MANUALS OF ELEMENTARY SCIENCE

PHYSIOLOGY.

A. MACALISTER, LL.D., M.D., F.R.S., F.S.A

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BY

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PREFACE.

In this book I have endeavoured to present, in a simple and concise form, some of the elementary principles of the Physiology of Man. As the space at my disposal is too small for the adequate treatment of the whole subject, I have selected such portions of it as are calculated to be of use to the general reader who desires to possess an intelligent appreciation of the nature of the parts of his own body and their several functions.

It has been impossible to avoid the use of some technical terms, but I have, as far as it is necessary, defined these. I have had also to refer to some of the fundamental principles of chemistry and physics, but I have not assumed that the reader has more than a very elementary acquaintance with these subjects.

Knowledge of a practical subject such as Physiology cannot be acquired by reading alone. The examination of the organs of the body of a rabbit, and of certain of the parts of a sheep, which can be easily procured from the butcher, will greatly aid in giving clear and adequate conceptions of the parts referred to. I have consequently suggested in some of the sections the obtaining of these material aids, which are within the reach of all, and which can be examined without the use of any apparatus more complicated than common domestic utensils.

For the illustrations I am indebted to the publishing firms of Messrs. Churchill, Collins, Griffin, and Engelmann; and I have to thank Dr. Donald MacAlister for kindly reading over the proofs, and for many valuable suggestions.

ELEMENTARY PHYSIOLOGY.

1. The Material Universe is made up of aggregated particles of matter which are capable of undergoing change in form and position. To the act of inducing these changes against resistance we give the name *work*; and the capacity of doing work is called *energy*. It has been shown by experiment that part of the energy in any aggregation of matter is capable, in certain conditions, of undergoing transformation into some of the other forms in which energy manifests itself, such as chemical action, heat, or electric action. In any apparatus devised for the accomplishment of this transformation the matter whose energy is transformed is, by virtue of the alteration, changed in some of its characters, and its energy is diminished by the amount of work done by it on matter external to itself; for the energy of a body is not capable of spontaneous increase or decrease. In order therefore that such transformation may take place continuously, an amount of energy equal to the output must be supplied; that is, the transforming apparatus must be acted on by matter external to it, which transfers its energy to the working substance.

In apparatus of human device this reinforcement of energy is accomplished by some external process; fuel must be supplied, or the spring must be wound up; moreover the wear and tear of the machine must be made good by the engineer. But in the animal body, which is itself a machine, reinforcement and repair take place by its own action. It can of itself take in and utilise the material necessary for

its continued existence. The living animal is therefore a self-reinforcing and self-repairing machine.

The nature of the work of a machine as it affects the matter external to it depends on their mutual relations in space. In the case of any mechanism made by man the mode in which these activities are exercised depends on the environments in which its maker places it, and it has of itself no inherent powers other than those definitely provided in its construction to alter these in direction or amount. The living animal can of itself so modify its relation to external matter as to change the sphere of its action at will, and it possesses a voluntary power of regulating within limits the amount of the external work it performs. The animal is therefore a self-directing and self-regulating machine.

ANATOMY treats of the structure of the animal body and the way in which its several parts are built up. PHYSIOLOGY treats of the methods and processes whereby the organs which make up the body perform their work. In the succeeding paragraphs we shall confine our attention to the physiological processes of the human body.

2. METABOLISM.—The work done by the human body is various in kind and large in amount. It consists chiefly in the transformation of the energy of chemical combination into motion, heat, &c. The substance in the body, by whose changes this energy is set free, is a material consisting chiefly of the elements carbon, hydrogen, oxygen, and nitrogen, which is called **protoplasm.** This substance is found in every living tissue both of the animal and of the plant. The exact chemical constitution of protoplasm is unknown, but it is a body of extreme instability, whose molecules, which are probably of relatively large size and complexity, are easily broken up into their component groups of atoms, and these again are built up into more stable compounds, such as water, carbonic acid, &c. As long as life continues these changes are constantly taking place

in the protoplasm of the body; and to these processes the name *metabolism* is given. The energy which is transformed into heat and motion is the amount set free by the oxidation of the elements which make up the complex molecule of protoplasm. As this liberated energy is dissipated by the activities of the body, it is necessary for the continuance of life that new material capable of oxidation should be taken into the organism and made an integral part of its substance.

There are, therefore, while life lasts, two correlative sets of changes taking place in the body, **katabolism**, or oxidation of protoplasm setting free energy for transformation, and **anabolism**, or the building up again of new protoplasm molecules. The products of katabolism must for the most part be got rid of from the body, as their retention would clog the organs and interfere with the necessary transformation of energy, just as the smoke and ashes, the katabolic products accompanying the transformation of energy in a steam-engine, require to be got rid of if the machine is to continue efficient.

In consequence of this elimination there is a continual waste taking place in the material of the living body. By the process of breathing a man gets rid of an amount of carbonic acid each day which contains 8 oz. of carbon, together with more than a pint of water. About two pints of water pass off from the skin in the form of perspiration, and about the same quantity is separated by the kidneys and discharged as urine; this contains in solution about $1\frac{1}{4}$ oz. of a waste substance called *urea*. This consists of carbon, hydrogen, oxygen, and nitrogen; and in this form 300 grains of nitrogen are daily eliminated.

3. Food.—It is plain that if anabolism is to be the reciprocal of the katabolic processes which are essential to life there must daily be taken in food containing sufficient quantities of carbon, hydrogen, oxygen, and nitrogen to repair the daily loss.

These must be taken in the form of compounds with complex molecules, whose elements are capable of oxidation and so of liberating sufficient energy to be dissipated in the form of the external work of the body. The repair must be of a twofold nature, restoration of substance, and reinforcement of energy; and it is necessary that the molecules of the food shall be in the first instance converted into protoplasm that they may fulfil this dual requirement.

We classify engines according to the material whose transformation sets free the energy to do the work required, and we speak of gas-, steam-, or oil-engines. Man may be regarded as a self-stoking food-engine.

The materials suitable for food may be grouped in several categories:—

1. *Oxygen* is the only element taken into the body in an uncombined state, and a separate apparatus, that of respiration, is provided for its introduction. A free supply of oxygen is essential to the maintenance of life, as all katabolic changes are processes of oxidation.

2. Certain inorganic compounds are necessary to supply the waste attendant on elimination; of these *water* is the chief. Some other substances, such as sodium chloride (common salt) and salts of calcium and iron, are also required in small quantities.

3. The loss of carbon is generally made up by the ingestion of two kinds of food: (*a*) carbo-hydrates, such as starch and sugar, and (*b*) fats, such as butter, oils, and fat meats.

4. Some of the most necessary elements of a perfect diet are those which contain one of those complex nitrogenous substances which are called **proteids.** The most familiar of these are *albumin* (the nitrogenous component in white of egg), *myosin* (the nitrogenous component in lean meat), *glutin* (the proteid constituent of wheat flour and other vegetable foods), and *casein* (the chief component of cheese).

For the maintenance of the most perfect organic activity of the body it is found necessary to use food-stuffs containing representatives of these several classes. The following table shows the composition of a few of the commoner articles of diet:—

Food.	Water.	Starch.	Sugar.	Fat.	Proteid.	Salt, &c.
Milk................	87·2	—	4·5	4·3	3·2	0·8
Egg	74·5	—	—	10·0	14·0	1·5
Lean Beef	72·0	—	—	3·0	20·0	5·0
Bread	37·0	47·0	2·0	1·0	10·0	2·0
Pea Flour	14·0	56·5	2·0	2·0	23·0	2·5

This table shows plainly the advantages of a mixed diet. Lean meat contains most of the essentials of nutrition, but to supply the necessary 8 oz. of carbon which are lost daily a man would require to eat more than 5 lbs., which would give him three times the necessary amount of nitrogen. On the other hand, bread, which contains all the necessary elements, has the nitrogenous constituent in too small a quantity. It would require the consumption of $3\frac{3}{4}$ lbs. to supply the necessary proteids, and this would give an excess of more than half a pound of carbon.

By a judicious use of smaller quantities of those foods which are rich in nitrogen combined with larger quantities of carbo-hydrates and fatty foods the necessary balance can be preserved between waste and renewal. Were we to restrict ourselves to one article of diet it would require 5 lbs. of lean meat to supply the requisite carbon, but $1\frac{3}{4}$ lb. would suffice for the proteids; while if the staple chosen were potatoes, 21 lbs. daily would be required for the supply of the nitrogenous element, whilst $4\frac{1}{2}$ lbs. would be enough for the carbon required.

The best diet is that which satisfies the following conditions:—

1. It should be capable of easy assimilation.

2. It should contain each of the necessary elements of diet in sufficient, but none of them in excessive, quantities.

3. It should not contain any substance which may prove injurious to healthy digestion; and should contain as small a quantity as possible of insoluble material.

Tried by these canons we can determine the relative dietetic values of different articles of food; for example, cheese, of which $\frac{4}{5}$ lb. would suffice to supply the required daily amount of proteid, and $4\frac{1}{4}$ lbs. the necessary amount of carbon, has yet a very low place as an article of food as it is difficult of assimilation. In like manner, pea flour, which theoretically should be one of the most perfect of foods, as $1\frac{1}{4}$ lb. contains the requisite amount of nitrogen and 2 lbs. the desired weight of carbon, on account of its not being easy of assimilation takes rank below wheat flour.

The minimal quantities of these elements of food required by a healthy adult are—$\frac{1}{4}$ lb. of proteids, 1 lb. of carbo-hydrates, 4 pints of water, $1\frac{3}{4}$ lb. of oxygen, 3 oz. of fat. These would be liberally supplied by a daily diet such as the following:—bread, $\frac{1}{2}$ lb.; butter, 2 oz.; sugar, 1 oz.; milk, $\frac{1}{2}$ pint; water, 3 pints; meat, 8 oz.; fish, 4 oz.; potatoes, 8 oz.; rice, 2 oz.; cheese, 1 oz.

4. Assimilation.—Before the food can serve to repair the tissues of the body wasted by katabolism it must be assimilated, that is, transformed into a substance similar to the material of living tissue, and capable of building up fresh protoplasm. These processes of transformation take place in certain parts of the body called the **digestive organs**, which consist of, first, the *alimentary canal*, which begins at the mouth and is over 28 feet in length; and, secondly, the *salivary glands*, *liver* and *pancreas*, those great glandular masses appended to the alimentary canal which pour their juices into it.

The changes which the food undergoes in this

apparatus are, first, mechanical division; secondly, solution; and thirdly, much of it undergoes a modification in its molecular constitution which makes it capable of *diffusion*, that is of soaking through the membranous wall of the alimentary canal.

If two fluids which are capable of mixture, such as distilled water and salt solution, be put into the two compartments of a vessel, divided by a porous animal membrane, a certain degree of intermixture will take place in the course of a short time through the partition. This process of intermixture is called **diffusion** or **osmose.** All substances will not diffuse in this manner with equal rapidity, and some, such as solution of starch, albumen or gelatine, will scarcely diffuse at all. To such bodies the name *colloid* substances has been given. A considerable part of our food consists of colloid substances, and these must undergo an essential change in molecular structure whereby they become capable of diffusion before they can be of use in nutrition of the tissues. This change is induced by the admixture with the food of certain substances called *ferments* which exist in juices formed by the glandular parts of the digestive organs. By the action of these ferments the colloid elements are changed into substances called *crystalloids*, that is, into substances capable of diffusion.

In order to prepare the food for solution and for the fermentative changes just referred to it is desirable that its materials should be softened and mechanically divided before being taken into the alimentary canal. To this end food is subjected to heat by one or other of the processes of cookery, boiling, baking or roasting. These produce certain changes in each element of the food. The fibres of lean meat, which are enclosed in fine membranous sheaths and tied together by connective tissue, have these sheaths broken up and their connective tissue softened and partly dissolved by boiling. The fat

of meat, which consists of minute oily particles contained in membranous capsules, becomes much easier of assimilation when these capsules are broken by heat. Starch, which consists in its natural state of minute granules made up of concentric layers of an insoluble substance, cellulose, enclosing a softer inner matter, is rendered more readily soluble by baking or boiling, as by heat these enveloping layers are broken up (fig. 1).

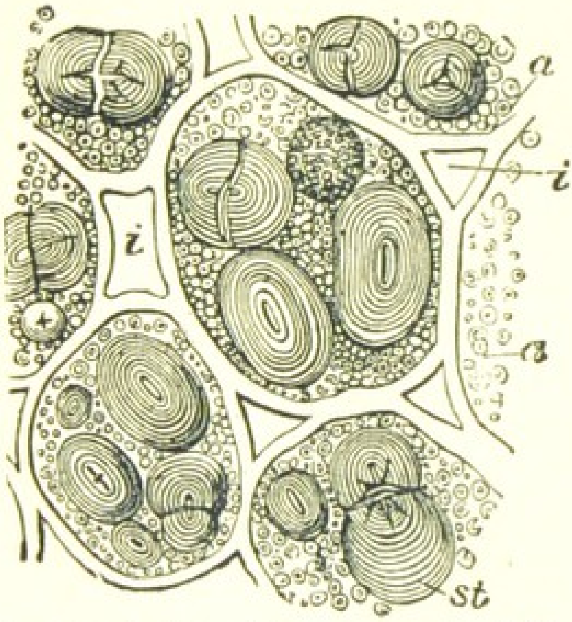

Fig. 1.—Section of a pea magnified 250 diameters, showing starch granules (*st*) with their concentric layers, and granules of aleurone or vegetable proteid (*a*). *i*, intercellular space.

There is a second function fulfilled by cookery, that of making the food palatable. It is found that, when the elements of the food are treated so as to develop agreeable odours and tastes, they stimulate those parts of the alimentary canal whose function it is to pour out the juices containing the ferments.

Cooking also kills some, and in some circumstances all the micro-organisms which exist in the materials of the food. For this reason it is a useful precaution to boil all water required for purposes of food if there be any reason to suspect its purity.

Cooking is good when it fulfils these functions, and bad when it fails either in the adequate disintegration of the food, or in rendering it agreeable to the palate. Bad cookery is wasteful because it renders the food incapable of being fully dissolved, and so a portion of it passes unchanged through the alimentary canal, in which it acts as an irritating foreign body.

5. Mastication.—The first change which solid

food undergoes when introduced into the alimentary canal is mastication, or subdivision by the teeth. The mouthful of food, shut in by the closure of the lips, is compressed, ground and torn by the pressure and impact of the lower teeth against those in the upper jaw, the tongue internally and the cheek externally keeping it between the opposed teeth whilst it is being chewed.

There are thirty-two teeth in the adult human mouth, sixteen in each jaw, those of the two sides being symmetrical. Each tooth is fixed by one or more *fangs* or roots, which are inserted into sockets in the jaw-bone. The body of the tooth is made of a hard elastic material called **dentine** or ivory, which is shown by the microscope to be permeated by exceedingly minute and closely set parallel tubules. The free face or crown of the tooth is covered by a still harder material called **enamel.** The body of the tooth is hollow, and contains within it a soft pulp into which a minute nerve and artery enter through a hole in the extremity of each fang.

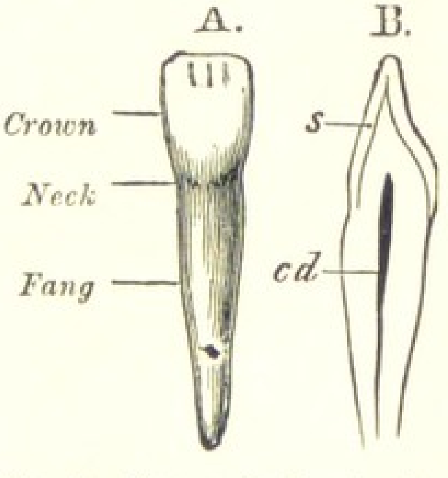

FIG. 2.—Human incisor tooth. A, front view; B, vertically divided; *s*, enamel; *cd*, pulp-cavity.

The two teeth on each side of the middle line in each jaw are called **incisors,** and have chisel-like crowns and single fangs; the next tooth, external to these, which is called the **canine,** is thicker and has a somewhat pointed crown and a longer single fang. Behind this are the two **premolars** on each side of each jaw; each of these has two points or cusps on the crown, and is rooted by a single, partly divided fang. Behind this are the three **molar** teeth, each of which has a broad crown with four or five cusps, and each is rooted by two or three fangs.

Coating the jaw about the sockets of the teeth is

the smooth elastic *gum* whose margins secrete the *tartar*, which when not removed is apt to encrust the teeth. The conditions within the mouth are such as favour putrefaction and the development of micro-organisms. Fragments of food embedded between the teeth decay rapidly, and the products of decomposition are very liable to attack the dentine and produce disease (*caries*). This is especially prone to occur when there are fissures in the enamel, a condition which is not uncommon. Hence the necessity of daily cleansing the mouth with a soft brush and water, and the advisability of having every deficiency in the enamel properly protected by some permanent filling. When caries extends through the dentine, the pulp with its nerve endings is liable to inflame, producing toothache.

In the infant at birth the teeth are enclosed in cavities in the gum; and the first tooth to appear is usually the central lower incisor, which cuts about the sixth month. By the end of the second year twenty teeth have cut, five on each side of each jaw. These are two incisors, one canine, and two molars. About the seventh year these temporary or **milk teeth** begin to drop out, and are replaced by the permanent teeth of the adult. The premolars of the second dentition replace the milk molars, and the permanent molars have had no predecessors in the temporary set.

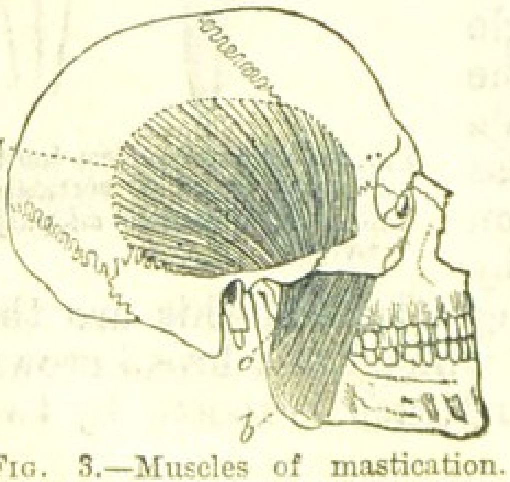

FIG. 3.—Muscles of mastication. *a*, temporal muscle; *b*, masseter muscle; *c*, deep fibres of masseter.

The motions of the lower jaw upon the upper are produced by five pairs of muscles which pass from the sides of the skull to the lower jaw (fig. 3). The joint between the lower jaw and the skull allows not only of the up and down motion of the former bone, but also of its protrac-

tion, and of a considerable amount of lateral motion. By the combination of these actions the food can be minutely divided. This is a necessary preliminary to the subsequent processes, for there is no more fertile cause of indigestion than the swallowing of imperfectly masticated food. Hence also the importance of supplying by the art of the dentist any losses which time or disease may have caused in the dental arcades.

6. Mucous Membrane.—The soft usually pinkish layer which lines the alimentary canal from the mouth downwards, whose surface is generally moistened by a thin somewhat slimy fluid, is called *mucous membrane.* When a section of this membrane is examined under the microscope, its free surface is seen to consist of minute, more or less regularly shaped masses of protoplasm called **epithelial cells**, each of which has usually a definite boundary wall which is in contact with that of its neighbour.

These cells differ in shape in different parts of the digestive canal. In the mouth they are disposed in strata, the surface cells being flat, the deeper ones cubical. In general, however, the epithelium is in one layer and the cells are columnar in shape. The name **cell** is applied in anatomy to any of those minute, definitely circumscribed masses of protoplasm which form important constituent elements of the various tissues. Each cell contains within it a denser mass of protoplasm, the *nucleus*, and many cells have a definite boundary layer or *cell wall.*

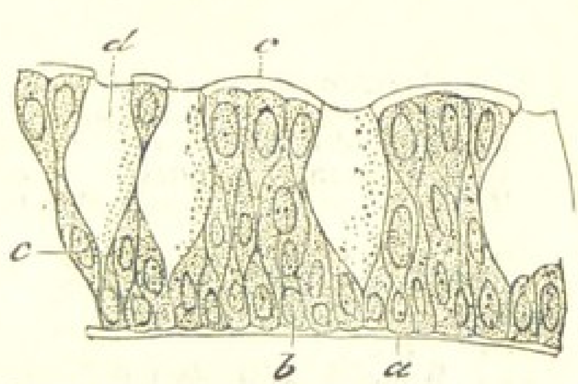

Fig. 4.—Epithelial cells from the small intestine. *a*, new cells in contact with the basement layer; *c*, nucleus; *d*, cell filled with mucus; *c* (above), surface of membrane, × 350.

Beneath the epithelium there is a firm layer containing blood-vessels, which is named the **corium**

(fig. 5 A*d*), outside which, for the whole extent of the alimentary canal, there is a thin muscular layer (fig. 11).

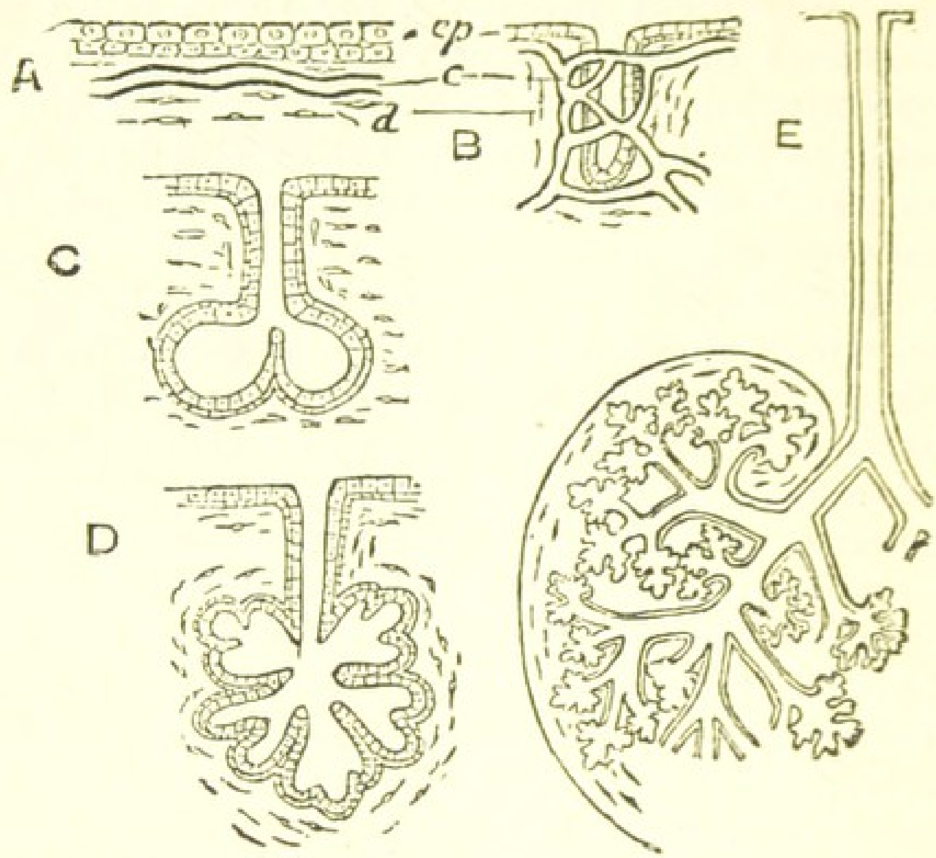

FIG. 5.—Scheme of the structure of mucous membrane and of glands. A, ordinary mucous membrane; *ep*, epithelium; *d*, corium containing capillary blood-vessels (*c*). B, simple gland-pit with its blood-vessels. C, D, more complex glands. E, compound gland with acini and duct. The blood-vessels are omitted in C, D, and E.

Some of the cells of the epithelium have the power of forming out of their substance the thick fluid which moistens their surface, and which is called *mucus* (fig. 4 *d*). A group of cells having this property is sometimes found lining a small pit in the membrane which opens on its surface. To such a pit the name **mucous gland** is given. The process by which these cells take in materials from the blood and modify them, discharging them when modified into the central hollow of the gland, is called **secretion.** There are various degrees of complexity in the structure of glands. The gland-pit may be divided at its deepest part (fig. 5 C), or these divisions may again divide, so that the single tube which opens on the surface may give access to

a complex series of branching tubules. In this case the gland-cells are restricted to the terminal blind pits or *acini*, as they are called, and the tubular passages communicating with the surface are lined by a simpler non-secreting epithelium and are called *ducts*.

