wrong way"? Illustrate your answer by drawings.

4. Describe the minute structure of the walls of the stomach, especially that of its mucous membrane.

5. State the composition of gastric juice. On what kinds of food-stuffs does gastric juice act? What is the nature of *chyme?*

6. Describe the inner coat of the small intestine. How do pancreatic juice and bile reach the small intestine? What is the composition of pancreatic juice, and how does it assist in the digestion of food?

7. What are villi? How big is a villus? Describe the structure of a villus. What is the function of the villi?

8. Tell what you know about the position of the large intestine. What changes does the food, that has not already been absorbed, undergo in the large intestine?

9. In what parts of the alimentary canal are the various kinds of food absorbed? What is the nature of the processes called digestion, absorption, and assimilation? How does the fat of food reach the blood stream?

10. Tell what you know about the position, structure, and uses of the following:—the pylorus, Lieberkühn's glands, lacteals, the ileo-cæcal valve.

11. How would you obtain gastric juice for experiments, and how would you proceed to show its digestive action on fibrin or coagulated white of egg?

12. What is the effect of (*a*) breathing into lime-water, (*b*) putting a few drops of iodine on a slice of bread, (*c*) putting a few drops of strong nitric acid on a slice of bread, heating the moistened part and adding ammonia; (*d*) boiling Benger's liquor pepticus before using it to form an artificial gastric juice?

## QUESTIONS ON CHAPTER XIII.

1. Describe carefully the position of the liver. Describe also the appearance of its upper surface and of its under surface. What vessels enter the liver, and what vessels leave it? What is the nature of the fluid in these various vessels?

2. What is meant by the lobules of the liver? What is their size? What is the structure of a lobule? What small vessels have their origin in the liver lobules, and what fluid do these vessels convey from the liver?

3. What are the functions of the liver, that is, the functions of the hepatic cells? What different appearances do liver cells present under the microscope when a thin section of liver is examined (*a*) from a fasting animal, (*b*) from an animal that was fed a little time before being killed?

4. Describe the shape and position of the gall-bladder. What is its use? What tubes are connected with it? What kind of fluid would you obtain from an ox's gall-bladder? Describe some properties of this fluid.

5. Describe the shape, situation, and structure of the pancreas. How is the main pancreatic duct formed?

6. What is the situation and shape of the spleen? What appearances does it present when cut into? What are the functions of the spleen?

## QUESTIONS ON CHAPTER XIV.

1. What are the chief excretions of the body? By what channels do they leave the body? State the average daily amount of the excretions of an ordinary sized adult?

2. Describe the exact shape and situation of the kidneys? What vessels enter each kidney, and what vessels leave it? Give a drawing.

3. Give a description of a sheep's kidney as it appears to the naked eye. What is seen when a section is made parallel to its two faces?

4. What is a uriniferous tubule? How does it begin? Where does it terminate?

5. Explain how urine is secreted by the kidney, how it is carried away from the kidney, and how it is stored before being expelled from the body.

6. What do you understand by the terms Malpighian body, glomerulus, papilla, calyx, and pelvis, as applied to structures found in the kidney?

7. A certain element of the tissues of the body is discharged almost entirely in a compound dissolved in the urine. What is this element? What is the compound in which the element exists? What other compounds exist in the urine?

8. What is the average amount of urine excreted daily? What causes lead to variations in the amount?

## QUESTIONS ON CHAPTER XV.

1. Give a general account of the two layers composing the skin, with a diagrammatic figure to illustrate your answer.

2. Describe carefully the structure and function of a sweat gland. Where are these glands most numerous?

3. What is the composition of sweat? What is *insensible perspiration* and *sensible perspiration?* What leads to the latter?

4. How does the skin act as a regulator of the heat of the body?

5. What are hairs, and how are they situated in the skin? What glands are connected with the hair follicles?

6. State a few facts about the following :—the papillæ of the skin, the fine ridges on the outer surface of the epidermis of certain parts, the pores of the skin, the subcutaneous fat, vaso-motor nerves.

7. Enumerate the various functions of the skin. How are any of the functions of the skin related to a function of the kidney?

## Questions on Chapter XVI.

1. How would you find the temperature of the body? What is the temperature in health, in degrees F. and C.? What is meant by feeling hot or cold?

2. Where is the heat of the body produced? As heat is continually being produced in the body, how is it that its temperature does not rise?

3. How does the body lose heat? What is the use of clothing? What is the cause of a "cold sweat"?

4. Explain clearly how the heat of the body is regulated so that its temperature is kept constant. What occurs in a Turkish bath where the temperature of the air may be 110° F.?

## Questions on Chapter XVII.

1. Give a general account of the nervous system and its functions.

2. Describe, with the aid of drawing, the structure of a nerve cell and of a nerve fibre. How are nerve fibres related to nerve cells?

3. What does a nerve in a limb look like? How are nerves classified according to function? What is a nervous impulse?

4. Write an account of the various parts of the brain, and of the membranes which protect it.

5. Name the chief cranial nerves, giving their superficial origin and the functions of each.

6. Where is the medulla oblongata or spinal bulb placed? With what structures is it connected above and below? What nerve centres are situated in the bulb?

7. Describe the structure and functions of the cerebral hemispheres. Why is it that, when one side of the brain is injured, paralysis is produced on the opposite side of the body?

## Questions on Chapter XVIII.

1. Describe clearly the situation and form of the spinal cord. How is the cord protected and supplied with blood? What is seen when a section of the cord is made, and the cut surface examined by a lens?

2. Explain how a spinal nerve arises, and how it leaves the spinal canal. How are the functions of the two roots of a spinal nerve ascertained?

3. What are the functions of the spinal cord? When a person breaks his back, that is, injures or severs the spinal cord in the region of the back, what results follow? What is the result of breaking the neck?

4. Explain clearly, with the aid of a diagram, the nature of a reflex action. Give examples of reflex actions.

5. What is the sympathetic nervous system? What connection is there between the sympathetic chain and the spinal cord?

6. Tell what you know about the vagus nerve and the great sciatic nerve.

7. When the cerebral hemispheres of a frog are removed, of what actions is it capable? What is a stimulus?

## Questions on Chapter XIX.

1. What is meant by *sensation* and by *sense organ?* How many fundamentally different kinds of sensation may we experience?

2. How do the sensory nerves end in the skin? How can we estimate the delicacy of the sense of touch? What is referred sensation?

3. Give some account of the tongue, describing in particular the papillæ on its upper surface. In what state must a substance be before it can be tasted?

4. Describe a nasal chamber—its openings, its forms, and its mucous membrane. How do the filaments of the olfactory nerve reach the nasal chamber, and how do they terminate?

5. What is the effect of a bad cold on the senses of taste and smell? How do you explain this effect?

6. What do we learn from the muscular sense and from the temperature sense? With what nerve fibres are these connected?

## Questions on Chapter XX.

1. Describe the situation of the eyeball and the ways in which it is protected. What is the *conjunctiva*, and how is it related to the eyelids and the front of the eye?

2. Where are the lachrymal glands? What is the nature and purpose of their secretion? What becomes of the secretion?

3. Explain the various modes in which the eyeball can be moved.

4. Give a general account of the structure of the eyeball, illustrating your answer with a figure of a section of the eyeball from front to back.

5. Describe carefully the position, connections, form, and structure of the iris. What is the pupil of the eye? How are changes in the size of the pupil brought about, and under what circumstances?

6. Explain how you would dissect an ox's eye so as to show its chief coats, and to obtain its crystalline lens.

7. Describe, with the aid of a figure, how you can obtain the image of an object on a screen by means of a double convex lens. When you have got the image clear, what will be the effect of bringing the object nearer to the lens?

8. What changes take place in the eye when the attention is directed from a distant to a near object? Why are these changes necessary, and how are they brought about?

9. Give some account of the position and structure of the retina. Which part of the retina is most sensitive to light, and which part is insensitive to light? How would you prove the existence of a blind spot on the retina?

10. Explain the following:—(*a*) Pressure on the eyeball on the inner side produces the sensation of a ring of light; (*b*) a glowing stick, rapidly twirled, causes us to see a complete ring of light; (*c*) on looking steadily for some time at a bright red cloth, and then turning the eye to a white surface, a patch of green appears; objects form inverted images on the retina, but are seen erect.

## Questions on Chapter XXI.

1. Describe the tympanum or middle ear. What openings are found in it, and where do they lead to? What is the use of the auditory ossicles?

2. Give some account of the structure of the cochlea. How does the auditory nerve reach the canal of the cochlea, and how does it terminate there?

3. Explain how a sound wave reaches the *membrana tympani* (drum of the ear), and how it passes on to stimulate the nerve endings in the organ of Corti.

4. Describe the semicircular canals of the inner ear. What parts of these canals are supplied with filaments from the auditory nerve? What is the probable function of the canals?

### Questions on Chapter XXII. and General Questions.

1. Describe the relations of the pharynx, larynx, gullet, hyoid bone, and tongue.

2. Give a general account of the structure of the larynx, describing especially (with drawings) the form and position of the chief cartilages of the organ.

3. What are the vocal cords? How would you find the vocal cords in the larynx of a sheep, and what would they look like? How does a physician view the vocal cords of a patient?

4. What is the position of the vocal cords (*a*) in ordinary quiet breathing, (*b*) when voice is being produced. How are changes in the position and tension of the vocal cords brought about?

5. What is the difference between *voice* and *speech*, between vowel sounds and consonant sounds?

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6. State what you know about the *size* of the following :—the trachea, a red blood-corpuscle, a capillary, a nerve fibre, a nerve cell, a pyramid of the kidney, the spinal cord, the thoracic duct, the heart.

7. What elements exist in carbohydrate and fats? Do the elements exist in the same proportion in these two classes of bodies? What element, needed for building up tissue, is not found in these two classes?

8. What do you know of the position, general structure, and function of the following :—the spleen, the parotid glands, the urinary bladder, the epiglottis, the tympanic membrane?