The functions of the different kinds of glands which are connected with the alimentary canal vary with their positions. In the case of most of the larger glands the fluid secreted is not like the mucus of the smaller glands, but is a more watery fluid containing a ferment. Most of these larger glands are thick masses which lie either beneath the mucous membrane, or else at a little distance from it; but in all cases the ducts open into the canal.

7. INSALIVATION.—While mastication is in progress the food is mixed with the secretion of the first great set of the glands of the digestive system, the **salivary glands.** There are three pairs of these, one placed below and in front of each ear, the *parotids;* one on each side under the edge of the lower jaw, the *submaxillaries;* and one on either side of the floor of the mouth under the tongue, the *sublinguals.* These glands pour their secretions into the mouth by their respective ducts. The parotid ducts open through the cheek opposite the second upper molar tooth; the submaxillary and sublingual ducts open beneath the tongue. From these

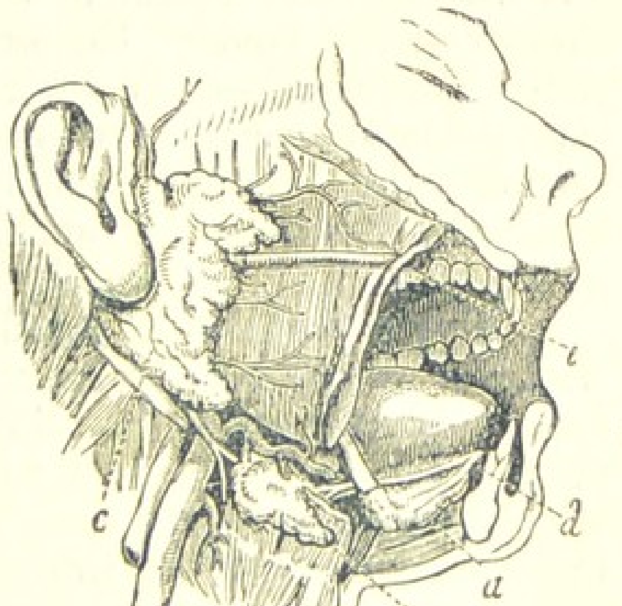

FIG. 6.—Dissection of side of face, showing the salivary glands; *a*, sublingual gland; *b*, submaxillary gland, its duct opens at *d*; *c*, parotid, its duct is shown crossing the masseter muscle and opening at *i*.

glands a quantity of saliva which varies from 10 to 50 oz. is daily poured into the mouth.

This secretion, formed in the epithelium of the acini of these glands, contains a peculiar ferment called *ptyalin*, which has the property of changing into sugar starch which has had its cellulose capsules burst by boiling. This is the first of the chemical processes of digestion; and its occurrence at this stage affords another reason for the thorough mastication of the food, especially of such as contains starch.

It has been found by experiment that tea checks this sugar-making action of the saliva. It is therefore undesirable to sip tea when eating bread or other starchy food. It is much better to eat first and drink afterwards.

Another noteworthy point is that there is scarcely any ptyalin in the saliva of newly-born infants, an indication that it is improper to feed such on starchy food. Indeed it may be laid down as a rule which admits of few exceptions that the only food necessary and appropriate for the infant, until it has cut its first teeth, is the mother's milk; and that even the best of the artificial foods is apt to cause more or less disturbance of digestion, and may lay the foundation of permanent disorder. A serious responsibility rests, therefore, upon any mother who wilfully neglects to suckle, her first duty to her child.

8. Deglutition.—By standing in front of a mirror with the mouth widely open, some of the parts concerned in the act of swallowing are brought into view. Above is the soft palate, in the middle of which the *uvula* hangs as a pendant. On each side there pass down from the palate two folds, one in front to the side of the tongue, the *anterior pillar of the fauces*, and one behind, the *posterior pillar*, which descends into the pharynx or cavity behind the tongue. The *tonsils*, which are masses of areolar tissue containing some mucous glands, appear between

these pillars. The cavity behind the soft palate and tongue is the **pharynx**, which communicates above the soft palate with the hinder openings of the nose, and below with the windpipe and with the œsophagus, or food passage. If the finger be thrust downwards along the back of the tongue the gristly *epiglottis* can be felt.

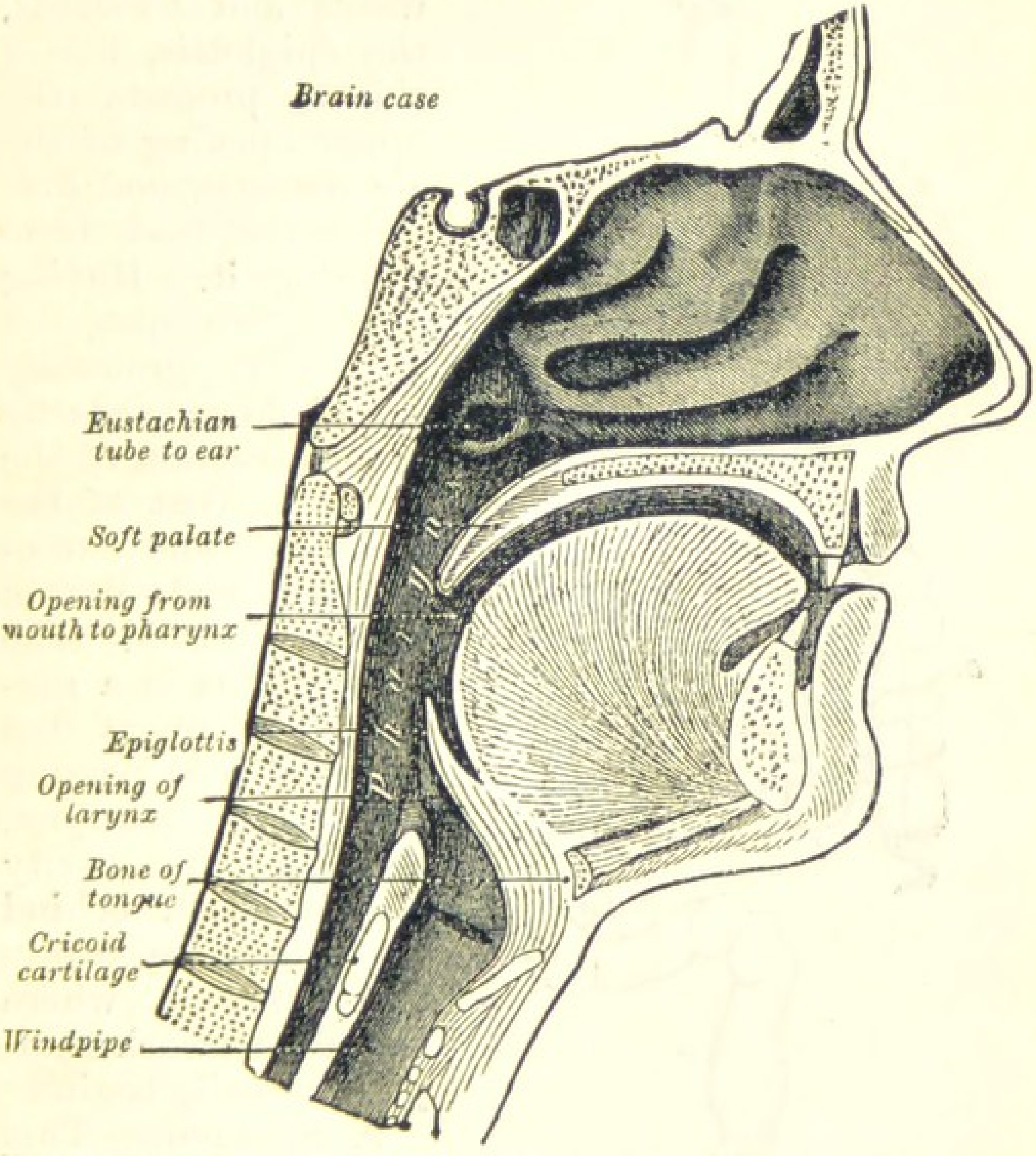

FIG. 7.—Vertical section through middle of face, showing the cavities of the nose, mouth, and pharynx, with the vertebral column vertically divided.

When the food is ready to be swallowed, it is gathered on the back of the tongue and pressed backwards against the soft palate; this is raised so as to shut off the nasal region of the pharynx, and the mass of food is grasped by the pillars of the

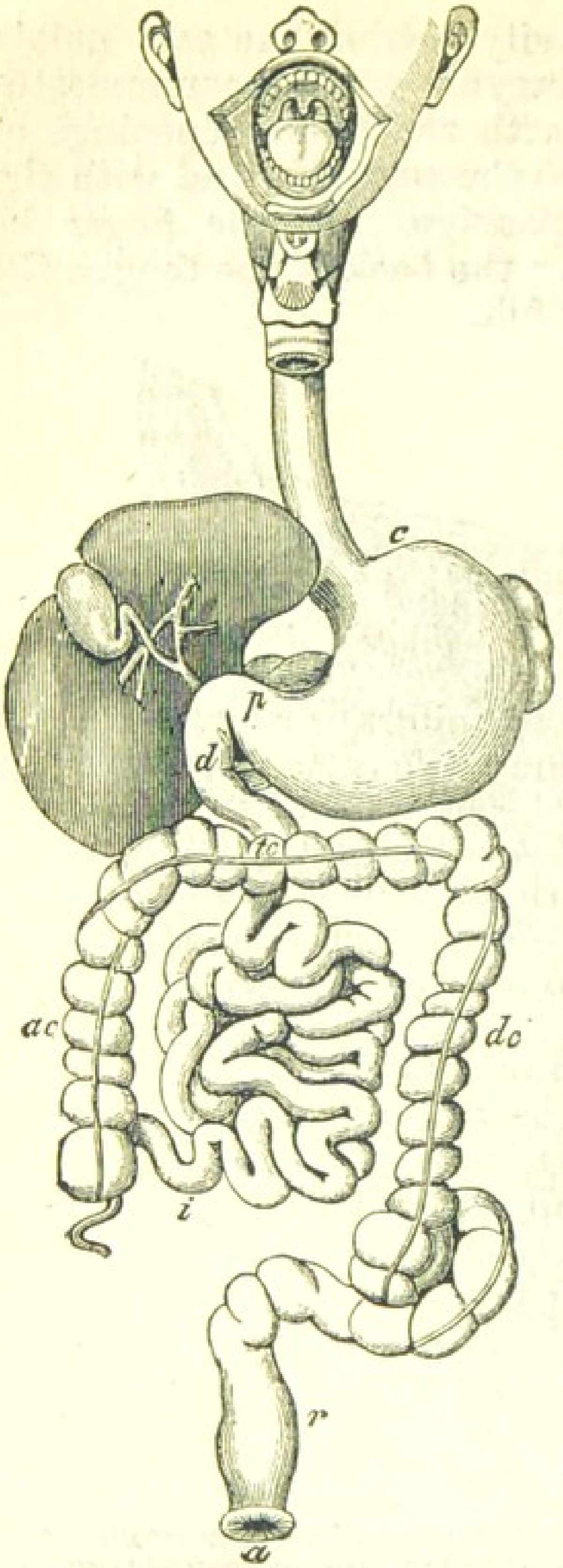

Fig. 8.—Diagram of digestive organs, showing the mouth and soft palate above, joined by the œsophagus to *c*, the cardiac orifice of the stomach. *p*, pylorus; *d*, duodenum receiving the duct of the liver; *i*, small intestine; *ac*, ascending colon; *tc*, transverse colon; *dc*, descending colon; *r*, rectum; *a*, anal opening.

fauces and by the muscular wall of the pharynx, which drives it downwards. As the tongue is pressed backwards and the windpipe drawn upwards and forwards, the epiglottis, like a shield, protects the upper opening of the air passage, and prevents the food from entering it. Having passed this spot, the food is gradually forced downwards by the contraction of the muscular coat of the pharynx and œsophagus, and driven to the stomach. The **œsophagus** is a narrow tube about ten inches long passing from the pharynx, through the cavity of the chest, behind the heart, to open into the stomach, where the serious work of digestion really begins.

9. Stomach.—This pear-shaped sac is about ten inches long, and lies obliquely for the most part to the left of the middle line, at the upper part of the abdomen below the

ribs. The opening from the œsophagus into the stomach is called the *cardiac* orifice; that from the stomach into the intestine is named the *pylorus*.

The stomach wall consists of two sets of layers of tissue, the outer coat being muscular, the inner mucous. The muscular coat is made up of longitudinal and circular fibres, which by their contraction keep the contents of the stomach in motion during the process of digestion, and finally expel the digested material by degrees into the intestine.

The mucous membrane of the stomach is thick and soft. In a man in whom it had been permanently exposed by an old wound it was seen to be pale when empty, but became red when food was introduced. It is wrinkled, except when unusually distended. The surface is lined by a single layer of columnar epithelium, and is thickly dotted with the mouths of tubular glands, which are packed closely side by side in the thickness of the membrane. These secrete a watery fluid, the **gastric juice**, which contains 2 per cent. of hydrochloric acid, and a peculiar ferment named *pepsin*. A variable amount, probably from 80 to 100 oz., of this fluid is secreted in the course of the day. This fluid acts principally on the proteids of the food, converting them into a highly diffusible proteid body named **peptone**. The food remains in the stomach from one to five hours, and as it becomes peptonised it passes through the pylorus into the first part of the intestine. It appears now as a greyish white semi-fluid mass, which is called *chyme*. The pylorus is surrounded by a strong band of circular muscular fibres which by their contraction prevent, until the end of digestion, the passage into the intestine of any material not perfectly softened.

Gastric digestion is a chemical process easily affected by disturbing agencies. In the artificial conditions of civilised life the powers of the stomach are frequently taxed to the limits of their endurance,

and this ill-treatment often causes a permanent impairment of the function of digestion.

As the gastric juice is only secreted under the stimulus of food, and as a large quantity of this fluid is required to be rapidly formed to dissolve the ingesta, it is necessary that the blood-supply to the stomach should be large and uninterrupted. Hence any conditions which call away large quantities of blood to other organs interfere with the secretion. For this reason violent muscular exercise or excessive mental activity act injuriously on the process, especially during the earliest stage when the secretion is being elaborated and poured out. Mental shocks which affect the nerves supplying the blood-vessels of the stomach have the same effect of arresting digestion. Small quantities of common salt increase the secretion of the gastric juice, so does warmth applied to the abdominal wall, while exposure to cold has a contrary effect. On this account copious draughts of cold water at the beginning of the digestive act are hurtful; but hot water in moderate quantities taken during a meal increases the amount of the secretion. Tea and coffee retard the peptonising influence of the gastric juice, but unless they form more than 15 per cent. of the material in the stomach they do not interfere with its ultimate completion. Most wines are prejudicial to perfect digestion, and hinder the solution and peptonising of the proteids.

As gastric digestion requires about four hours for its completion there should be at least this interval or a little more between meals; more especially as partly peptonised food in the stomach is found to interfere with the proper digestion of fresh unpeptonised food.

Considering the great solvent power of the gastric juice it is remarkable that the stomach itself does not become digested. Its surface is to some extent protected by its thin coating of mucus, which is alkaline; in like manner the blood in the minute

vessels, which is also alkaline, exercises a powerful protecting influence, for gastric solution is hindered by the presence of an alkali.

Occasionally it is found that when death has taken place suddenly while digestion is in progress the hinder wall of the stomach has become dissolved by its own secretion.

10. DUODENUM.—The chyme formed in the stomach passes directly through the pylorus into the first part of the intestinal canal, the **duodenum** (fig. 8 *d*). This is a looped tube about nine inches long, firmly tied in its place against the back wall of the abdomen. Into its lower angle the ducts of the liver and pancreas open, and through these canals the bile and pancreatic juice are poured into the intestine. These mix with the chyme and produce important changes in its composition.

11. LIVER.—This is the largest gland in the body, and in the adult man its average weight is 3 lbs. It performs several important functions in the economy of life, one of which is the secretion of bile. The liver is a dark brown solid organ of a firm fleshy texture, and it lies at the upper part of

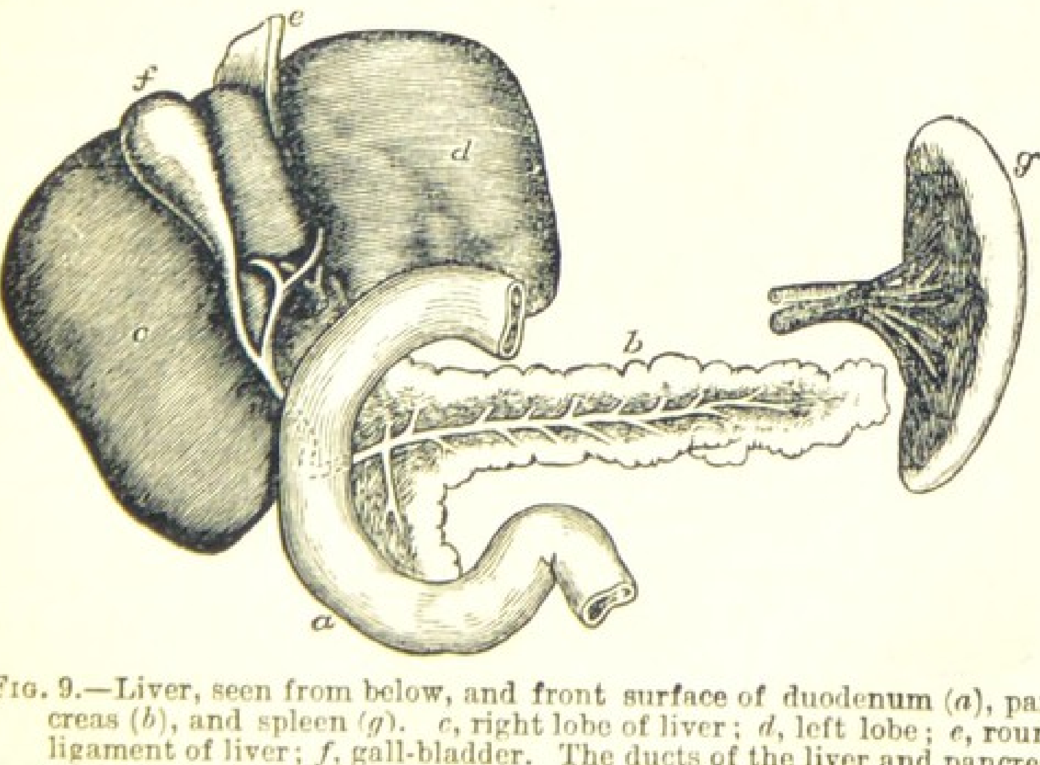

FIG. 9.—Liver, seen from below, and front surface of duodenum (*a*), pancreas (*b*), and spleen (*g*). *c*, right lobe of liver; *d*, left lobe; *e*, round ligament of liver; *f*, gall-bladder. The ducts of the liver and pancreas are shown. One-fifth natural size.

the abdomen, for the most part on the right side, and beneath the lower edge of the ribs. Its upper surface is convex and smooth, lying directly below the diaphragm or muscular partition which separates the abdomen from the thorax. Its lower surface is directly in contact with the stomach, duodenum, and other organs.

The liver receives the largest blood-supply of any organ in the body. This is conveyed to it by two vessels. One of these, the *hepatic artery*, brings to it pure arterial blood, while the other, which is named *vena portæ*, carries to it the impure blood collected from all the other digestive organs in the abdomen. Both these vessels break up into branches where they enter the liver, and ramify through the whole mass of the organ. The fine branches of the two sets for the most part unite into a common system of minute vessels which permeate the gland.

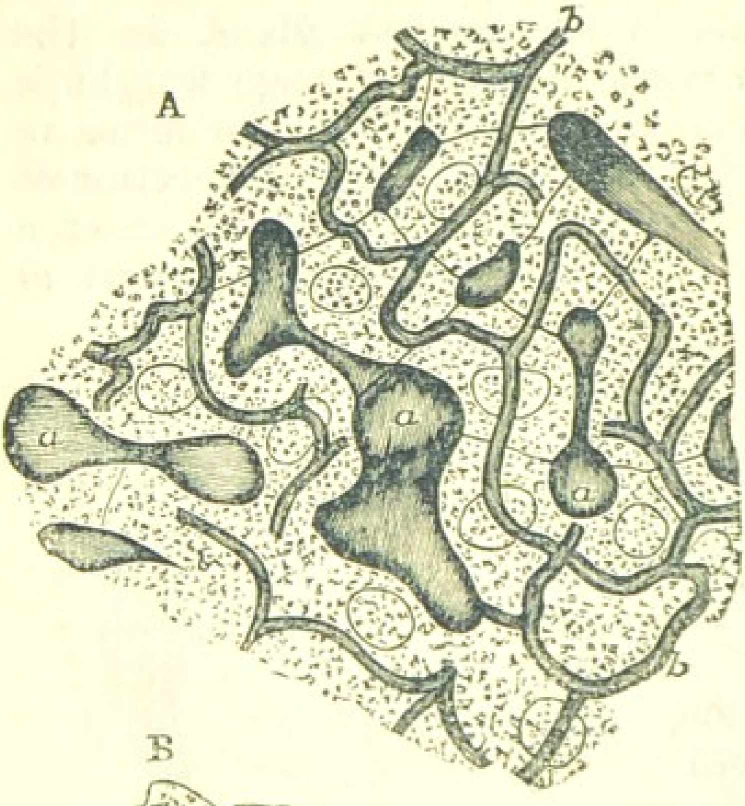

FIG. 10.—A, section of liver×400. *a*, blood-vessel; *b*, minutest capillaries; B, separated group of hepatic cells.

When a thin section of the liver is examined under the microscope it is found to consist of closely packed, polygonal cells, the *hepatic cells*, each of which is about 1/1000th of an inch in diameter. These are grouped together into little polyhedral lobules, each of which is about 1/15th of an

inch in length, and can be seen with the naked eye, especially in the livers of some animals such as the pig. Around each lobule the fine branches of the two above-named vessels ramify and send minute vessels into the substance of the lobule, the finest branches of these being little more than interstitial canals between the cells. The hepatic cells take from the blood certain materials, out of which they elaborate the bile. The blood purified from these materials is collected in a small vessel, the *intra-lobular vein*, which runs like a stem in the axis of each lobule, and pours its blood into a larger *sub-lobular vein*. This, uniting with its fellows, ultimately forms a set of large blood-vessels, the *hepatic veins*, and these carry the blood upwards towards the heart.

The hepatic cells discharge the bile which they form into minute channels on the surfaces of the cells; these by their confluence form the radicles of the hepatic ducts, which coalescing end in a large tube, the *hepatic duct*, in size equalling a goose quill. This leaves the liver and passes down to open into the duodenum.

The bile, of which about two pints are secreted in the course of a day, is a yellowish brown or greenish fluid with a bitter taste. It is complex in composition and contains among other substances a pigment called *bilirubin*, a crystallisable fatty body named *cholesterin*, and two peculiar acids, *tauro-cholic* and *glyco-cholic*, which are combined with sodium.

The effects of the bile on the chyme are manifold, but it chiefly acts on the fatty parts of the food, making them into an emulsion, and under some circumstances actually saponifying them. This gives to the fats the power of diffusion, which they do not otherwise possess; and thus they are rendered capable of passing through the lining coat of the intestines into the absorbent vessels. Bile also acts as a stimulant to the muscular coat of the intestine,

and so causes it to contract and to drive onward the material which it contains.

The secretion of bile is continually in progress, but the fluid is only required in the duodenum while digestion is taking place. In the intervals when there is no chyme in the duodenum the bile passes through a side branch of the main hepatic duct into a small pear-shaped bag appended to the lower surface of the liver, the **gall-bladder**, in which it accumulates until the next digestive act, when the gall-bladder empties its contents into the duodenum, sending it out through the same tube as that by which it entered the sac (see the under side of the liver in fig. 9), and thence down through the main duct into the intestine. The rate at which bile is secreted is not always the same. It increases from the first to the fourth hour after taking food, and is greatest when the diet consists largely of meat. It is also increased by drinking water, but is diminished by violent exercise, and by the same influences which check the formation of the gastric juice.

The other functions of the liver, which are equally important, will be considered later on.

12. THE PANCREAS.—This is a soft pinkish white gland of irregular shape and about seven inches long, which lies in the concavity of the loop of the duodenum. It resembles the salivary glands in structure; and its duct, which is a little smaller than that of the liver, opens into the duodenum with the hepatic duct.

The secretion of the pancreas is in amount a little more than half that of the bile; and is, next to the gastric juice, the most important of the digestive fluids. It is alkaline, and neutralises the acidity which the chyme has acquired in the stomach. It also contains three powerful ferments, one of which, *steapsin*, acts on the fats, altering their composition. Pancreatic juice therefore co-operates with the bile in emulsifying the fats and so increasing their capability of diffusion. A second ferment, *amylopsin*

acts like the salivary ferment and changes starch to sugar. There is scarcely a trace of this ferment in the pancreatic juice of the infant. The third ferment, *trypsin*, acts on proteids, and converts them into peptone. In this manner the pancreatic fluid assists in the digestion of all parts of the food, and so finally prepares the chyme for absorption. This digestive power of pancreatic juice may be utilised in the preparation of what are called peptonised foods for persons of weak digestion. If a small quantity of the extract of the pancreas of the ox be mixed with milk or gruel, and the mixture kept for about two hours at blood heat, and then boiled for a few minutes and strained, the material is rendered easy of digestion. The direct administration of pancreatic juice itself is, however, comparatively valueless, as the gastric juice destroys trypsin.

13. SMALL INTESTINE.—Below the duodenum the small intestine is continued as a coiled canal about $22\frac{1}{2}$ feet long, and a little over three inches in circumference. The upper third of this long tube is named **jejunum** as it usually appears collapsed and empty in the dead body; the remaining part is called **ileum** as its coils are conspicuous at the lower part of the abdomen. The whole intestine is attached to the margin of a membranous fold, the *mesentery*, which is pleated like a great irregular fan and holds the intestine in its place, yet allowing to it a considerable amount of mobility. This is part of the lining membrane of the abdominal cavity, the **peritoneum**, and it is continued as a thin, smooth coating over the intestine, so as to permit the neighbouring folds to glide smoothly on each other to some extent. Under this peritoneal layer there are in the wall of the intestine two thin strata of muscular fibres, longitudinal and circular; these by their contraction cause alterations in the length and calibre of different parts of the tube, thus forcing along the chyme and thoroughly incorporating with it the several digestive fluids.

Within the muscular coats is the mucous membrane, and this for the upper half of the tube is nearly twice as long as its enclosing envelopes. It is consequently folded permanently into a number of circular tucks called *valvulæ conniventes*, which project into the cavity when the intestine is distended. By this arrangement the mucous surface with which the food comes in contact is greatly increased. These tucks diminish in number towards the ileum, in the last third of which they become few and far between.

The mucous membrane which forms these folds and lines their intervals is beset with minute processes, like the pile of velvet, which project on its surface. These projections are called *villi*, and there are over 4,000,000 of them on the intestinal surface. Between these the mucous membrane is studded with numerous tubular pits which are mucous glands.

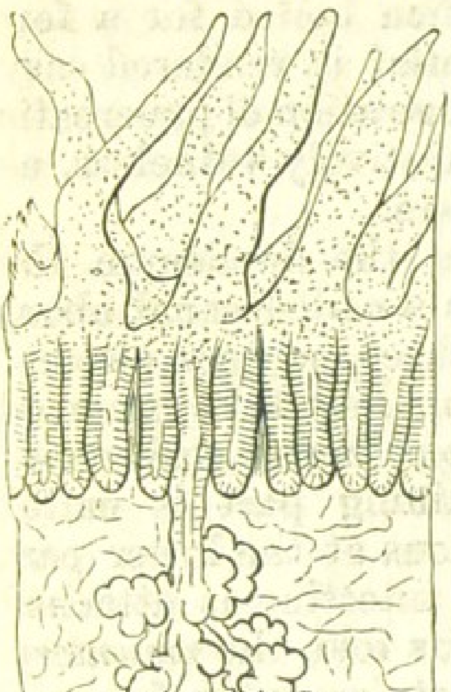

FIG. 11.—Vertical section of a small portion of the duodenum × 35, showing seven villi, at the bases of which are eleven mucous glands (Lieberkühn's glands). Below these is a larger gland (Brünner's), whose acini are in the submucous tissue, under this are the muscular and the outer or serous coat.

The chyme which leaves the duodenum mixed with bile and pancreatic juice becomes in the intestine thoroughly incorporated with these fluids, and here the digestive process is completed; all the starches are converted into sugar; all the various sugars are changed into the form known as grape sugar; all the fats are emulsified or saponified, and all the proteids are changed into peptones. Thus all the materials of the food are rendered diffusible, and fitted for the next stage, that of absorption.

14. Absorption.—The mucous surface of the small intestine is paved with a layer of columnar epithelial cells, under which is a thin corium closely permeated with blood-vessels. The arteries which

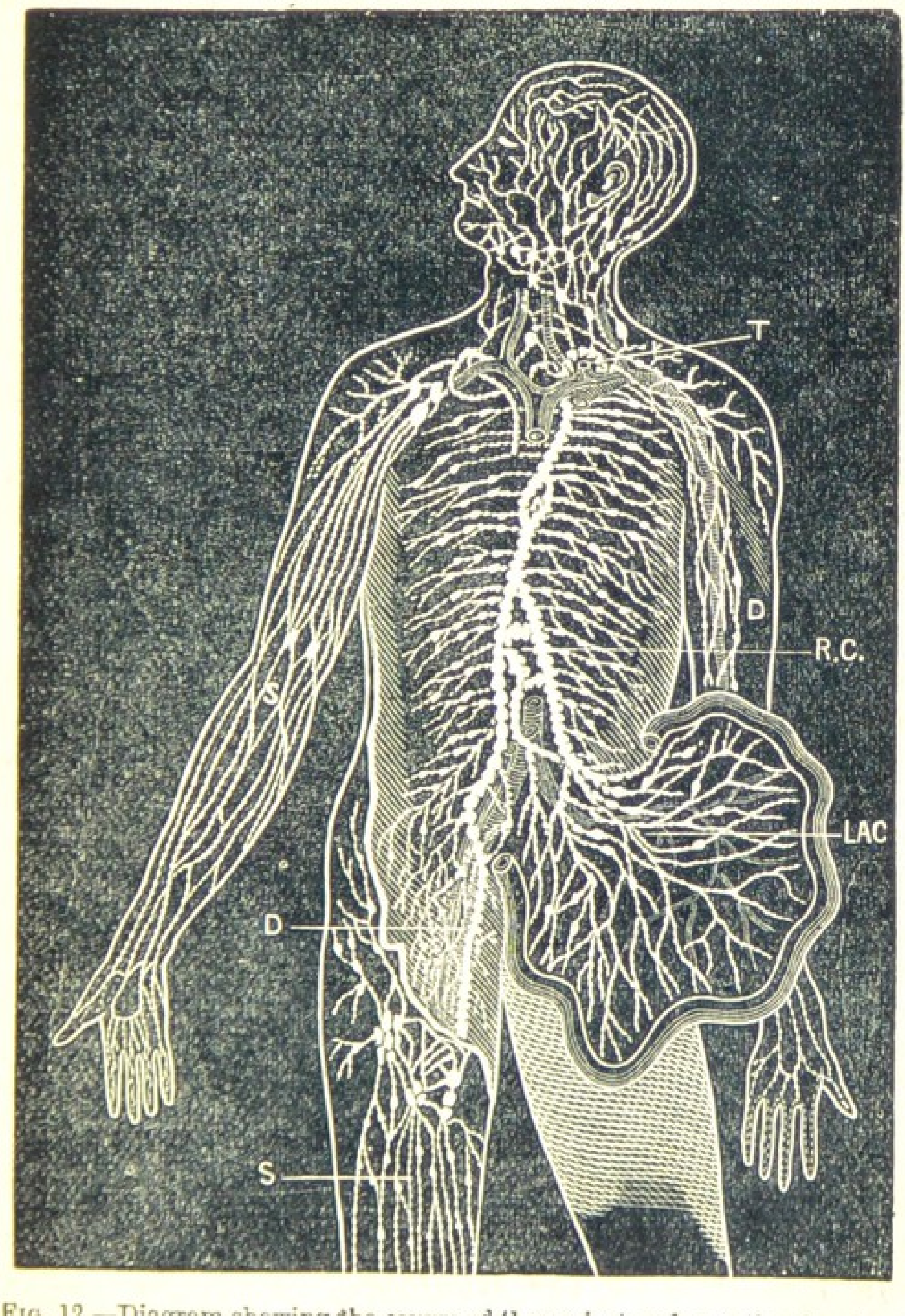

Fig. 12.—Diagram showing the course of the main trunks of the absorbent vessels. LAC, lacteals from the intestine; R.C., central receptacle from which the thoracic duct ascends to T, where it ends in the subclavian vein; S, D, lymphatics of leg and arm. The white spots in the course of these are lymphatic glands.

branch in this layer send minute twigs into the villi to nourish them, and small veins carry back from the villi the blood after it has repaired the waste of these tissues. In the centre of each villus there is also an irregular tubular space. The diffusible materials of the food pass by osmose through the epithelial layer; some parts, like the water, sugar, peptones, and saline matters, entering directly into the blood-vessels and being carried at once in the blood stream. Others, like the finely divided fats, enter into the central space in the villus. These spaces communicate at the base of each villus with a fine network of tubes whereby they are united with the central spaces of the surrounding villi, and this network forms the starting-point of a system of thin-coated vessels which are called **lacteals,** as the fatty emulsion which they contain when absorption is taking place gives to them a milky colour.

The veins and lacteals pass from the intestine in the layers of the mesentery, the former vessels, uniting with each other, ultimately form the vena portæ which we have already seen entering the liver. The lacteals also unite and form a long tube, the **thoracic duct,** which ascends in front of the spine to the left side of the neck. There it joins the subclavian vein behind the inner end of the left collar bone, and so mixes with the circulating stream of blood.

15. Large Intestine.—By the time the contents of the small intestine have reached the end of the ileum, almost all the nutritive parts of the food have been absorbed, and there is left only such parts as are insoluble and undigested, together with the bile-pigment and some other elements of the juices of the intestine. These are carried into the last part of the alimentary canal, the large intestine, which is about double the calibre of the small intestine, and usually about $4\frac{1}{2}$ feet long. The large intestine begins as a slightly dilated sac,

the **cæcum**, which lies in the lower part of the right side of the abdomen. Its course is shown in fig. 8, first upwards, then turning across as a looped tube to the left, then downwards into the pelvis to end at its terminal or anal orifice. This part of the intestine is not cylindrical like the small intestine but is sacculated, as its longitudinal fibres are shorter than the other coats, and as these are disposed in three longitudinal bands the mucous surface is puckered in the interspaces.

In this part of the tube much of the remaining watery part of the material, and any diffusible substances which have escaped absorption in the small intestine, are taken up by the blood-vessels in its walls (which are destitute of villi). The remaining material before it is finally discharged undergoes certain fermentation-changes chiefly by the action of micro-organisms.

The opening by which the small intestine ends in the large is a narrow chink with two lips which project into the large intestine. These act as valves and prevent matter, when it has passed through, from returning into the small intestine.

Below this opening a curious narrow tube about four inches long is connected with the cæcum. This **vermiform appendix** is remarkable in that it is present in very

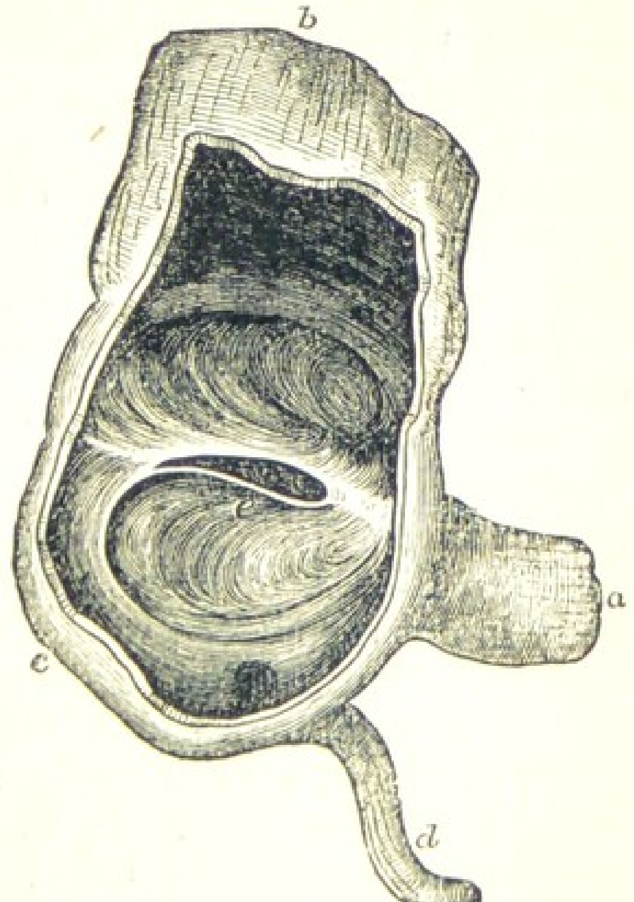

FIG. 13.—Cæcum, laid open, and vermiform appendix, one-fourth natural size. *a*, end of small intestine; *b*, ascending colon; *c*, cæcum; *d*, vermiform appendix; *e*, ileo-cæcal valves.

few animals, and that it is occasionally the seat of dangerous disease when solid foreign bodies become retained in it. This is not a separate organ, still less a rudimental organ. The human cæcum in the earliest period of life before birth is a spirally twisted spindle-shaped sac which gradually tapers to a blind point. After birth, when the food *débris* begins to enter the large intestine, it gravitates into some of the sacculi (fig. 13 *c*) of the cæcum, as these are the lowest parts of the tube. These become distended, giving to the cæcum its adult appearance; while the original spiral tip remains nearly of its original size and is now named vermiform appendix. It is therefore one of the results of the upright position of the human body.

16. Blood.—The material about to be used in building up the tissues, having undergone its preliminary preparation in the digestive organs, is carried in the blood throughout the whole body. The blood likewise conveys the waste products which result from the metabolism of the tissues in the course of the processes of life to the several apparatuses whereby they are eliminated. Blood is therefore the medium of communication between the tissues of the body and the materials of the outer world.

Blood is a dense opaque fluid, varying in colour from scarlet to deep purple. It has a salty taste, and in the healthy man ranges in temperature from 97·4° to 100°F. The total amount of blood in the body is not a constant quantity, but varies owing to different conditions of feeding, exercise, and fasting. In the average man there is probably a little over 12 pints of blood, a little under the 1/13th of the total weight of the body. It is contained in a closed system of branching tubes which permeate the entire body; and within these it moves in a definite course, the chief factor in maintaining its circulation being the action of the heart.

When examined by aid of the microscope blood is

seen to consist of two parts, a thin transparent fluid, the **plasma,** in which float a prodigious number of minute biconcave bodies, the **red blood corpuscles,** to which the fluid owes its colour.

Each corpuscle is somewhat like a coin which has been hollowed on each surface, and is about 1/3200th of an inch in diameter, but does not measure more than one-fourth of this in thickness. There are about 82,000,000,000,000 of these in a cubic inch of blood, and it has been estimated that if all the blood corpuscles of an adult man were laid out as a pavement they would cover a square whose side measured forty paces.

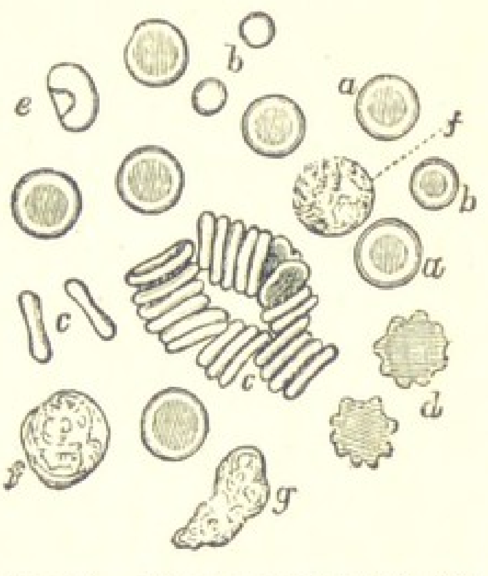

FIG. 14.—Blood corpuscles × 500. *a*, ordinary red corpuscles, flat view; *c*, edge view; *b*, *d*, *e*, varying shapes; *f*, *g*, white corpuscles.

Each red corpuscle consists of a protoplasmic framework called the *stroma*, which is elastic, capable of being compressed when passing through very narrow vessels and of resuming its shape in wider channels. In the meshes of this stroma a colouring matter named *hæmoglobin* is entangled. This substance has the power of combining with oxygen, the compound, which is named oxyhæmoglobin, being of a light scarlet colour. This combination takes place in the lungs, and in this form oxygen is carried to the tissues of the body. Here the oxyhæmoglobin is reduced, its oxygen combining with carbon to form carbonic acid; which is conveyed in the blood back to the lungs, and there breathed out. The bright scarlet hue of arterial blood is due to the presence of oxyhæmoglobin, and the dark purple of the blood in the veins is due to the darker colour of the reduced hæmoglobin. The gases can be separated from blood by the air pump; and it has been found that

the gas so extracted from arterial blood contains 17 per cent. of oxygen and 30 per cent. of carbonic acid, but in venous blood the oxygen has fallen to 6 per cent., and the carbonic acid has risen to 35 per cent.

Besides the red corpuscles, blood contains, but in smaller numbers, another kind of solid body, paler in colour and rounded in shape. These are called **colourless corpuscles** or **leucocytes.** They are about 1/2500th of an inch in diameter and are capable of spontaneously altering their shape while alive. Owing to this they appear to move and act like minute animalcules. Each of these leucocytes contains a distinct nucleus, in which respect they differ from the red corpuscles of the adult, which are not nucleated. The number of colourless corpuscles varies not only in different parts of the body but in the blood of the same part in different conditions. Commonly there are about 350 red corpuscles to each colourless corpuscle, but the number of the latter may be increased during digestion. They are more numerous in venous than in arterial blood, and are diminished in number by fasting.

Under certain circumstances, the colourless corpuscles act like independent living beings. If they come in contact with micro-organisms they can take them into their substance and digest them, and in this way they are supposed to have a protective influence by destroying germs which otherwise might give rise to disease. This process of conflict between the colourless corpuscles and the invading germs is known as *phagocytosis*.

17. COAGULATION.—When blood is removed from the body it undergoes a rapid chemical change, due to the action of a peculiar ferment contained, most probably, in the white corpuscles. It consolidates into a viscid jelly which in the course of a short time contracts and squeezes out a straw-coloured fluid, the *serum*, the remaining part being a solid mass, the *coagulum* or *clot*. This consists of a net-

work of soft threads of a material called *fibrin*, in whose meshes the red corpuscles are entangled.

Fibrin does not exist in the blood before the fermentation change. The plasma of blood contains, among other substances, three proteid bodies in solution, albumin, globulin and fibrinogen. The last-named is that which is acted on by the ferment and becomes changed into fibrin. Fibrin can be obtained free from corpuscles by whipping freshly drawn blood with a whisk of fine twigs. The fibrin separates as an elastic whitish stringy mass which adheres to the rods of the whisk, leaving the corpuscles in the serum. The other two proteids remain in solution, and can be made solid by boiling the serum. Coagulation of blood can be delayed by adding to it a solution of common salt or of Epsom salts.

Blood will not ordinarily coagulate within the vessels; but in some abnormal states in which the white corpuscles are in excessive numbers spontaneous coagulation may take place, causing obstruction to the vessels and disturbances of nutrition. When a blood-vessel is cut the stoppage of the bleeding is due to the supervention of coagulation, and the gaping mouth of the vessel becomes plugged by a clot, hence substances that favour coagulation, which are called *styptics*, are used to stop bleeding; ice, alum, and vegetable astringents containing tannin, are of use in this manner. In the condition (fortunately rare) in which there is a deficiency of the fibrin-ferment this salutary clotting does not take place, and wounds become in such persons, who are often spoken of as "bleeders," exceptionally dangerous, as fatal bleeding may occur from a trivial wound. The other ingredients in blood are water, which constitutes about 78 per cent., and saline matters, of which there is less than 1 per cent. There are also small quantities of fat and sugar.

Red corpuscles are made in certain tissues of the body, such as the red marrow of bones and the

supra-renal capsules. After a short life, probably of 10 to 14 days, these become broken up in the spleen and liver. The effete hæmoglobin which has done its work undergoes decomposition, and much of it becomes the pigment of the bile, in which form it is eliminated and excreted by the intestines.

18. CIRCULATION.—Almost all the tissues of the body are permeated by closely-set minute vessels which are called **capillaries.** Through the thin coats of these the nutrient material passes by diffusion, separating from the rest of the blood, and entering the tissues directly. In the capillaries likewise the corpuscles part with much of their oxygen, which enters into combination with some of the materials of the bodily organs. To the fluid which in this manner leaves the blood to enter the interstices of the tissues the name **lymph** is given, and it is this material, which differs little in composition from blood plasma, that directly feeds the elementary tissues of the body. Red corpuscles do not in normal circumstances pass through the coats of the vessels, but white corpuscles, although they are larger, may do so under certain conditions by virtue of their power of changing their shape.

Contiguous capillaries unite and form larger vessels through which the blood passes in its return from the tissues. These vessels are named **veins,** and the blood contained in them is peculiar in that it has parted with the materials of its lymph, and much of its oxygen, and has received in return, by the process of diffusion, the products of tissue-waste, including carbonic acid. This blood is called *venous blood.*

Veins are thin-coated tubes, and they present at certain points in their course half-moon-shaped folds of their lining membrane which are called valves. These are arranged in pairs, and are so disposed that although they do not obstruct the passage of blood towards the heart, yet they prevent its flow in the opposite direction, as when forced

backwards the blood distends the vein above the valves and presses their free edges together, so closing the channel. This can be easily tested by pressing the tip of the middle finger firmly on one of the superficial veins of the hand or arm so as to arrest the current in it. If then the blood above (*i.e.* on the heart-side of) this point be pushed upwards by the tip of the index finger it will be found that in the places where a valve exists, when the pressure of the index finger is taken away, the blood will not flow backwards beyond the valve, from which to the point at which the middle finger compresses the vein the tube remains empty.

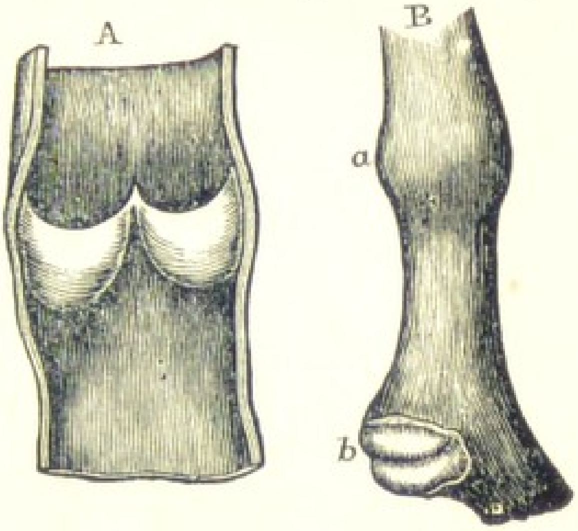

FIG. 15.—A, vein cut open to show the two pouches of a valve; B, an unopened vein dilated opposite a valve at *a*; at *b* a closed valve is seen from below.