9. How do we know (1) that the renal veins contain the purest blood in the body, (2) that consciousness is a function of the cerebral hemispheres?

10. Describe the form and connections of the following :—the clavicle, one of the middle ribs, the lower jaw-bone.

11. What food-stuffs exist in a beef-steak pudding? Where and how is each kind of food-stuff digested and absorbed?

12. What do you know of the composition and properties of carbonic acid, sugar, and urea?

13. What are the causes of the following :—the red colour of arterial blood, coughing, alterations in the size of the pupil of the eye, blushing?

14. Tell what you know of the origin, distribution, and functions of the pneumogastric nerve.

15. "Ordinary inspiration is mainly the result of certain muscular actions, while ordinary expiration follows on the cessation of these muscular actions." Explain and expand this statement.

16. Tell what you know of vaso-motor nerves, the gases of the blood, the articulations of the ribs to the vertebræ.

17. How are the following actions brought about :—swallowing, nodding the head, standing on the toes, flexing the leg?

18. Describe the appearance and properties of bile, chyle, and synovia.

# BOARD OF EDUCATION EXAMINATION PAPERS IN HUMAN PHYSIOLOGY

## STAGE I., OR ELEMENTARY STAGE.

### INSTRUCTIONS.

YOU are permitted to answer only *eight* questions.

Put the number of the question before your answer.

The value attached to each question is shown in brackets after the question, but a full and correct answer to an easy question will, in all cases, secure a larger number of marks than an incomplete or inexact answer to a more difficult one.

You are to confine your answers *strictly* to the questions proposed. An answer which deals with the essential points of the question in a *clear* and *concise* way will be valued more highly than one which is made long by the introduction of diffuse or irrelevant information.

*The examination in this subject lasts for three hours.*

### 1903.

1. What does human blood look like under the microscope? Describe, with the aid of appropriate drawings, the appearances presented by such microscopic examination?

2. What happens when freshly drawn blood is (*a*) kept in a bowl, (*b*) stirred vigorously by a bundle of twigs? Describe and explain in general terms the phenomena.

3. Into what groups are the food-stuffs divided, and what chemical elements are present in each group? To what extent do these various groups occur in bread, meat, and milk respectively?

4. Describe, with the aid of appropriate drawings, the course of the blood into, through, and out of the pulmonary vessels. What is the precise importance of this blood flow?

5. Give a short description of the situation of the thorax and of the structures which form its walls. To what extent does its shape alter in respiration, and how do such alterations of shape cause the entry or exit of air?

6. Describe the position and general form of the stomach, and show by an outlined drawing how it is connected to other parts of the alimentary canal. What changes does food undergo in the stomach, and how are these brought about?

7. State quite shortly the position, general structure, and functions of the villi, the submaxillary glands, the ureters, and the carotid arteries?

8. What structures form the pelvis? Describe the way in which the lower limbs are articulated with it? What position would a lower limb assume in respect to the trunk if it were (*a*) flexed, (*b*) abducted?

9. Describe the position, general structure, and blood supply of the liver. With what great abdominal blood-vessels are those vessels connected which enter and leave this organ?

10. What is the general effect of violent muscular exercise upon respiration as regards both its rate and the amount of carbonic acid given off? How do you account for the fact that the temperature of the body is not increased under these conditions?

11. Make a drawing of the eyeball to show especially (*a*) the position of the lens, (*b*) the alteration in the direction of parallel rays of light entering the cornea and then traversing the eyeball.

12. What is meant by the term "reflex action." Give examples in illustration of your statement, selecting ones in which (*a*) involuntary muscles and (*b*) secreting glands are involved?

## 1904.

1. State the general composition of the blood. What is lymph, and how does it differ from blood? [12]

2. Describe the general character, position, and use of the various valves of the heart, illustrating your answer by drawings. [12]

3. What does milk look like under the microscope? What substances give milk its importance as a food, and what chemical elements do these substances contain? [12]

4. Describe, with the aid of an illustrative drawing, the arrangement of the various parts of the intestinal portion of the alimentary canal. What is the nature of the digestive processes which are carried out in the intestine? [13]

5. Explain what happens when we breathe, stating (*a*) the muscles which are used, and (*b*) how these cause air to enter and leave the chest? [13]

6. What bones are concerned in forming the following joints:—(i.) the head on the spine, (ii.) the elbow, (iii.) the hip? State what movements can be carried out in each case. [12]

7. State the chief chemical substances by means of which each of the elements carbon, hydrogen, nitrogen, and oxygen leave the body, and give in each case the organs which are concerned with the excretion. [13]

8. Enumerate the different kinds of sensation. What do you consider to be the fundamental distinction between the sensory and motor nerves of such a structure as a limb? [13]

9. State in general terms, and quite shortly, the position, form, and function of each of the following structures:—(*a*) the clavicle; (*b*) the crystalline lens; (*c*) the larynx; (*d*) the urinary bladder. [12]

10. Explain, by means of appropriate drawings, the means by which sound waves are conveyed from the external air to the internal air. [12]

# INDEX

[*The numbers refer to the paragraphs, and not to the pages.*]

THE END.



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