The small veins by their union form larger trunks; and these also coalesce, ultimately forming two great vessels. One of these, the **superior vena cava**, carries the blood from the head, arms, and upper part of body to the heart. The other, the **inferior vena cava**, conveys to the heart the blood of the lower limbs and the lower half of the body, including that which comes from the liver. These two veins pour their streams of blood into one large chamber of the heart, which is named the **right auricle.**

19. THE HEART.—The position of this organ can be determined during life, as its action communicates a perceptible thrill to the chest wall and causes characteristic sounds which can be heard by applying the ear to the left side of the breast-bone. For all practical purposes of elementary description the heart of a sheep resembles the human, and if one be procured from the butcher the several parts can be recognised and their relations to the circula-

tion more easily apprehended than by any lengthened description. It is advisable to obtain a heart to which the lungs (called by the butcher the "lights") are attached.

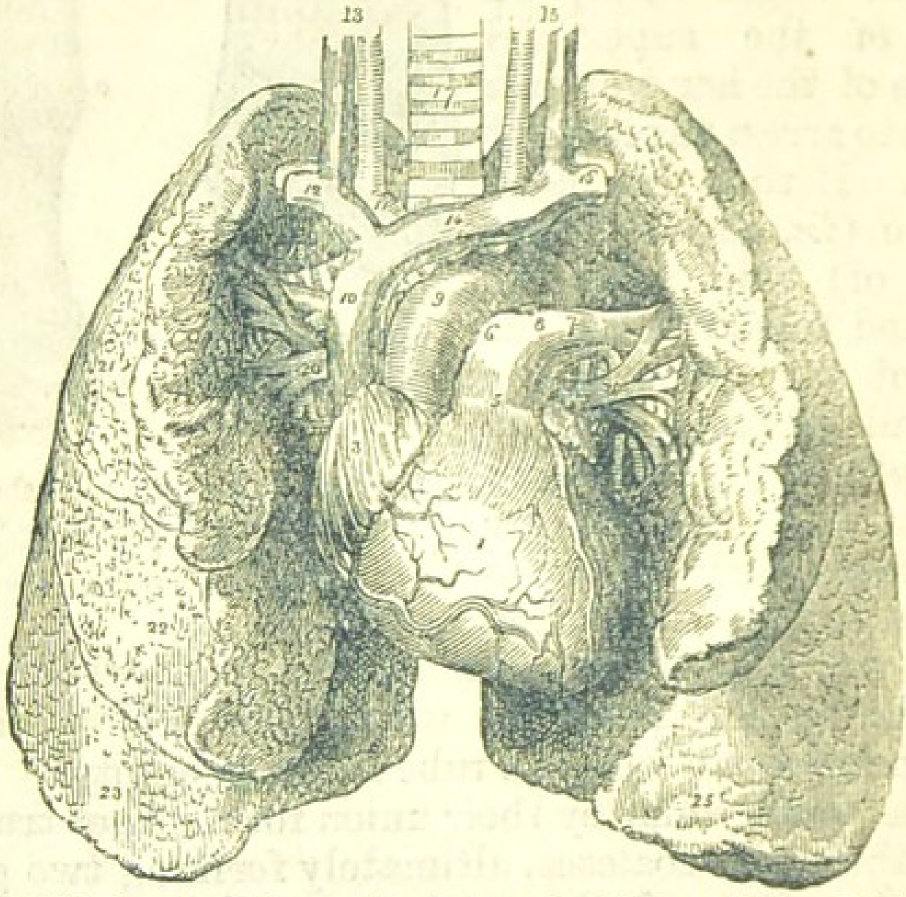

Fig. 16.—The heart and lungs, front view. 1, right ventricle; 2, left ventricle; 3, right auricle; 5, pulmonary artery; 9, aorta; 10, superior vena cava; 13, 15, carotid arteries and jugular veins; 17, trachea; 20, pulmonary veins; 21, 22, 23, lobes of right lung; 24, 25, lobes of left lung.

The heart is a hollow muscular organ, made up of four chambers with contractile fleshy walls. It has a rounded apex, which is directed to the left side and downwards. The cavity of the heart of which this is the lowest point is called the **left ventricle.** On the anterior surface of the heart there is an oblique superficial groove containing some fat. The part which is placed above and to the right of this is the **right ventricle,** while the left ventricle is below and to the left. From the top of the right ventricle a wide oblique tube arises which soon divides into two branches of which one passes to either lung. This vessel is named the **pulmonary artery.** From the top of

the left ventricle there arises a tube with thicker walls, which remains cylindrical when cut across and does not collapse. This is the **aorta**, the chief artery of the body; it appears behind the pulmonary artery, and forms an arch above from which the vessels of the head and arms arise.

On each side of these great vessels when they are looked at from the front, there appears the

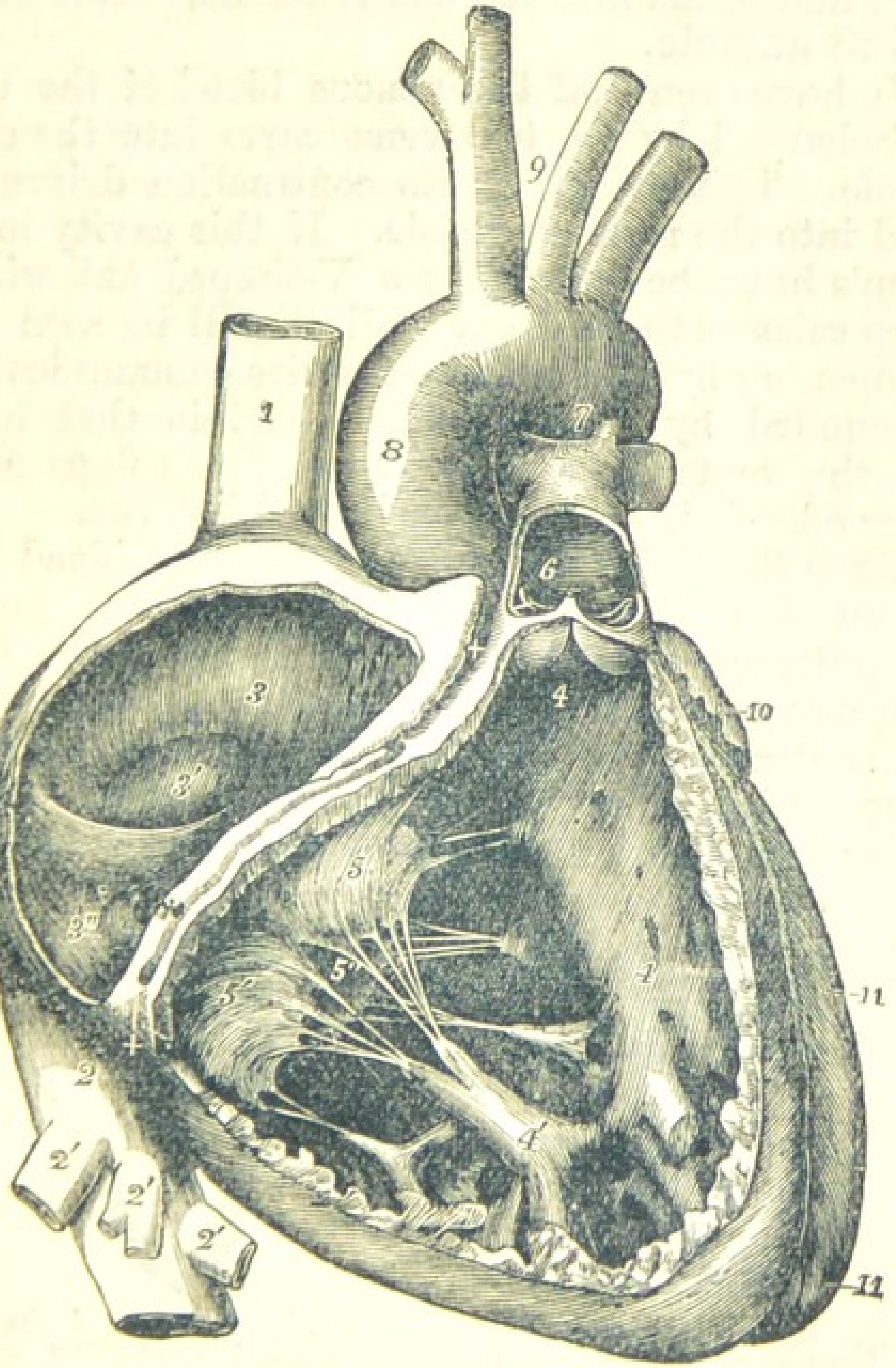

FIG. 17.—Right side of the heart laid open. 1 and 2, venæ cavæ; 3, cavity of right auricle; 4, cavity of right ventricle; 5, tricuspid valve; 6, pulmonary artery and its valves; 8, 9, aorta and branches; 11, left ventricle.

extremity of a thinner walled part of the heart. If the back of the heart be turned it will be seen that these are the two lateral parts of a large crescentic sac which lies above the ventricles and crosses the back of the two large arteries. This portion of the heart is divided by a partition into two cavities. One of these is above the right ventricle, opening into it, and is called the **right auricle**, the other is above and opens into the left ventricle, and is called the **left auricle.**

We have seen that the venous blood of the body is discharged by the two venæ cavæ into the right auricle. This cavity by its contraction drives the blood into the right ventricle. If this cavity in the sheep's heart be opened by a V-shaped cut with a sharp scissors in its front wall, it will be seen that the opening by which these cavities communicate is surrounded by a membranous curtain that hangs into the ventricle, and as it has three flaps at its lower edge it is called the **tricuspid valve.**

When the right ventricle is filled with blood from the auricle it contracts and drives the blood through the pulmonary artery into the lungs. The blood is prevented from returning into the auricle during the contraction of the ventricle by the tricuspid valve, which, as shown in fig. 19, is closed by the pressure of the blood on its lower surface and held

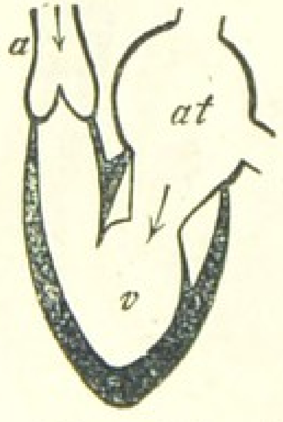

FIG. 18.—Scheme of the valves of the heart when the auricles (*at*) are contracting and the ventricles (*v*) dilating; the auriculo-ventricular valves are open and the arterial valves are shut.

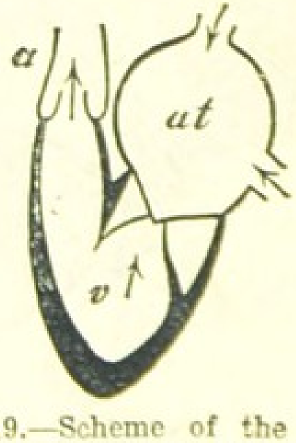

FIG. 19.—Scheme of the valves when the ventricles are contracting; the auriculo-ventricular valves are shut and the arterial valves open.

in position in the middle of the opening by a set of muscular cords.

If the pulmonary artery be slit up there will be found at its attachment to the ventricle three *semi-lunar valves* resembling in appearance and function those we have already seen in veins. These prevent the back-flow of blood into the ventricle once it has been driven forwards into the lungs.

The blood returns from each lung by two **pulmonary veins.** These four vessels open into the left auricle and empty their blood into it. The left auricle drives the blood into the left ventricle through an opening which is surrounded by a curtain, the **mitral valve,** of the same sort and function as the tricuspid valve in the right ventricle. The left ventricle when it contracts drives its contents into the aorta, whose orifice is guarded from back-flow by valves of the same kind as those at the mouth of the pulmonary artery. From the aorta there arise the arteries, which divide into branches, and these ultimately end in the capillaries, at which point our survey of the circulation began.

The arteries are much thicker coated than the veins, and they do not collapse when cut open. They have no valves, and their walls are highly elastic; in most arteries there is muscular tissue as well. As the blood in arteries flows from the heart, in the case of a wounded artery pressure must be applied above the wound; venous hæmorrhage, which can be recognised by its dark purple colour, is arrested by pressure applied below the wound. The blood in the arteries, bright scarlet owing to its oxyhæmoglobin, is also rich in nutritious matter. The intestinal veins and the lacteals have poured their stores of newly absorbed food into the great veins before they enter the heart; and this material, when oxygenated by passing through the lungs, is driven by the left ventricle through the arteries to be the medium for the nourishing of the tissues.

The heart beats on an average about 70 or 80

times each minute. These pulsations are due to the contraction of the muscular tissue of the ven-

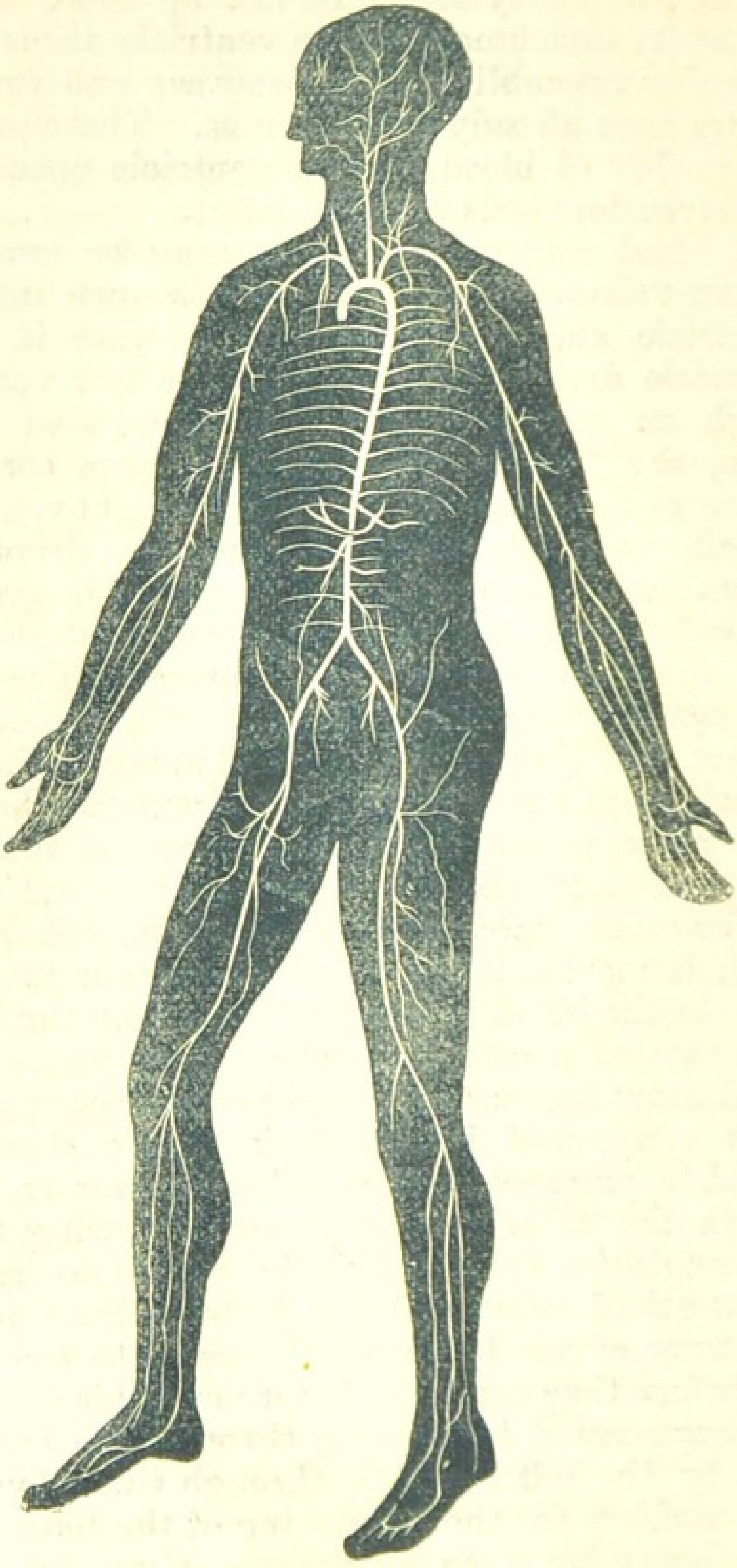

FIG. 20.—Scheme of the arterial system.

tricles. This thickens as it contracts and is pressed against the wall of the chest, causing the thrill that is perceptible when the hand is placed on the left side of the breast-bone. This is called the *impulse* of the heart.

If the ear be placed in contact with the surface of the chest over the heart a double sound can be heard. The first is a duller and longer note, which has been compared to the sound of the syllable "*lub*"; the second succeeds it immediately, and is a short and sharp sound, compared to the syllable "*dup*." The first is chiefly produced by the noise made by the muscular wall of the ventricles in contracting, supplemented by the sound of the vibration of the mitral and tricuspid auriculo-ventricular valves, which are thrown upwards by the contraction, to shut the mouths of the auricles. The second sound is produced by the sudden closure of the semilunar valves at the mouths of the aorta and pulmonary artery.

The rate of the heart's action is quickened by work, by mental excitement, and by certain conditions of disease. Shock, depressing emotion, or impure air may suddenly diminish or arrest the heart's action, causing fainting fits or *syncope*. The loss of consciousness is due to the sudden stoppage of the blood-supply to the brain; and the natural remedy is therefore to place the body in the horizontal position, and to stimulate the heart to renewed action. This can be done by the sudden application of cold to the face, or of irritating vapours, such as smelling salts or burnt feathers, to the nose, or of stimulants, such as alcohol or ether. The mode in which these stimulants act we shall see when we come to consider the functions of the nervous system.

Experiences of the extreme susceptibility of the heart to be affected by varying mental conditions led mankind in early days to regard the heart as the seat of emotions and affections.

The arterial system is like a tree whose trunk is

the aorta, whose branches are the arteries, and whose terminal twigs are the capillaries. The combined sectional areas of the primary branches of the aorta exceed that of the aorta. In like manner the collective sectional area of the secondary branches exceeds that of the primary, and the total area of the capillaries is the greatest of all.

The arteries during life are so full that their elastic coats are stretched, and the heart at each contraction forces more blood into them. The stress thus produced upon the wall of the vessels is called the *blood pressure.* The elasticity of the arterial wall squeezes the blood onwards into the capillaries and keeps up a continual pressure from behind, impelling the fluid onwards in spite of the friction occasioned by the enormous area of surface in the capillaries over which the blood has to be driven. The blood pressure in the arteries is increased at each beat of the heart, and the quickened wave thus caused, which can be felt in all arteries, is called the **pulse.** This is especially distinct in those superficial arteries which can be compressed by the finger against some hard part, such as the radial artery at the wrist or the temporal artery on the temple. The pulse wave travels at the rate of $28\frac{1}{2}$ feet in the second, taking 0·22 second to reach the toes. It is lost in the minute arteries which end in the capillaries; hence the flow of blood in the veins is continuous, without pulsation, and slower than in the arteries. The veins are all wider than the corresponding arteries, and the blood pressure is less in the veins than it is in the capillaries.

The amount of increase of blood pressure due to the actions of the heart may be represented graphically by means of the *sphygmograph.* This is an instrument which consists of a small pad that rests on the artery at the wrist, against which it is pressed by a weak spring. Connected with this pad is the short arm of a lever, whose long arm carries a fine point or style, which is in contact with

a piece of glass covered with a thin film of carbon. This glass is made to move at a regular rate by clockwork. The pulse wave moves the short arm of the lever, and the style is made to travel up and down on the moving glass slip, scraping as it does so a wavy line whose ascent marks the impact of the wave, and its sloping side the various stages of the elastic recoil of the vessel. The shape of this line varies in different conditions of the heart and arteries.

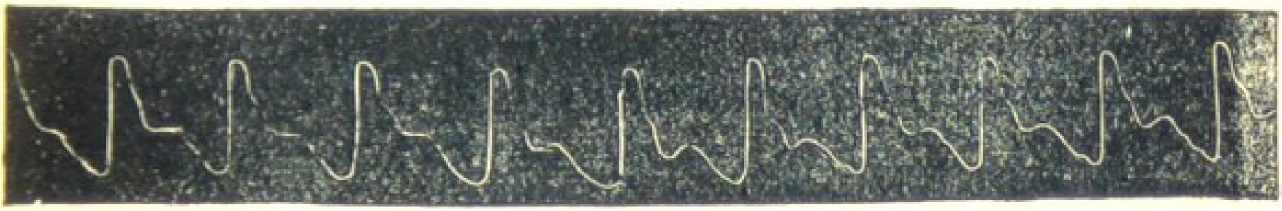

FIG. 21.—Pulse-tracing, drawn by the sphygmograph. The vertical up-stroke is due to the shock of the ventricular contraction, the top of the little hillock on the down-stroke is caused by closure of the aortic valves.

At each contraction the left ventricle expels about six ounces of blood into the aorta; but as this vessel is already full of blood the ventricle must drive its contents into the aorta with a force sufficient to overcome the blood pressure in that tube. This pressure has been found by experiment to be equal to the pressure of a vertical column of blood $10\frac{1}{2}$ feet high. As the heart beats about seventy-five times in the minute the work done by the ventricle in a single contraction must be multiplied by $75 \times 60 \times 24$ to obtain the total amount of work done by it in a day. The work done by the right ventricle is one-third that of the left, so we may estimate the daily work of the heart as equal to the work done in raising 280 tons to the height of one foot, which is a little more than half of the work which an ordinary labourer can accomplish in eight hours of hard work. This toil becomes more remarkable when we remember that it is carried on unintermittingly night and day, waking and sleeping.

We may perhaps realise in a more striking manner the amount of energy expended by the heart

if we remember that the muscular work done by the heart in a day is about equal to the work done by a man of average size in ascending Snowdon. When there are no special obstacles an active man can raise his own weight in mountain climbing at the rate of a thousand feet in the hour; but if the work which the heart performs could be expended by it in the task of raising its own weight, its power is such that it could lift itself to the top of the highest peak of the Himalayas in an hour and a quarter.

Almost all this energy is expended in overcoming the resistance in the capillaries, and transformed into heat. Experiment has proved that the amount of energy in the form of mechanical work which suffices to raise 772 lbs. to the height of one foot will, if transformed into heat, be sufficient to raise the temperature of 1 lb. of water by 1° F. We may estimate therefore that the amount of heat produced in the body in twenty-four hours by the transformation of the heart's energy is equal to the amount required to raise 812 lbs. of water 1° F.

20. Lymphatics.—When the plasma for the nutrition of the tissues is poured out into the interstices of the different parts, all that is not used up for that purpose, or restored by diffusion into the blood-vessels, passes into a series of minute thin-walled tubes which permeate all parts of the body, and which are called lymphatic vessels. These fine vessels unite, like the blood-vessels, into larger tubes and ultimately end in the thoracic duct, where the plasma mixes with the fatty chyle from the lacteals of the intestines and is carried with it into the general current of the circulation (fig. 12).

In the course of these lymphatic vessels, and especially in regions where many lymphatics converge, there are small firm roundish masses, called **lymphatic glands**, whose size varies from that of a grain of corn to that of a plumstone. Into each gland there pass a number of lymphatic vessels. The gland is enclosed in an investing layer or capsule, containing

muscular tissue, within which is a sponge-like meshwork into whose interstices the inferent lymphatics pour their fluid. This travels through the network and passes out of each gland into a smaller number of larger tubes which convey the lymph stream onwards. In the meshes of the glands there are many leucocytes which are continually growing and increasing in numbers. Some of these are from time to time detached and driven onwards in the ascending lymph stream. In this manner the blood receives its reinforcement of white corpuscles to make up for those which are broken up, or which have otherwise left the vessels.

Lymphatic vessels have in their course numerous valves, like those in veins, which prevent any backflow. The circulation of lymph is kept up by the compressive action of the muscles of the body and by the pressure from behind of the new lymph as it is poured out, which is much greater than the pressure within the large veins into which the thoracic duct opens.

21. Respiration.—The free supply of oxygen to the blood is a necessary condition for the maintenance of life, and this is provided by the process of breathing, whereby air is taken into the lungs.

In quiet breathing the air enters through the nostrils and nasal passages, where it is warmed and moistened, into the upper part of the pharynx (fig. 7). When the nose is obstructed, or when the breathing is hurried, the air is taken in by the mouth; but the use of the mouth for ordinary breathing should be avoided as much as possible. The upper opening of the air passage, or **glottis**, is placed in the pharynx at the back of the tongue. Through this opening air is admitted into the **larynx**, or organ of voice, whose most prominent part is the thyroid cartilage, or "Adam's apple," which can be felt in front of the neck. From the lower part of the larynx the **trachea**, or windpipe, passes downwards into the chest (fig. 16). This tube is about 5 inches long and about 2 inches

below the top of the breast-bone, divides into the two *bronchial tubes*, which pass down obliquely, one on each side, to the lungs. The windpipe has in its wall about fifteen nearly complete rings of gristle, which keep the tube open. It is lined with columnar epithelial cells, each fringed with minute vibratile processes, called *cilia*.

22. The LUNGS are two large conical organs placed one on either side of the heart, filling up the largest part of the cavity of the thorax, which is bounded by the ribs. The apices of the lungs rise in the neck a little above the level of the collar bones, and the concave bases rest below on the upper convex surface of the diaphragm, which is a thin muscle placed transversely between the cavities of the thorax above and the abdomen below. The lower surface of the diaphragm, which is concave, is moulded on the upper surfaces of the liver, stomach, and spleen.

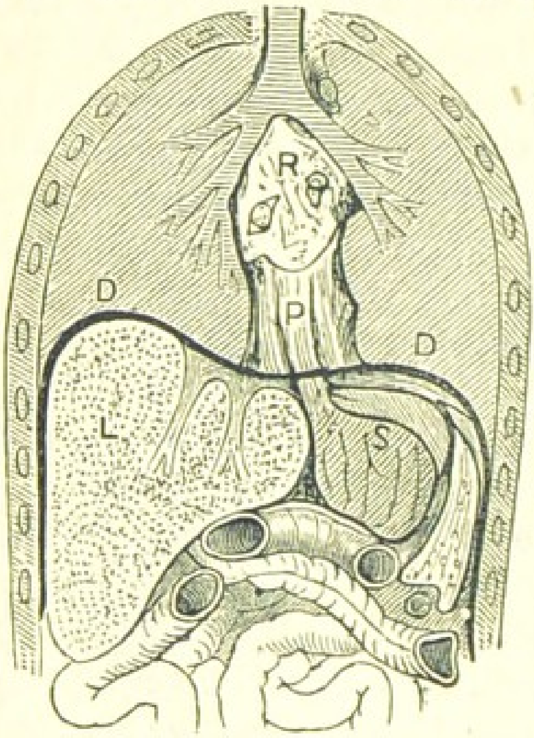

FIG. 22.—Diagram of vertical section through chest from side to side, showing the lungs above the diaphragm D. Below are the liver (L) and stomach (S). P, œsophagus.

When the bronchial tube enters the lung it divides into branches; these again divide and subdivide four or five times, and the terminal *bronchioles*, as these fine divisions are named, end in small funnel-shaped dilatations, whose walls are beset with saccular pouches, the *air cells*. These are minute thin-walled sacs, lined by fine scale-like epithelial cells. The pulmonary artery (fig. 16), which arises from the right ventricle, divides, like the trachea, into right and left branches, which pass to their respective lungs, entering close to the bronchial tube. They divide within the lung, and

their minutest branches ramify between and on the walls of the air cells. By the union of these capillaries the pulmonary veins begin, and ultimately form two large trunks in each lung, the pulmonary veins. These pass out in front of and a little below the pulmonary arteries, and they open separately into the left auricle of the heart. The blood in the pulmonary artery is venous blood, and this, in the capillaries of the lung, is exposed to the action of the oxygen of the air, which enters into combination with its hæmoglobin, brightening it in colour and making it arterial. The venous blood also gives out, in these capillaries, a large portion of its carbonic acid, which passes through the coats of the vessels into the air cells. The purified or oxygenated blood is returned by the pulmonary veins into the left auricle. This process of circulation through the lungs is called the lesser or pulmonary circulation. The current is maintained by the contractile force of the right ventricle.

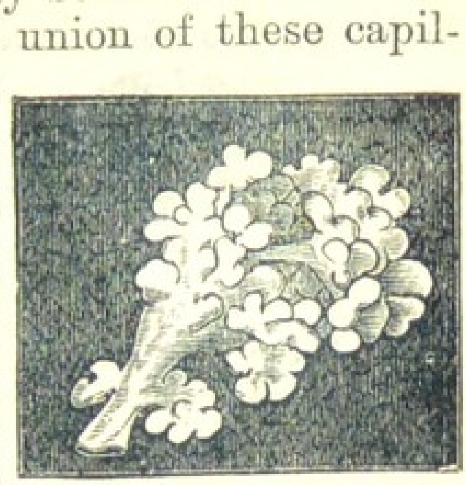

FIG. 23.—Cast of the interior of the air cells at the end of a bronchiole.

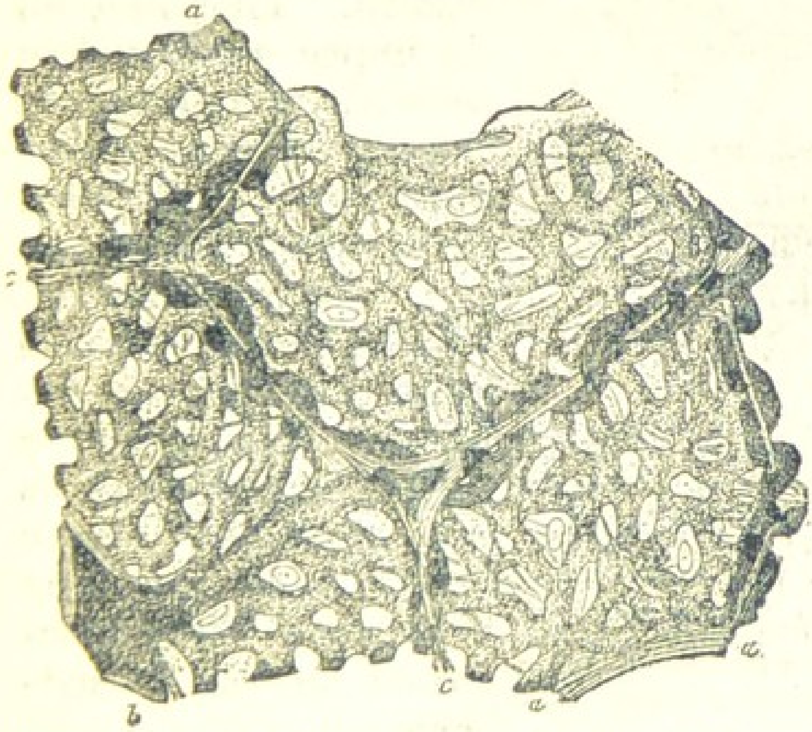

FIG. 24.—Blood capillaries of the air cells of the lung × 250. *a*, *c*, wall of air cell; *b*, minute arteriole.

23. PROCESS OF RESPIRATION.—Each act of the process of breathing consists of two parts, *inspiration*

and *expiration*. The cavity of the thorax in which the lungs are contained is perfectly closed, the only opening into it being that by the trachea into the lungs themselves; when the cavity is enlarged the air from without rushes in through this tube to occupy the increased space. This process of enlargement is accomplished in several ways:—First, by the contraction of the diaphragm forcing down the abdominal viscera. This renders its upper surface less convex, and so enlarges the cavity from above downwards. Second, by the elevation of the ribs. These bones, of which there are twelve pairs, are placed obliquely, their hinder ends being hinged to the back-bone, their front ends for the most part being connected to the breastbone.

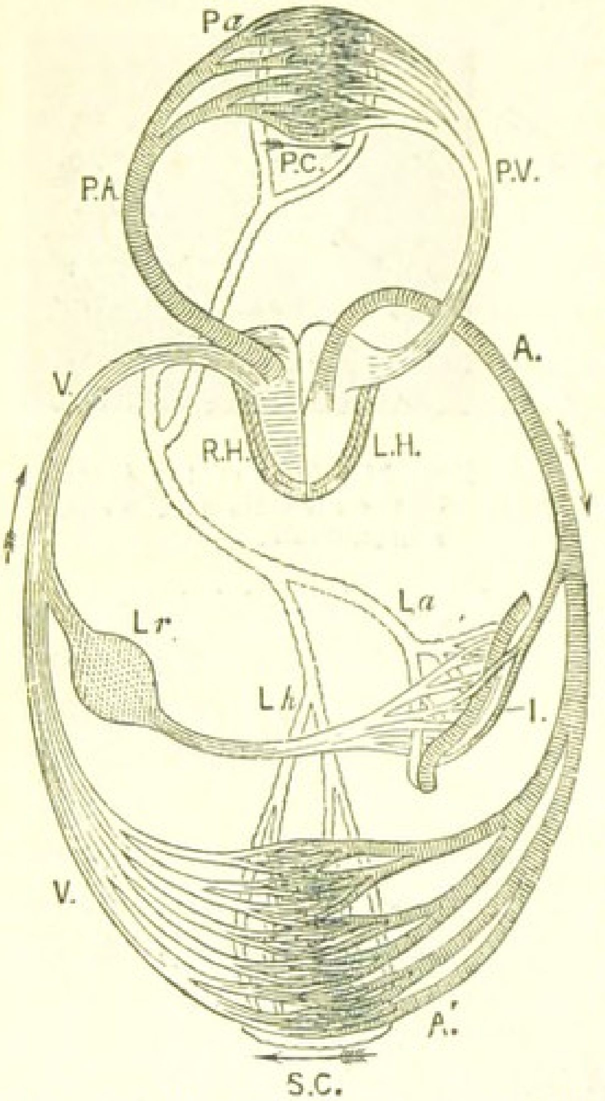

FIG. 25.—Diagram of the course of the circulation of the blood. R.H. the right heart receiving blood from the veins (V) and forcing it into the pulmonary artery P.A.; P.C., pulmonary capillaries; P.V., pulmonary veins; L.H., left heart; A., aorta; A′., arteries; S.C., systemic capillaries; I., intestine whose blood is returned by the vena portæ to (Lr) the liver; La, lacteals; Lh, lymphatics.

When the front ends of the ribs are elevated the cavity of the thorax is enlarged from before backwards. The ribs also are obliquely curved, so that when they are raised their lower borders become rotated outwards, and the cavity is widened from side to side. The spaces between the ribs are occupied by intercostal muscles, which pull one rib towards its neighbours. When the first rib is raised

by certain muscles in the neck the successive intercostal muscles draw up the ribs towards it, and so elevate the entire system of ribs.

On the cessation of the muscular actions which raise the ribs the weight of the thoracic wall causes the front ends of the ribs and the breast bone to descend. The elasticity of the abdominal wall also forces up the diaphragm to its original position. By these changes in position, assisted by the elasticity of the lungs, expiration is accomplished and the air which had been taken in during inspiration is expelled. At each ordinary inspiration about 20 cubic inches of air are taken in and the same amount is expelled in ordinary expiration. By bringing other muscles into play it is possible by drawing a deep breath to take in a much larger amount of air even to the extent of 100 cubic inches, complemental to the ordinary tidal volume of 20 cubic inches.

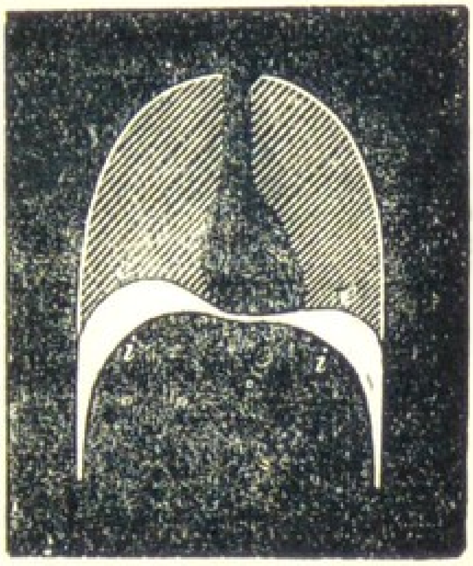

FIG. 26.—Diagram of vertical section through chest from side to side; the white space shows the extent to which the diaphragm sinks in inspiration.

Conversely by an extraordinary effort it is possible to expel from the lungs by a deep expiration about 100 cubic inches of reserve air which is not ordinarily expired in breathing.

There yet remain in the lungs nearly 100 cubic inches of air which cannot be driven out by any effort. Thus in the course of an extraordinary expiration following the deepest possible inspiration the amount of air which can be driven out will amount to 100 cubic inches of *complemental*, 20 of *tidal*, and 100 of *reserve* air. This volume of 220 cubic inches is known by the name *vital capacity*. There is a considerable individual range in the

amount of the vital capacity in different persons, and this can be measured by breathing into a special form of gasometer which is known as a *spirometer*.

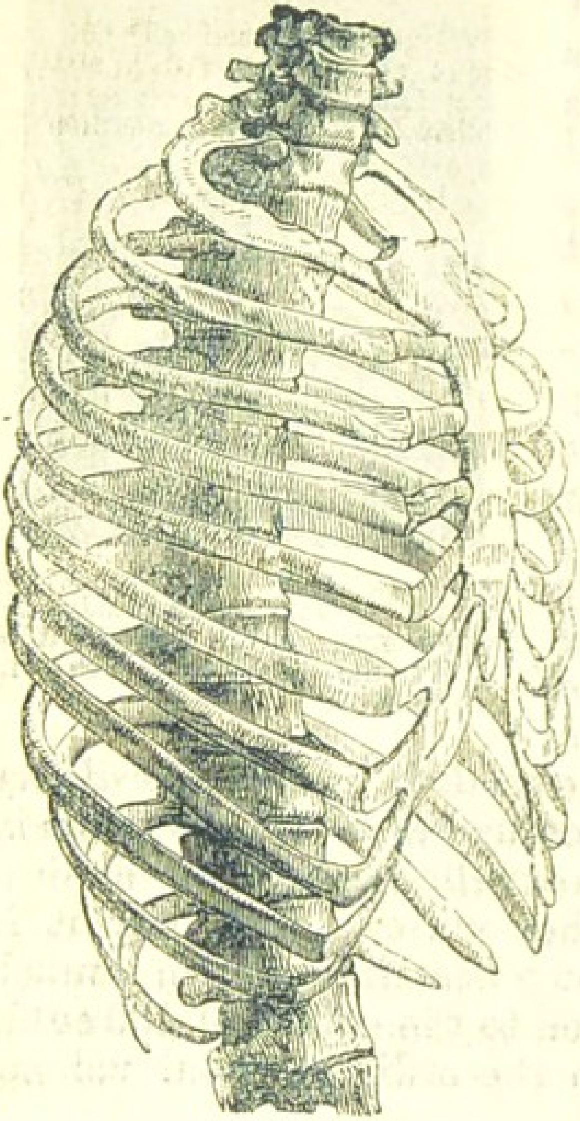

Fig. 27.—Skeleton of the thorax, vertebræ, ribs, and breast-bone (sternum).

24. Changes in the Air during Breathing. A considerable change is effected in the composition of the air which takes part in the process of respiration. Atmospheric air consists chiefly of oxygen and nitrogen in the proportions of 20·9 volumes of the former to 79·1 of the latter. There is also in ordinary air 0·8 per cent. of the singularly inert substance argon, and about 0·03 per cent. of carbonic acid and smaller amounts of other materials. In the air that is breathed out the oxygen has diminished in quantity, and the carbonic acid has increased to about $4\frac{1}{2}$ per cent., that is to more than 100 times the amount that previously existed. This can be shown by breathing through a glass tube into lime water: the expired carbonic acid combines with the lime and forms an insoluble compound, calcium carbonate or chalk, which makes the water milky.

The average man breathes about 16 times per minute; so that in a day about 270 cubic feet of air pass in and out of his lungs. The expired air contains about 2 lbs. of carbonic acid, a quantity representing about 8 oz. of solid carbon; with this

is expelled about $1\frac{1}{2}$ pint of water in the form of vapour, while on the credit side of the account 1·64 lb. of oxygen is taken in. Expired air is nearly of the temperature of the body, namely about 97° F. The body therefore dissipates much heat in this process.

As it is found that the presence of 0·2 per cent. of carbonic acid with the other products of respiration vitiates the air so as to render it injurious, it is necessary that provision should be made for a free circulation of air in inhabited rooms. In one hour a man vitiates about 200 cubic feet of air, and an ordinary gas-burner produces about the same deleterious effect. In arranging for this circulation it must be remembered that heated air ascends, being lighter than cold air; also that carbonic acid when the air is cooled is heavier than ordinary air, and therefore subsides. At least 2,000 cubic feet of air should be allowed per head in the room in which men sleep, and even with this allowance there should be sufficient means of ventilation to allow the whole air to be changed each hour.

The extent to which the lungs fill the cavity of the chest can be determined by the clear sound emitted when the wall of the chest is percussed. If the ear be applied to the chest wall over the lung, a rustling sound is heard during breathing due to the passage of the air into the smaller tubes. The change of the air in the chest during breathing, which is produced by the action of inspiration and expiration, cannot directly affect the air in the ultimate cells but only that in the larger tubes. The interchange in their ultimate branches is effected by the operation of the law of the diffusion of gases, in accordance with which when two gases of different densities and composition are brought into contact they will rapidly mix.

25. Varieties of Breathing.—There are certain familiar actions which consist essentially of more or less noisy disturbances of respiration. A *cough*

is a sudden series of explosive expirations through a narrowed glottis, for the purpose of expelling some irritant from the air passages. A *sneeze* is a sudden spasmodic expiration through the nasal passages, to expel some irritating substance from them. A *snore* is the sound produced by the vibration of the soft palate when breathing takes place through the mouth during sleep; and it is usually due to lying on the back. A *sigh* is a long inspiration through a narrowed glottis. *Sobbing* consists of a series of short deep inspirations followed by long expirations, the successive expirations being generally irregular in length. In *laughing* there is a series of short expirations in rapid succession with a narrowed glottis. *Yawning* consists of a long deep inspiration after one or more short expirations. *Hiccough* is a spasmodic inspiration caused by a sudden contraction of the diaphragm, during which the ingress of air is suddenly checked by closure of the glottis.

26. ASPHYXIA.—When respiration is interrupted carbonic acid very rapidly accumulates in the blood, which is then returned to the heart by the pulmonary veins without the necessary supply of oxygen. When such blood is supplied to the brain it produces insensibility. Hence persons are liable to become drowsy or even unconscious in a vitiated atmosphere. If from submersion or any other mode of suffocation respiration be checked, the heart's action is arrested; hence suffocation is often called *asphyxia*, which means pulselessness. Breathing may in some such cases be restored if artificial respiration be resorted to without delay. The simplest method of accomplishing this is to put the person lying on his back with his shoulders slightly raised and his head hanging backwards. Then the tongue is to be drawn forward forcibly. The arms are then to be drawn quietly but forcibly upwards and outwards so as to expand the chest. They are then to be lowered and compressed against the side, while the front

wall of the chest and breast-bone are to be firmly compressed. These actions are to be repeated about eighteen times in the minute. It is by atmospheric pressure that air is forced into the lung when the thorax is enlarged by the muscles of inspiration, as there is no air in the space between the thoracic wall and the surface of the lung, the contiguous surfaces of which are covered by a smooth delicate membrane, the **pleura.** If by a wound of the inter-costal space **air** be admitted into the cavity of the pleura the pressure is equalised on the outside and inside of the lung and no respiration can take place. The effect of the admission of atmospheric pressure to act on the outside of the lung can be shown by a simple experiment. If the windpipe in the neck of a dead rabbit be tightly tied so as to prevent the escape of air, when the thorax is subsequently opened the lungs are found to fill the entire cavity of the thorax, but if the thorax be opened without previous ligature of the trachea the lungs at once collapse.

27. MUSCLE.—One of the most abundant of the solid constituents of the human body is the fleshy contractile substance which possesses during life the power of doing mechanical work. This substance is named muscular tissue, and it constitutes the material which we term the lean of meat, in which form its appearance and physical properties are familiar to all. When the limb of a fowl or rabbit is skinned the red lean flesh is seen to be disposed in a number of separable masses, each more or less smooth on the surface and attached to the bones by its extremities. These attachments may be direct, the muscle itself being fastened to the surface of the bone, or else indirect by the intervention of a white fibrous string which is called a sinew or *tendon.* To each of these separable masses the name of **muscle** is given.

There are about 260 pairs of these muscles in the human body, each of which has a characteristic shape and position, and to each of which the anatomist

has given a definite name. Thus the round fleshy mass which can be felt in front of the upper arm, and which bends the elbow, is named the *biceps*. The muscles in a full-grown man constitute about 60 lbs. of the weight of the body. If we deduct from this the tendons and non-contractile connective tissues, which weigh about 12 lbs., it leaves about 48 lbs. as the weight of the really contractile substance.

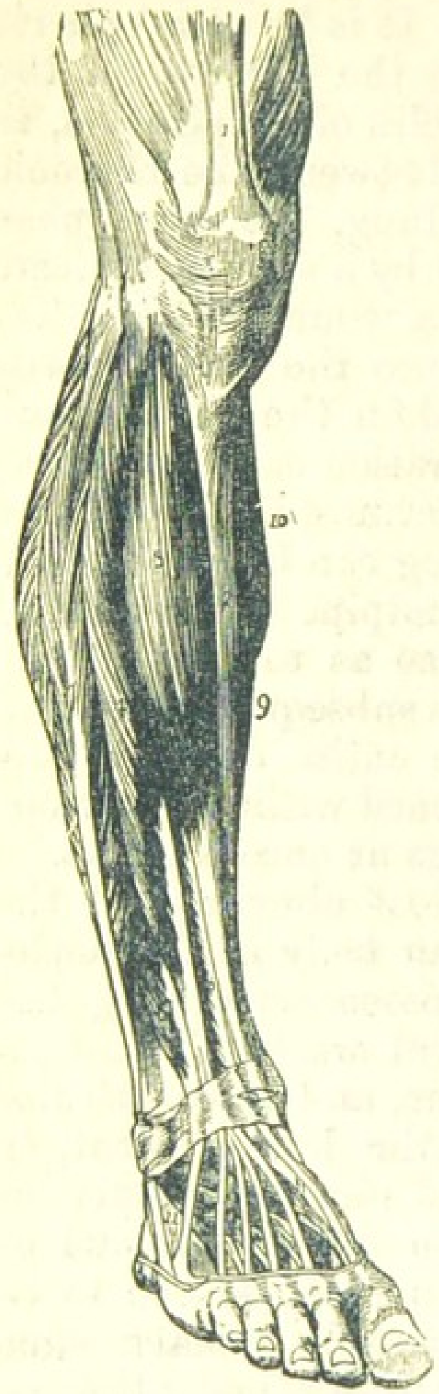

FIG. 28.—Muscles of leg, showing their tendons.

By teasing a muscle with the point of a fine knife it may be broken up into a number of separable strings which are called muscular **fascicles.** Each of these can be still farther subdivided into a series of **fibres** which vary from the 1/100th to the 1/600th of an inch in diameter. These fibres range from $\frac{1}{4}$ to $1\frac{1}{4}$ inch in length; of these fibres the fascicles are built up, and the fascicles may be several inches or even more than a foot in length.

Each muscular fibre consists of a semi-fluid material contained in a transparent elastic sheath, the **sarcolemma.** The sheaths of contiguous fibres in the fascicle are united by the intervention of a delicate layer of connective tissue in which are numerous capillary blood-vessels. The contiguous fascicles are likewise enveloped in coarser connective tissue, and the separate muscles have each a distinct connective sheath which separates them from their

neighbours but at the same time binds them together. One end of each muscle is attached to some fixed or nearly fixed part of the skeleton. This is termed the *origin* of the muscle and it forms the fixed basis from which the muscle acts. The other end is fastened to some movable part and is named its *insertion*. When a muscle acts it draws the structure into which it is inserted towards the origin.

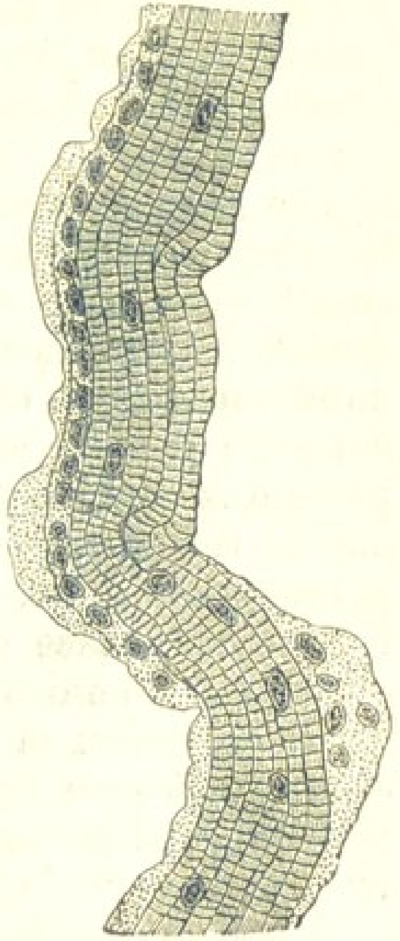

Fig. 29.—Striped muscular fibre, highly magnified.

The material which possesses the power of contracting, and which is contained within the sheath of sarcolemma, is one of the most remarkable substances in the body. The details of its minute structure have not yet been satisfactorily made out, and the exact chemical composition of its highly complex molecules is also unknown. It is easily decomposable into several forms of proteid, into a sugar-like carbo-hydrate, and into an acid which resembles that of sour milk. Shortly after death this substance, which during life appears as a semifluid plasma, undergoes a change resembling that of coagulation, and consolidates into a complex proteid called *myosin*. When this change takes place the muscles become stiff, and this condition is known as **rigor mortis**. In a few hours further decomposition takes place, owing to which the rigidity relaxes and the muscles become permanently flaccid.

28. Contraction and Metabolism.—During life the muscle plasma is continually undergoing change. It is abundantly supplied with lymph from the network of capillary blood-vessels which surrounds

each fibre, and it is continually taking in oxygen and giving out carbonic acid. It also takes from the blood a sugar-like carbo-hydrate called *glycogen,* which is formed in the cells of the liver out of the sugar absorbed from the food in the intestine and conveyed to the liver in the blood of the vena portæ. The making of this glycogen is one of the most important of the functions of the liver. Glycogen, when formed, is stored in the liver, but small quantities continually escape in a slightly modified form into the blood; and this is one of the most important of the elements which the blood supplies to the muscles. The proteid of muscle-plasma is continually undergoing decomposition, and one of the nitrogenous products formed during this process passes into the blood by diffusion as a crystallisable substance called **urea.** As a result of this continued chemical action in muscle there is a constant evolution of heat, in which form much of the energy set free by the conversion of the unstable molecules of muscle-stuff into stable compounds like urea and carbonic acid is dissipated.

When a muscle contracts it becomes shorter, thicker, and harder; rapid chemical changes take place in it, and the quantity of carbonic acid given off from it increases very much; from being alkaline it becomes acid, and there are other evidences that destructive action is taking place in the plasma, the energy set free by which is partly dissipated as heat and partly does work by the form of motion. The material at whose expense this work is done is not the nitrogenous proteid of muscle, for there is no increase of urea or other nitrogenous waste during muscular exercise; but it is apparently the carbohydrate which is decomposed, as the waste products consist chiefly of carbonic acid and water.

One result of muscular exercise is the supervention of fatigue. This sensation is chiefly due to the accumulation in the muscle of the acid products of the chemical action which accompanies the doing

of work; and it manifests itself in a diminished capacity for continuing the work. Chief among these waste materials are certain acid phosphates, and experiment has shown that the removal of these substances restores to the muscles the capacity of working.

29. FORCE OF MUSCULAR CONTRACTION.—The force which a muscle exercises when it contracts is great, and varies under different conditions of work. The amount of work a muscle can do is proportional to the number of fascicles in it, that is to the area of cross section of the muscle at right angles to its fibres. Under the most favourable circumstances a muscle whose sectional area is one square inch can support a weight of 100 lbs. The distance through which a muscle can draw its insertion is proportional to the length of the muscular fascicles. Thus, in the case of the biceps muscle of the arm, which in a man of average size has a sectional area of $1\frac{3}{4}$ square inches and fascicles of about 6 inches long, the contractile stuff is sufficient to raise a weight of 175 lbs. to the height of $3\frac{1}{2}$ inches

The area of cross section of all the muscles of the body amounts to a little over 200 square inches. The useful work which can be done by an average labourer in a working day of eight hours is equal to that which would be required to raise 500 tons to the height of 1 foot. Many animals have a much higher power of working in proportion to their weight than man possesses. Some insects can drag along the ground a weight 67 times that of their own bodies, while man can scarcely drag along three times his own weight.

The muscle considered as a machine does not create energy, it can only use that which results from the setting free of some of its energy derived from chemical combination. Much of this we have seen is liberated as heat, and this dissipation is greatly increased during exercise.

The muscle molecules broken down during

exercise are rebuilt from the elements of the food brought to it in the form of lymph. It is found by experiment that the potential energy which can be changed into heat by the combustion of the materials of the ordinary dietary given on p. 10 equals the work done in raising 3,300 tons to the height of a foot. In a day's labour therefore only about one-seventh of this amount is expended in useful external work, and the rest is spent in maintaining the heat of the body, in secretion and other constructive chemical changes, in nervous action, and other forms of internal work. We are not therefore to look upon the spending of seven-eighths of the available energy in the production of heat as a waste of power, for in order that the necessary processes may take place in the protoplasm of the body in the most perfect manner, it is needful that the temperature be maintained at about 98·4°F., which is the ordinary heat of the body. The amount of heat daily expended in maintaining this constant temperature is equal to that which would be required to raise $48\frac{1}{2}$ lbs. of water from the freezing to the boiling point. The proportion of useful external work which the human machine can do, in proportion to its food supply, is greater than that of the best steam-engines, in which only one-ninth of the energy of the fuel is utilisable as useful work.

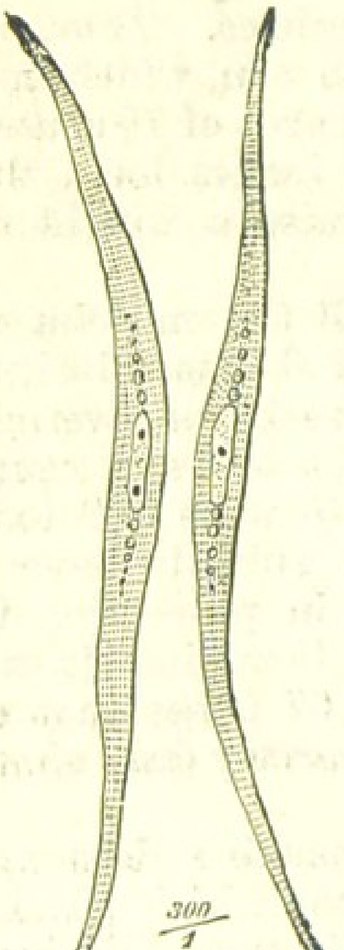

FIG. 30.—Two unstriped muscle fibres.

30. REPAIR OF THE MACHINE.—In another respect the muscle machine compares favourably with any of man's inventions. Instead of wearing out with constant action, it becomes stronger and better able to do useful and efficient work, and the fuel supplied to it contains the

substances required for the repair of the apparatus. In this way the best method of strengthening a weak muscular system is by its exercise, and a graduated system of gymnastic exercises like that which is generally known as Swedish drill, directed to the strengthening of those groups of muscles which are weakest, and which by their weakness produce deformity, is an important hygienic agency. Certain forms of massage are of use in assisting in emptying into the lymphatics the superfluous lymph of the muscles and promoting the local blood circulation, helping them to get rid of the waste products of oxidation.

31. Involuntary Muscle.—Two other forms of muscular tissue are met with in the human body. That which is found in the structure of most of the internal organs consists of minute spindle-shaped fibres which are called **unstriped muscle** cells, as they do not show the transverse striation seen in the muscles of the limbs. Each of these is a long cell about 1/400th of an inch in length, and about 1/5000th of an inch broad. Within this cell is a nucleus in shape like an oat grain embedded in the contractile protoplasm. The muscular coats of the stomach and other hollow internal organs are made of such cells placed side by side.

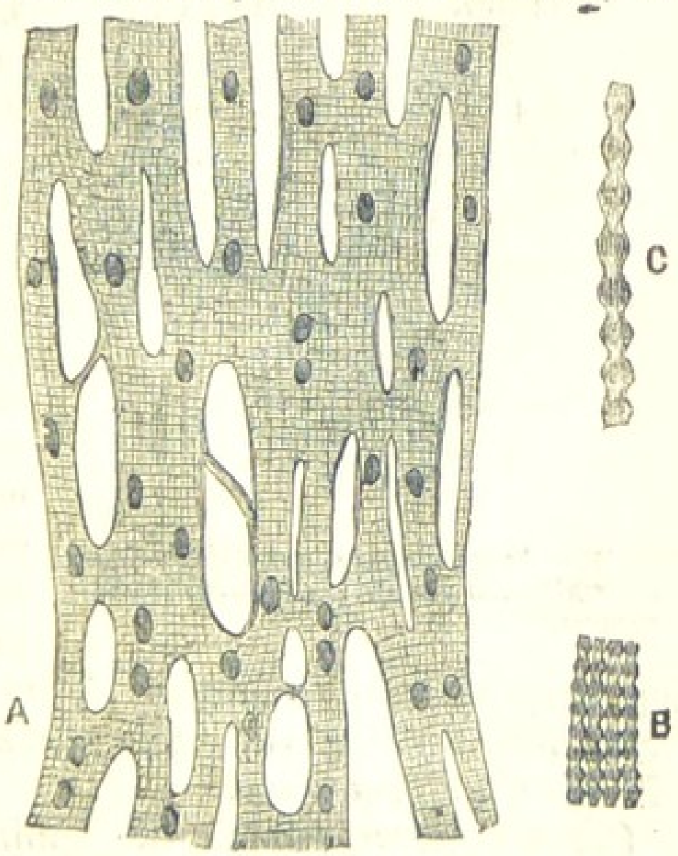

Fig. 31.—Striped muscle of heart, showing the branching and uniting of the fibres; B, C, are fibrils more highly magnified.

The muscular fibres of the heart are intermediate

between the striped and unstriped fibres both in structure and in function. Like the former they show a slight striation; but like the latter they are not directly under the influence of the will. On this account the unstriped and cardiac muscles are called *involuntary* while the striped muscle fibres are called *voluntary* muscles.

32. CONNECTIVE TISSUES.—The contractile substance of muscle is surrounded by and acts upon a series of structures which consist of the material known as **connective tissue.** There are several kinds of connective tissues in the body:—

FIG. 32.—Areolar tissue magnified, showing white and yellow fibres and connective tissue cells.

(1) That which surrounds the muscles and other parts, filling up the interstices of the other tissues, is named **areolar tissue**; it is made up of wavy unbranched fibres of a white colour, which interlace and form a loose network. Mixed with these are some branched yellowish elastic threads, and some microscopic cells, which are generally flattish, and consist of a little protoplasm containing a good-sized nucleus. These cells are usually branched, sending off from their surface a number of irregular processes.

(2) In some places oil globules are deposited in these connective tissue cells. They then appear swollen and are called *fat cells.* Fat cells are usually grouped in closely set masses, and when numerous, make up what is called *adipose*, or *fatty*

tissue, such as we see in the fat of meat. The chief use of fat is to act as a reserve store of nutriment; incidentally it fills interstices and smooths and rounds the surface.

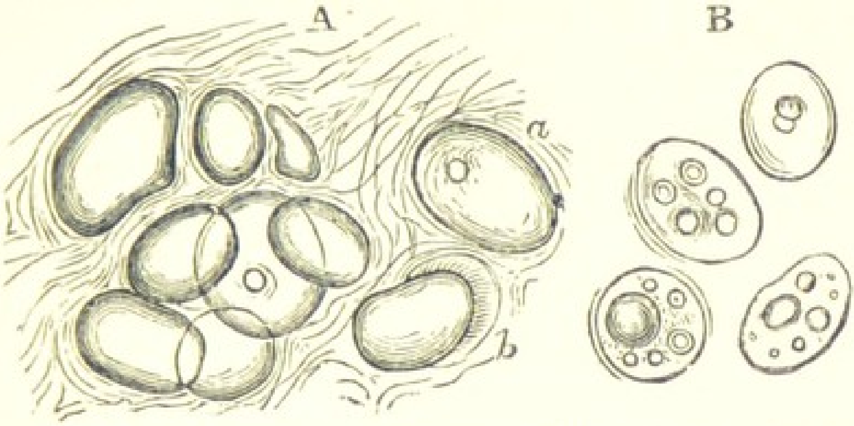

FIG. 33.—Adipose tissue, with fat cells; B, connective cells, containing fat globules × 300.

(3) Some masses of areolar tissue have groups of leucocytes entangled in their interstices. Tissue of this kind is found in the tonsils, in smaller or larger patches in the wall of the intestine, and in some other places, and is named *adenoid tissue*. The leucocytes contained in it multiply by growth and division, as in the tissue of lymphatic glands, to which it bears a close resemblance. The patches of adenoid tissue in the lower end of the small intestine are called **Peyer's patches.** These are the seats of diseased changes in typhoid fever.

(4) The tendon of muscle consists of threads of unbranched white fibres of the kind which makes up areolar tissue, but here they are disposed in parallel bundles. This material, if boiled, becomes converted into gelatine. The impure gelatine used in the arts under the name of glue is made by boiling the tendons and other connective tissues of the horse, cow, and other animals. Tendons appear as glistening white cords, the component threads of which are attached by one end to the sarcolemma of the muscle, and by the other to the surface of bone or of its fibrous sheath. Tendons are much narrower than muscles, and are flexible but not elastic or contractile, and by their means the force

of the contraction of a muscle is made to act upon parts at a distance from the muscle itself. Thus the last joint of each finger is bent by a muscle whose fleshy mass lies close to the elbow. In this way the fleshy elements of muscles may be packed in convenient places where they are most favourably placed to receive an adequate blood-supply.

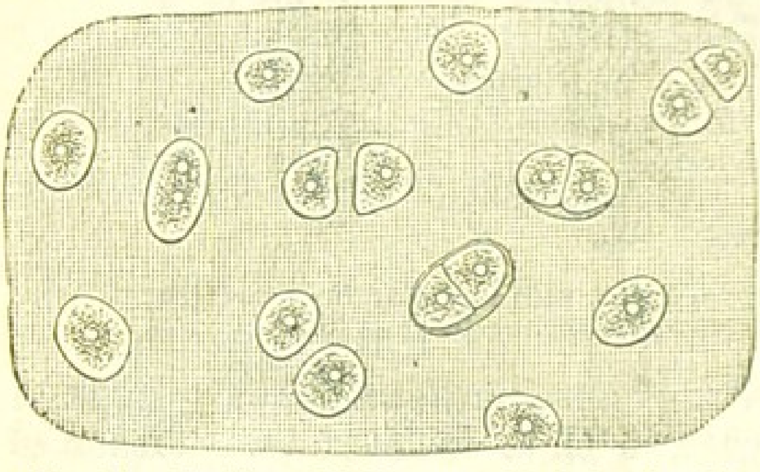

FIG. 34.—Cartilage, highly magnified, showing its cells and ground-substance.

Bands of this same form of white fibrous tissue surround joints where bones come in contact and bind them together. These are named **ligaments.** A few ligaments consist of the yellow, branched, elastic fibres which make up the second element of connective tissue. Such ligaments are elastic. A strong band of this tissue is found in the back of the neck of heavy-headed animals like the ox, and is called the *ligamentum nuchæ.* It is not softened nor converted into gelatine by boiling.

Very thin sheets of the white fibrous tissue form layers on the surface of muscles, binding them in their places; these are called **fasciæ.** A layer of similar texture covers the surface of bones, and is called **periosteum.**

(5) Gristle, or **cartilage,** which encrusts the joint-ends of bones, and which makes up the skeleton of the ear and larynx, is another form of connective tissue, differing in the shape of its cells and in the nature of the substance which surrounds them. Gristle is of use in many parts of the body on account of its firmness, flexibility, and elasticity.

33. BONE.—The material which makes up the skeleton is a sixth form of connective tissue, in

which the substance around the connective tissue cells is hardened by being infiltrated with salts of lime, especially calcium phosphate and carbonate. If bone be burnt and its animal matter thereby destroyed it loses one-third of its weight, and a brittle mass of its calcareous component is left. If bone be steeped in diluted hydrochloric acid the lime salts are dissolved out, and the animal matter is left as a flexible gristly mass.

Bone is of all substances the best adapted to form the solid basis of the human body. In specific gravity it is lighter than most other materials of equivalent strength. It is more elastic than almost any other organic body, while its capacity of bearing tensile stress without breaking and its power of bearing pressure without being crushed are also remarkable. These are shown in the following table. The numbers in the second and third columns are the weights in pounds required respectively to break across or to crush a square rod of the material measuring 0·039 of an inch across. The "modulus" in the fourth column is the weight in pounds which, if these substances were perfectly elastic, would be required to lengthen the square rod to twice its original length.

Substance.	Sp. gravity.	Tearing weight.	Crushing weight.	Modulus of Elasticity.
Bone	1·870	26	33	5,291
Oak	0·845	14	10·5	2,425
Cast Iron	7·207	28	160	...
Wrought Iron	7·788	90	48	41,887
Steel	7·816	225	319	46,300
Lead	11·352	10	11	3,968

A cube of bone whose side measures one inch can bear without being crushed a weight of more than 4 tons. The weight of the whole human skeleton, which is a little over 10 lbs., is rather less than the weight of a skeleton of steel of equal strength.

One condition which the human skeleton must fulfil is that of affording an adequate extent of surface for the attachment of the muscles. The adult bony framework exposes a surface a little over 1,000 square inches in area that is available for muscular attachment, much more than double the area which a steel skeleton of the same height and weight, and constructed so as to be of the greatest possible strength, would present.

The skeleton is suited for the work it has to do not only as regards its material but also in respect to the disposition of the material. It has been found by experiment that if an equal amount of material be used to construct two columns, the one solid and the other hollow, the latter will form the more effective pillar. This is shown in the subjoined table in which the crushing and snapping weights are regarded as unity. Those bones which have to

		Crushing limit.	Snapping limit.
Solid pillar	Diameter 1·00	1·000	1·0
Hollow pillar	,, 1·25	2·125	1·7

bear weight are hollow columns, whose extremities are dilated into masses of strong but delicate lattice-work of thin lamellæ arranged so as to bear pressure on their extremities. These plates are tied together by a similar set of lamellæ at right angles to them, which prevent tearing. This kind of spongy bone is called **cancellous tissue.** Bone is the most vascular form of connective tissue, and is traversed by many minute blood-vessels which run in tubular spaces in its substance, which are called **Haversian canals.** Around these Haversian canals the solid substance of the bone is arranged in layers, between which the connective tissue cells are arranged in concentric series. When bone is macerated and dried the spaces occupied by these cells appear as hollows, which are named **lacunæ,** and the minute

canals in which the branching processes of the cells lay are called **canaliculi.** The great hollow in the centre of each long bone is filled by a semifluid fat called yellow marrow.

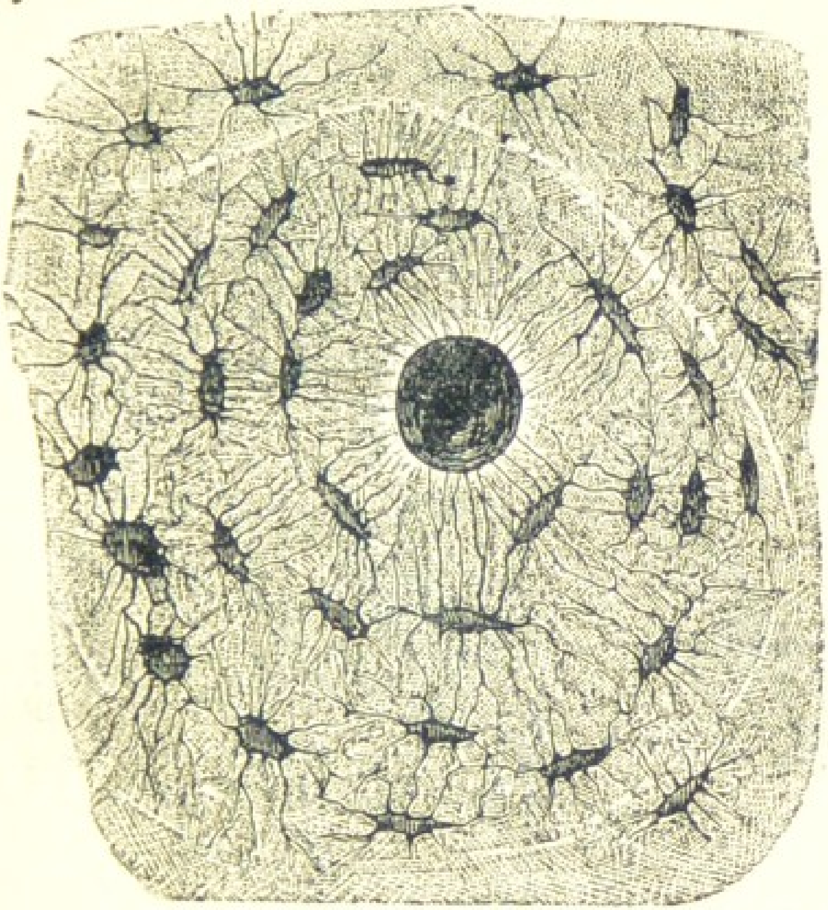

Fig. 35.—Transverse section of bone highly magnified, showing a Haversian canal surrounded by bone cells in lacunæ united together by canaliculi.

34. Skeleton.—There are 200 bones in the human skeleton. They are shown in fig. 36. 23 of these make up the skull and face bounding in the former the large cavity which contains the brain and in the latter the cavities for the sense organs; 26 bones form the vertebral column, which is the axis of support for the body. Each vertebra is a ring, whose anterior part is the thick vertebral body, and whose posterior part is prolonged into the spinous process. The column of rings forms the boundary of a canal, the *vertebral canal*, in which is contained the spinal cord. The 12 thoracic vertebræ and the 24 ribs and the breast-bone bound the thorax. There are 32 bones in each upper extremity, and 31 in each lower.

35. Joints.—Bones come in contact with their

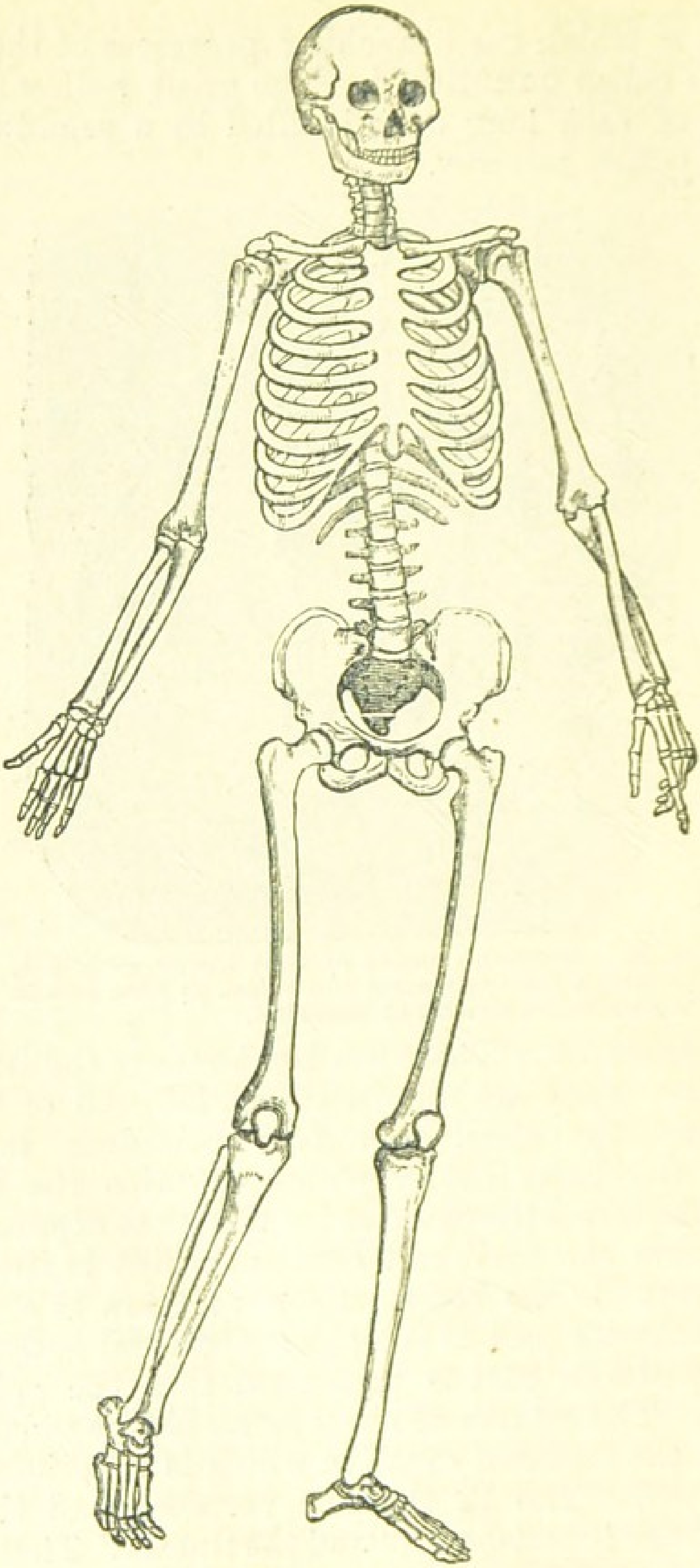

FIG. 36.—The skeleton.

neighbours at their extremities and form **joints.** The areas of contact are generally expanded, the compact bone changing into cancellous tissue. The bones of the skull unite with each other chiefly by immovable joints, the contiguous surfaces coming nearly in contact, often interlocking, the material between the bones being only a thin layer of membrane. In the vertebral column the bones are chiefly connected by plates of gristle interposed between the contiguous vertebræ.

The bones of the limbs usually unite by movable joints. The extremities which come in contact are covered by thin smooth layers of cartilage, and around these the bones are tied together by a sheath of fibrous tissue which is called a capsular ligament, often supplemented by separate external bands called accessory ligament. The inner layer of this capsular ligament is smooth and secretes a white-of-egg-like fluid called **synovia,** which lubricates the surfaces and diminishes friction. This inner lamina is named synovial membrane.

Some of these joints, like the shoulder and hip,

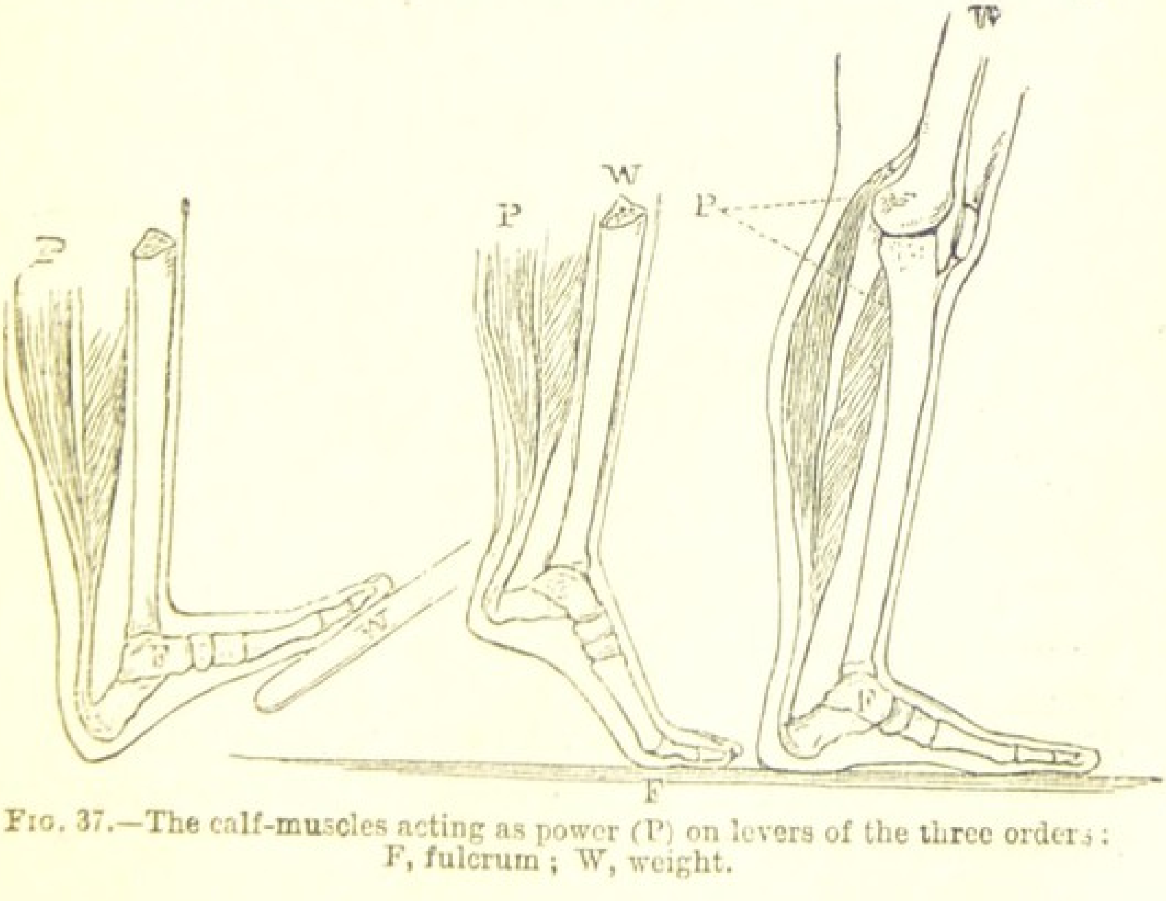

FIG. 37.—The calf-muscles acting as power (P) on levers of the three orders: F, fulcrum; W, weight.

are ball and socket joints in which the one bone is capable of moving in all directions. Some, like the elbow joint, can only permit motion either backwards or forwards in one plane, and are named hinge-joints. A few joints, like that between the first and second of the neck vertebræ are rotatory or pivot joints; while in others the opposed surfaces are flat and can only glide to a slight extent on each other.

36. Bones as Levers.—Bones act as levers, their upper joints being the fulcra, the distal ends the weights, and the insertion of the muscle which moves them the place of application of the power. There are in the body examples of the three orders of levers, indeed the same bone may in different actions present different arrangements of the three fundamental points (fig. 37). Thus in the act of bending up the foot, the solid mass of the foot-bones acts as a lever of the third order, the power being in front of the fulcrum, which is at the ankle, and the weight still farther forward at the toes. In using a treadle it forms a lever of the first order, as the power is at the heel and the fulcrum at the ankle between the power and the weight at the toes. When one stands on one foot and lifts the heel from the ground the foot acts as a lever of the second order, the weight being in that case intermediate between the fulcrum and power. When the calf-muscles by contraction prevent the body from falling forward, the leg bones act as levers of the third order, the ankle joint being the fulcrum. In like manner the forearm is a lever of the first order in the action of straightening the arm, but is a lever of the third order in the action of bending the elbow.

The lever is not the only mechanical power represented in the body; there are several very remarkable specimens of pulleys for altering the direction of forces. One of these is exemplified in the muscle which turns the eyeball downwards and outwards, the superior oblique muscle.

37. Co-ordination.—In most of the actions of the body a large number of muscles co-operate, and their actions have a definite mutual relation in time and extent. This co-operation is often rhythmic and attended with a certain alternation. Examples of this co-ordinated action are seen in such methods of locomotion as walking, running, leaping, &c. In standing upright the head, nearly balanced on the first vertebra (which is named the *atlas*), is kept steady by the muscles of the back and front of the neck. The vertebral column is kept rigid by the long muscles of the back. The perpendicular let fall from the centre of gravity of the body passes in the median plane behind the plane of the axis of motion of the hip joints, whose ligaments prevent their being extended backwards beyond the perpendicular. It passes in front of the axes of motion of the knee joints which cannot be over-extended forwards. The vertical line of gravity is also in a plane slightly in front of the mid-plane of the ankles which are kept from bending forwards by the strong muscles of the calf. Thus with the least possible amount of exertion the erect position can be maintained.

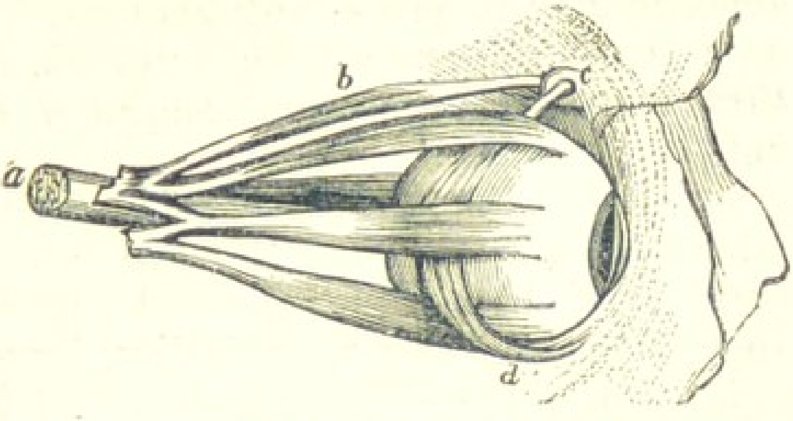

Fig. 38.—Muscles of the eyeball, showing the pulley (*c*) of the superior oblique muscle *b*; *a*, optic nerve; *d*, inferior oblique muscle.

In walking the base of support is alternately shifted; at one stage one leg acts as the pillar of support and the whole body is so adjusted that the vertical from the centre of gravity falls through the axis of this limb, the other leg being passive. Then the weight is thrown on the other leg which becomes the support, and the body is trimmed in accordance.

By this arrangement the muscular effort of walking is reduced to a comparatively small amount. It has been calculated that the work done by an average man in propelling his body by slow walking on a horizontal surface for a mile is about equal to that required to raise a weight of 14 tons to the height of a foot.

In running there is in each step a moment during which both feet are off the ground. Running thus consists of a regular and rapid succession of efforts to prevent the body from falling forwards.

38. Kidneys.—We have seen that the metabolism of muscle is accompanied by a certain amount of nitrogenous waste. One of the products of the decomposition of muscle plasma is the crystalline material called **urea**. As with all such decomposition products it is essential to the maintenance of life that this should be removed from the body, and for this purpose a pair of glands, the **kidneys**, are provided. These lie in the abdomen, in contact with the back wall of that cavity, and on either side of the spine. The right kidney is directly below

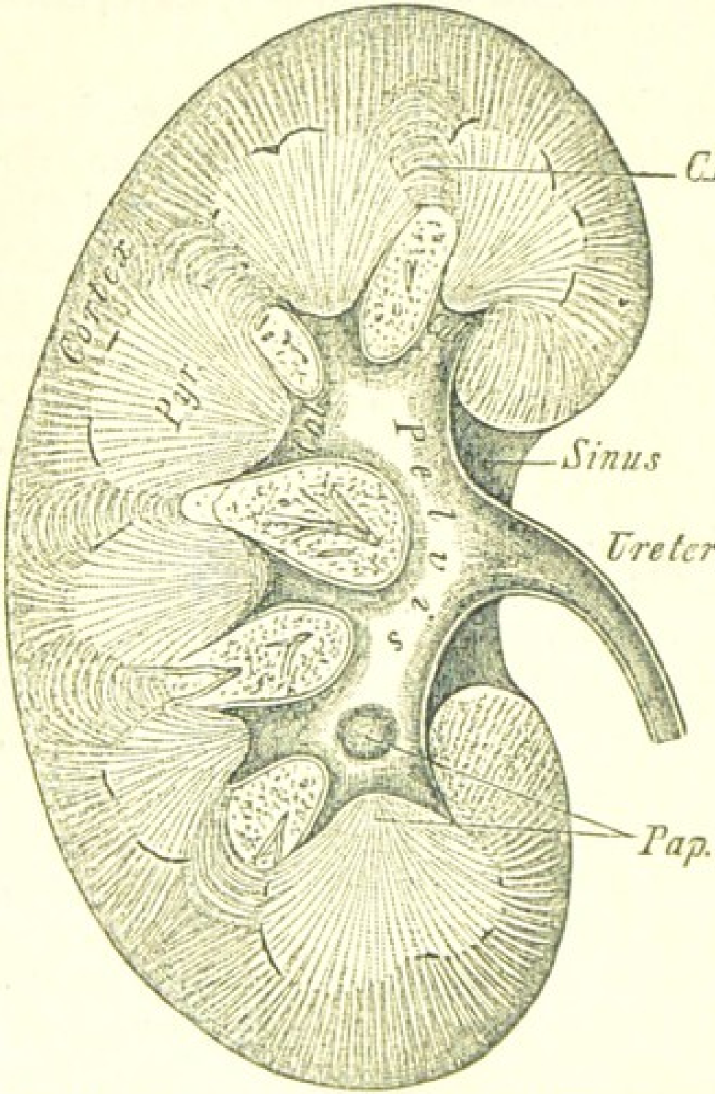

Fig. 39.—Section through kidney, showing secretory tissue of the cortex and tubular pyramids separated by processes of the cortex (CB) *Pap.*, papilla or apex of a pyramid.

the liver, and the left kidney below the spleen. They are dark brown organs, about 4 inches long, and about half this in breadth. They have two borders, the outer convex, and the inner concave. In the centre of the latter edge is a depression, the **hilum**, into which a large blood-vessel, the *renal artery*, enters, and out of which come two vessels, the *renal vein* and the *ureter*.

If a sheep's kidney be cut open from its convex to its concave border it will be seen that the organ consists of two layers—an outer, dark brown, the cortical layer; and an inner, paler, the medullary.

The medullary portion of the kidney consists of masses of very minute straight tubes. These can be seen by examining a thin microscopic section, and they appear to be grouped in pyramidal masses, the apex of each pyramid being directed to the hilum, where it projects into the dilated and branched upper end of the **ureter**. This is a membranous tube 18 inches long and as thick as a goose-quill, which carries the secretion of the kidney downwards to the urinary bladder in the cavity of the pelvis. The minute straight tubes, which open on the surface of the apex of each pyramid, if traced through the medullary matter to the cortex, are seen to become tortuous where they enter the latter layer, and they finally end by dilating into minute capsules, each of which is about $\frac{1}{200}$th of an inch in diameter.

39. Blood-vessels of the Kidneys.—The renal artery which enters the hilum of the kidney breaks up into branches which divide and subdivide; the minuter vessels run between and in the pyramidal masses of straight tubes in the medullary matter to the cortex. Here some of their terminal branches enter the flask-like capsules, within which they form a rounded *glomerulus* or close-wound cluster of capillary blood-vessels.

From this glomerulus a fine vein escapes; this joins with the surrounding minute veins, and forms with them a network of very fine and closely-set

veins around the tortuous tubes of the cortex. Out of this network there emerge some larger veins, which, coalescing with their neighbours, ultimately form the renal vein, which escapes through the hilum of the kidney and enters the inferior vena cava.

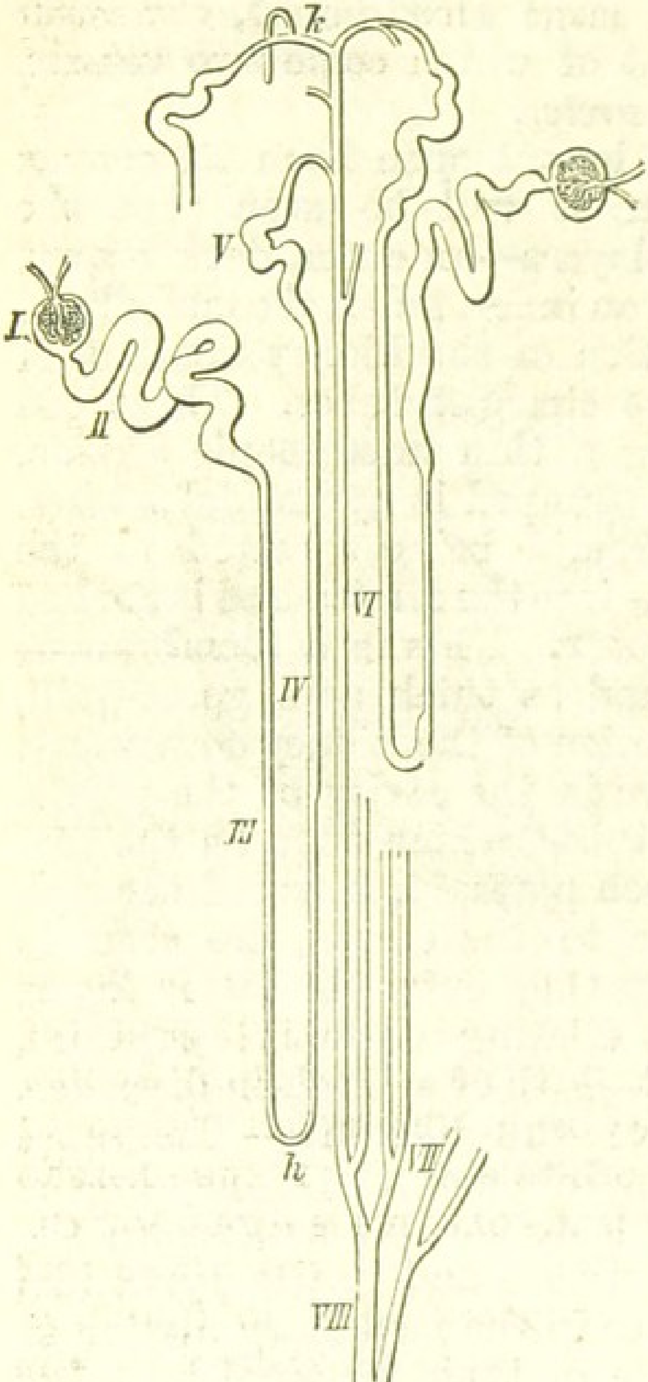

FIG. 40.—Tubular structure of kidney magnified; I, capsule; II, tortuous secreting tubule; III, IV, V, looped tube which, with VI, the straight tube, make up the pyramids; IX, opening of straight tube at papilla.

The blood which circulates in the capillaries of the glomerulus runs through very thin-walled vessels, which allow of the passage, through the cells which make up their coats, of some water and certain saline matters from the blood. This passes into the cavity of the capsule around the glomerulus and trickles from it into the tortuous tube. The wall of this tube consists of a layer of thick epithelial cells, surrounding which is the venous capillary network above described. These epithelial cells have the power of selecting urea and certain other materials from the blood and emptying them into the centre of the tube, where they mix with the water descending from the

glomerulus. The urine thus secreted is carried down by the straight tubes of the medullary substance and discharged into the ureter, which carries it away from the kidney to the bladder. In this manner about two pints and a half of water, containing about an ounce and a quarter of urea, are removed from the blood every day.

40. Uniformity of Composition of Blood.—Considering the amount and the variety of material absorbed from the digestive canal and mingled with the blood, it is a fact worthy of note that the composition of blood is singularly uniform. This is largely due to the fact that the epithelial cells in organs like the liver, kidney, and other glands are constantly engaged in their selective work of removal from the blood of certain materials. It is found that salts of iodine introduced into the blood are so rapidly laid hold of by the kidney that in 20 seconds they can be detected in its secretion.

41. Blood Glands.—There are in the body certain other organs which have much to do with the making and modifying of blood. One of these, the **spleen,** placed under the ribs on the left side of the abdomen, is a purplish oval organ which in many respects is like a large lymphatic gland. It is not only a source of leucocytes but is one of the places wherein the effete red blood corpuscles which are past their work become broken up. Their colouring matter is conveyed to the liver by the vena portæ and there becomes transformed into *bilirubin.*

The **thyroid** body in the front of the neck is another of these blood glands. It is usually small, but when diseased often becomes large, and in that state constitutes the swelling known as a *goitre.* The **suprarenal bodies** are likewise blood-making organs which are especially active before birth; at this time they are larger than the kidneys, over which they lie, but they become small and degenerated in the adult. Another organ of the same kind, the **thymus,** which lies in the thorax above

the heart, degenerates in the adult into a mass of fat.

42. NERVES.—Into every muscle in the body there passes a white cord which is called its **nerve.** Each of these cords breaks up into fine threads, one of which ends within each muscular fibre. These are called **motor** nerves. White cords which appear exactly like these can be traced into the substance of the skin, within which they break up into minute terminal branches. These branches end so close together that one cannot touch any part of the skin with the point of a needle without pressing on a nerve-ending. These are called **sensory** nerves. The sensory and motor nerves can be traced upwards towards the vertebral column, and as they ascend they unite into larger cords in which sensory and motor fibres lie side by side. The cords can ultimately be traced into the canal within the vertebral column and into the interior of the skull, where they join a great mass of nervous matter, the brain and spinal cord, which together are called the **nervous central organs.** To these the sensory nerves convey the impulses arising from the stimulation of their ends; hence they are sometimes called the *afferent* nerves. From the central nervous organs the motor impulses stream forth down the motor nerves to the muscles; hence these are named *efferent* nerves.

In the substance of the central nervous organs there are large numbers of **nerve cells.** These are minute masses of protoplasm, the largest being about 1/600th of an inch in diameter, but others are much smaller. Each cell consists of a central body containing a round nucleus surrounded by a network of protoplasm. From the central body a number of branching processes pass off, some of which form a close network in the nervous centre, but one large distinct and unbranched process passes off from each cell and is called the **neuraxial process**: it consists of a soft gelatinous protoplasm continuous with that of the cell. This process, soon after it leaves the

cell, becomes surrounded with a delicate fatty sheath, outside which is a thin transparent membrane, the

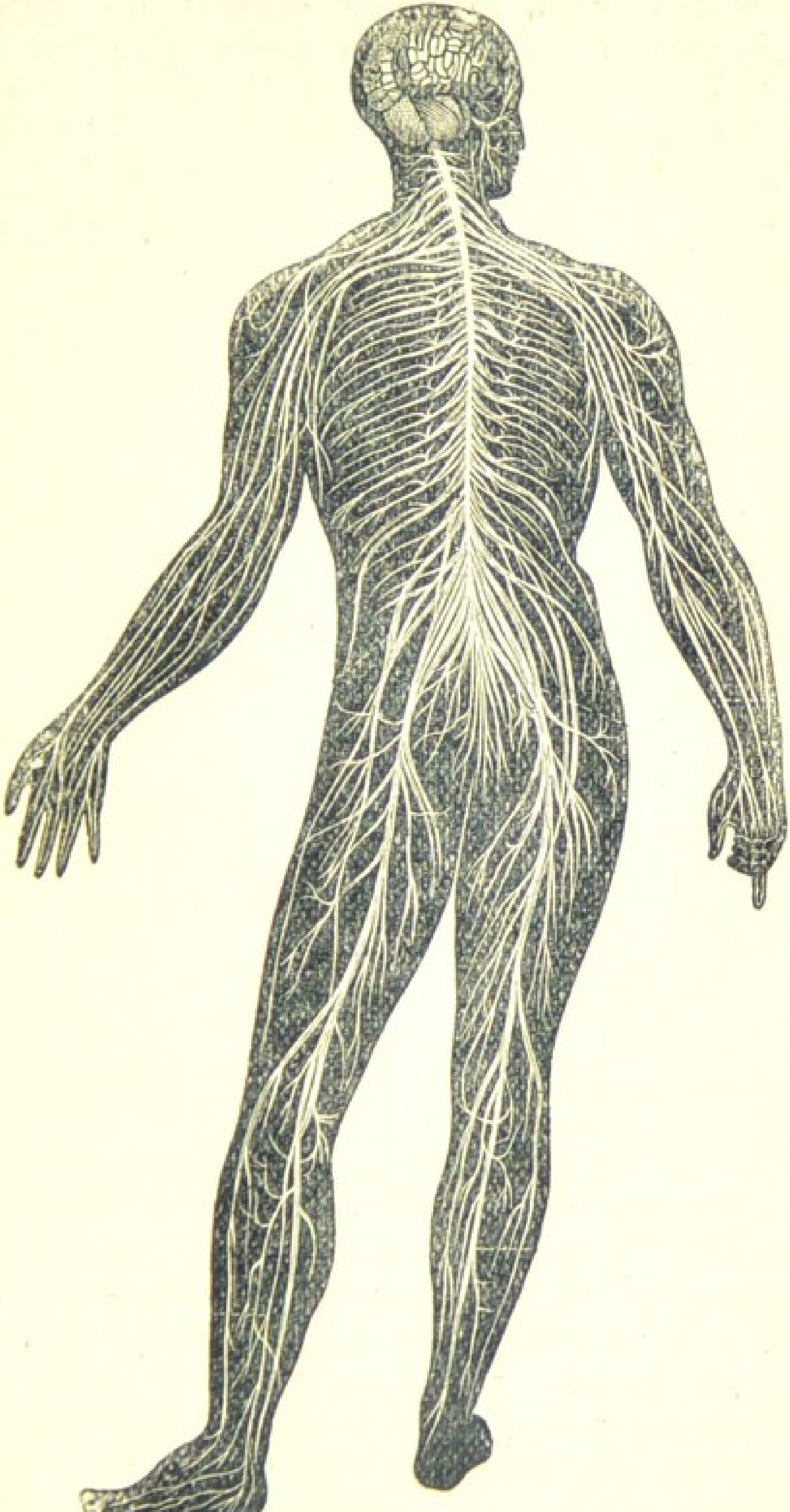

FIG. 11.—Diagram of the distribution of nerves through the body from the brain and spinal cord.

neurilemma. The fibres so constituted run out in bundles from the nervous centres and are the nerve fibres which pass to their several destinations throughout the body. Each nerve fibre can thus be traced from the nerve cell of which it is the neuraxial process through the nerve cord to its termination in skin, muscle, or other substance in the body. A cluster of nerve cells grouped together in a mass is called a **nerve ganglion.**

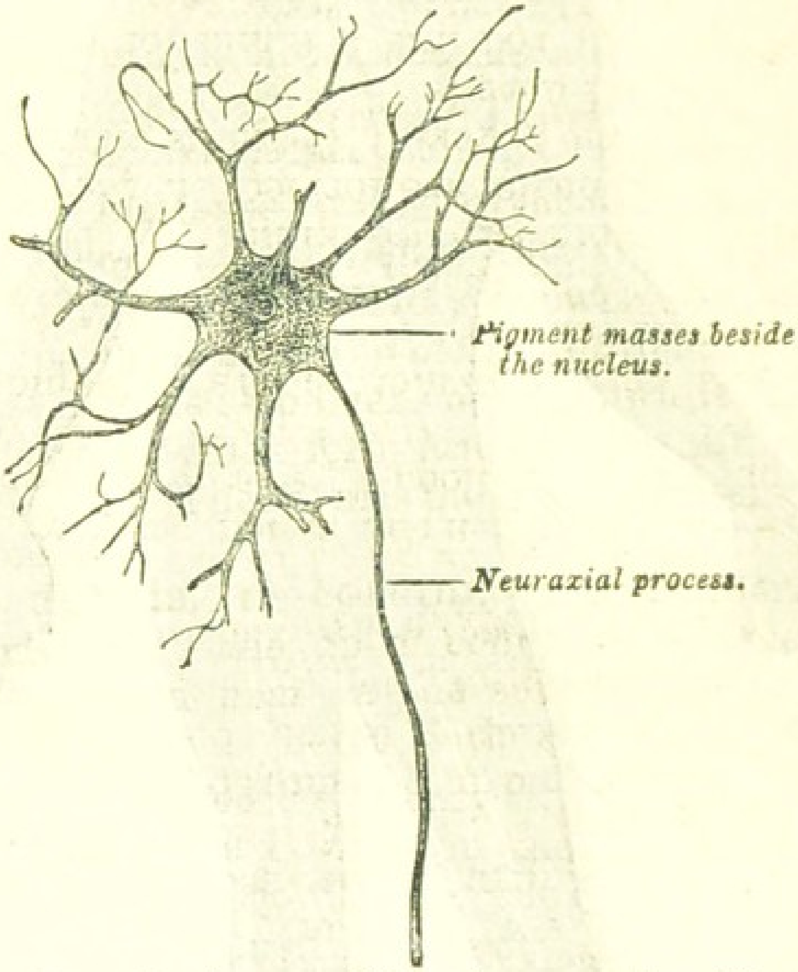

Fig. 42.—A nerve cell from the grey matter of the spinal cord highly magnified.

The part of the central nervous system in which the cells are chiefly massed together is of a greyish colour and is called *grey nerve matter*. The part which consists of the nerve fibres is called *white nerve matter*, from the whiteness of the medullary sheaths of the nerve fibres. These two sets of elements are supported by delicate connective tissue, in which numerous fine blood-vessels ramify for the nutrition of the whole mass.

43.—THE BRAIN is a large oval mass which almost fills the entire cavity of the skull. In the average adult man it weighs 47 oz., being about 1/36th of the weight of the body, in the average adult woman it weighs about 41 oz., forming about 1/35th of the weight of the body. The size of the brain is

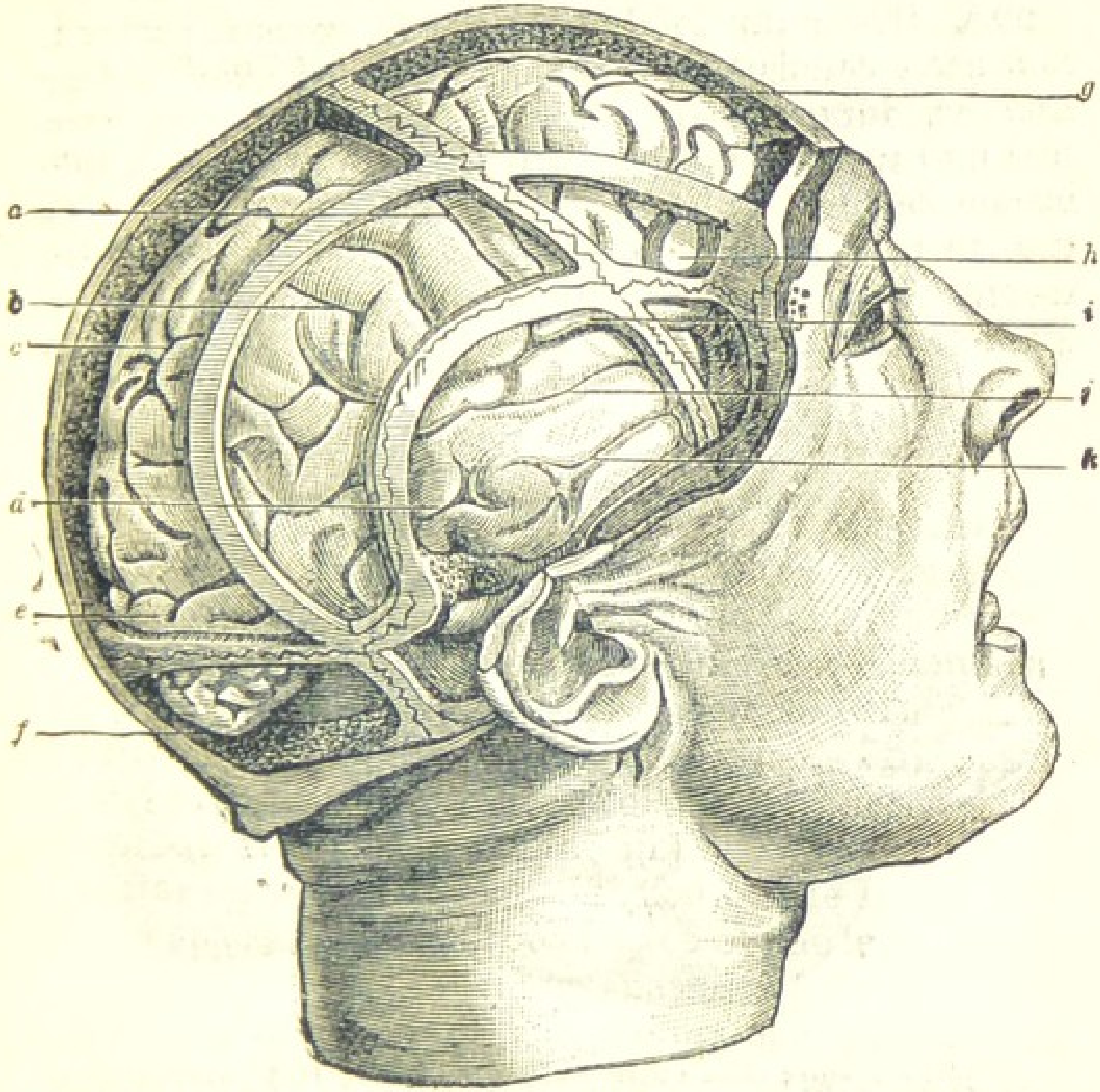

FIG. 43.—Position of the brain in the head. *a*, front edge of anterior central fissure; *b*, *c*, intra-parietal fissure; *d*, occipito-temporal fissure; *e*, *f*, occipital lobe; *g*, frontal convolutions; *h*, speech convolutions; *i*, sylvian fissure; *j*, superior temporal fissure; *k*, temporal lobe.

influenced by many conditions, such as stature, age, &c. In some persons it greatly exceeds this bulk. The brain of Tourgenieff weighed 64 oz.; that of Cuvier, 62 oz.; that of Gambetta, 47 oz. In imbeciles the brain is often of very small size, falling as low as 16 oz

The chief part of the brain consists of two large symmetrical masses, the **cerebral hemispheres,** which fill the greater portion of the skull cavity. The surfaces of these hemispheres are curiously wrinkled, marked by meandering deep furrows which cut them into long projecting tracts of surface, which are called the cerebral **convolutions.** These are fairly constant in general pattern, and each consists of a surface layer of grey matter and an inner mass of white matter. The two hemispheres are separated from each other on their upper surface by a deep longitudinal fissure. At the bottom of this is a transverse sheet of white matter which ties together the two hemispheres. This is called the **corpus callosum.** Below this

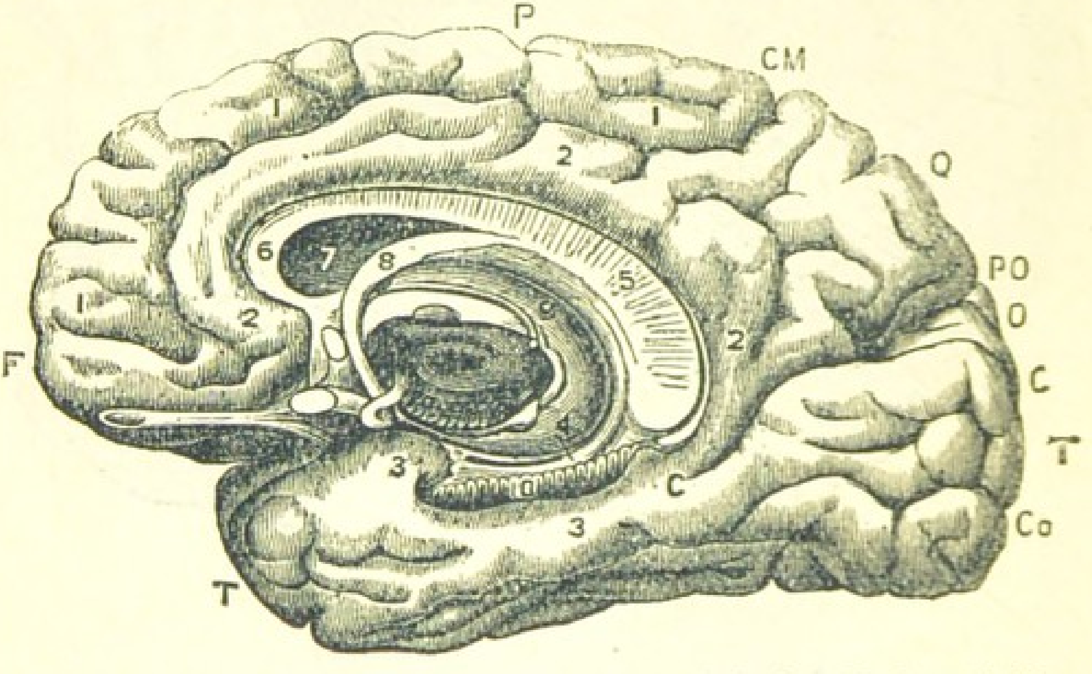

FIG. 44.—Longitudinal vertical section through brain. F, frontal lobe; P, parietal lobe; C M, calloso-marginal fissure; Q, precuneus; P O, parieto-occipital fissure; O C T, occipital lobe; 1, superior frontal convolution; 2, limbic lobe; 3, uncinate gyrus; 5, 6, corpus callosum; 7, septum lucidum; 8, fornix; T, temporal lobe.

on each side is a long sinuous cavity within each hemisphere, the **lateral ventricle,** on the floor of which are two great masses of grey matter, the foremost of which is the **corpus striatum,** the hinder is the **optic thalamus.** (Fig. 45, 2 and 4.)

On the under side there passes from each hemisphere a thick white footstalk about as large

as one's thumb, the **crus cerebri.** The two crura converge as they pass backwards and downwards, and run into a large quadrate mass on the base of

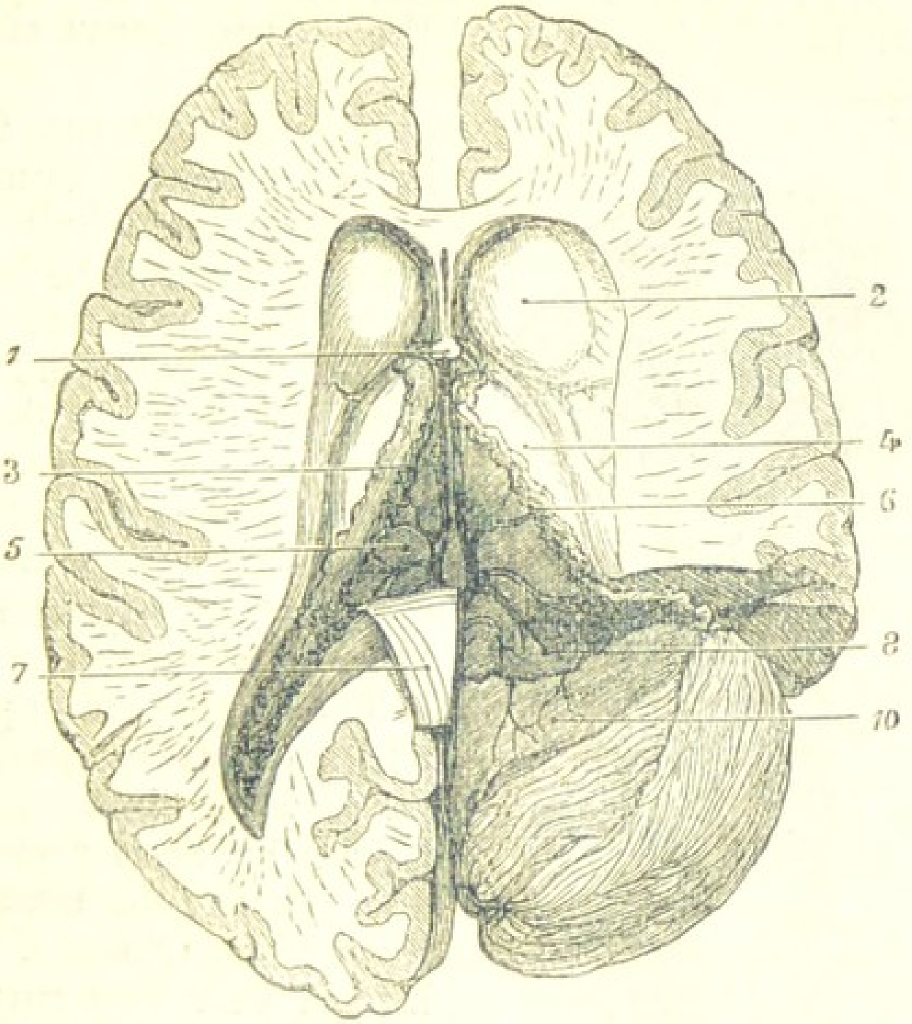

FIG. 45.—Horizontal section through brain, showing the great grey central ganglia 2 and 4 in the lateral ventricle; the cerebellum is exposed behind at 10; 1 and 7, fornix, cut and reflected.

the brain, the **pons.** Behind and on each side of the pons and below the cerebrum is the lesser brain, or **cerebellum,** about 1/8th the size of the cerebrum, and marked on its surface by closely-set irregular linear furrows which subdivide its surface into narrow convolutions. The superficial fibres of the pons which cover the under side of the crura cerebri pass directly into the cerebellum, and join one side of that organ to the opposite side. Such uniting fibres running from one part of the grey nervous centres to another are called **commissures.**

From the lower and back part of the pons a pear-shaped body projects downwards, the **medulla**

oblongata or **bulb.** This is continued through the foramen magnum, or great hole at the base of the skull, and becomes continuous with the **spinal cord,** which descends in the central canal of the vertebral column.

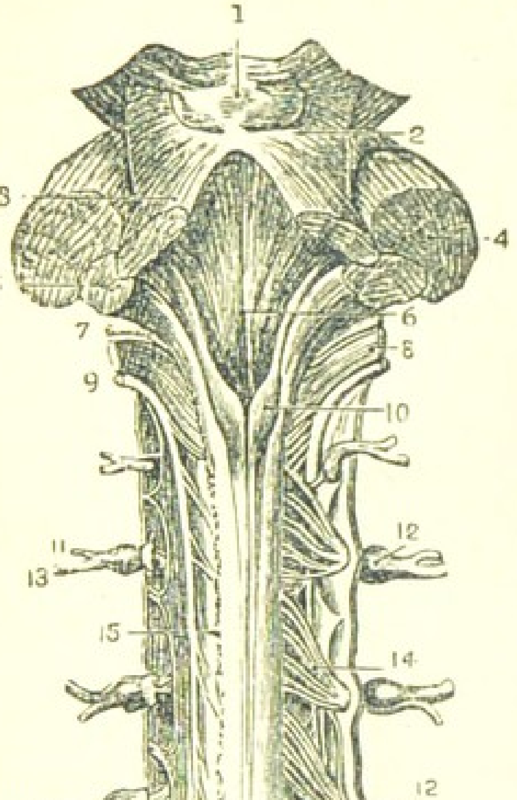

Fig. 46.—The bulb and the upper portion of spinal cord. 1, optic lobes; 2, 3, and 4, cerebellar peduncles; 6, fourth ventricle; 7, 8, 9, 10, cranial nerves; 11, anterior, and 12, posterior branches of spinal nerve; 12, ganglion of posterior root of nerve outside the opened fibrous sheath.

44.—The Spinal Cord is a flattened cylinder which in the adult man is usually about 18 inches long and half an inch thick. Its lower end is on the level of the 20th vertebra, about the level of a line drawn across the back from one elbow to the other when the arms hang by the side.

The spinal cord appears white on its surface, and is divided into lateral halves by deep **anterior** and **posterior fissures.** From the surface of each lateral half two rows of fine threads come off at intervals. One of these rows arises in a line at some little distance from the anterior fissure. These are called the **anterior roots** of the spinal nerves. The second row arises farther back, not far from the posterior fissure. These are called the **posterior roots** of the spinal nerves. That part of the surface of the spinal cord which lies between the posterior fissure and the posterior roots is called the **posterior column.**

that between the anterior roots and the anterior fissure is called the **anterior column**, and that between the anterior and posterior roots is the **lateral column.**

The contiguous posterior root-threads group themselves together in clusters and unite into a series of thirty-one successive cords, each of which swells into a small oval mass containing nerve-cells which

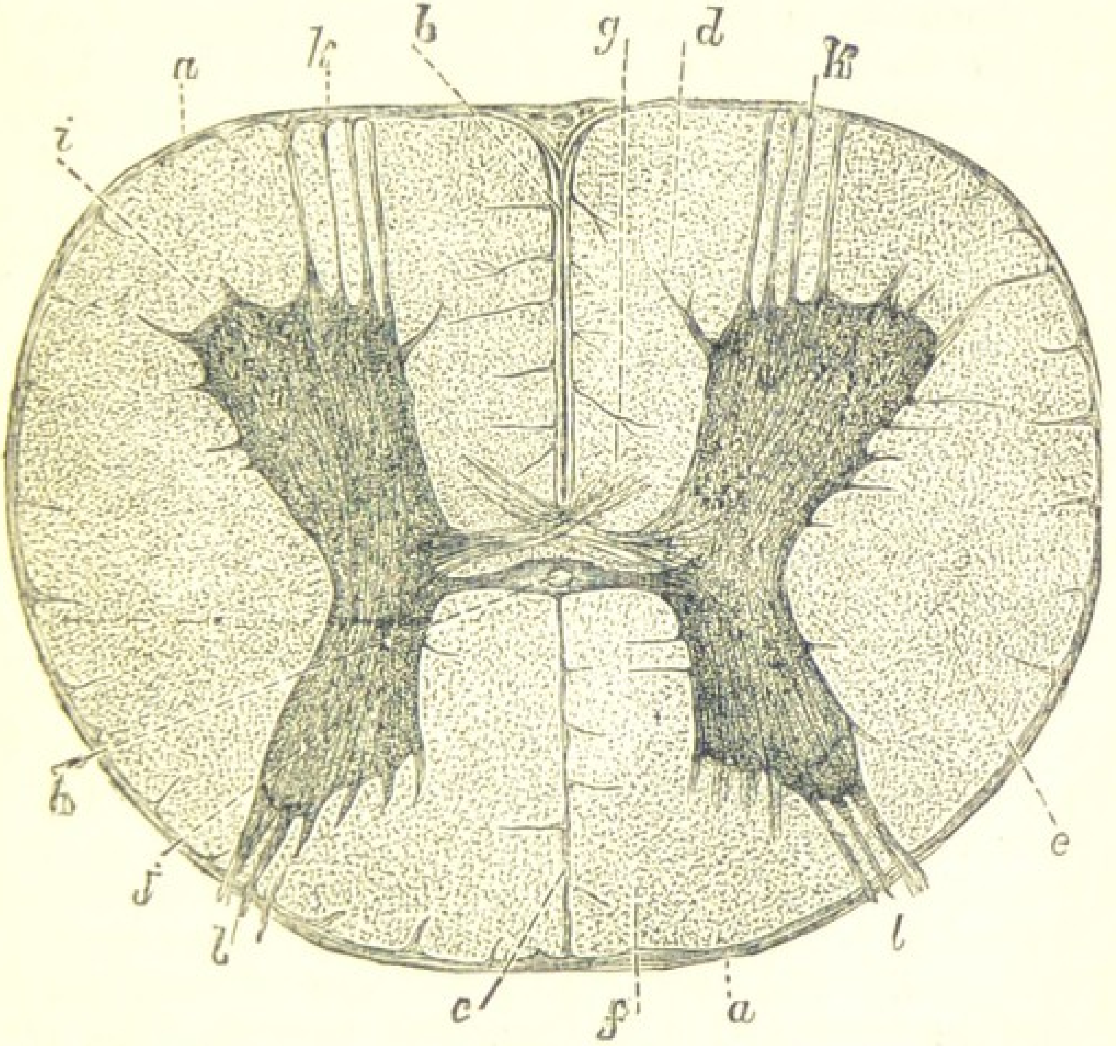

FIG. 47.—Transverse section through spinal cord × 8. *a*, investing membrane; *b*, anterior fissure; *c*, posterior fissure; *d*, anterior column; *e*, lateral column; *f*, posterior column; *g*, commissure; *h*, central canal; *i*, anterior horn of grey matter; *j*, posterior horn; *k*, anterior or motor nerve roots; *l*, posterior or sensory nerve roots.

is called the *ganglion of the posterior root.* The nerve threads of the anterior roots similarly unite into thirty-one anterior roots, each of which joins its corresponding posterior root close to that end of the ganglion which is farthest from the spinal cord. By this union they make up the thirty-one pairs

of spinal nerves. Each pair of spinal nerves makes its exit between adjacent pairs of vertebræ, and they are distributed to a definite area of the body.

It has been proved by experiment that the anterior roots of the nerves consist of motor filaments, and if they be divided motor impulses cannot pass to the muscles; similarly the posterior roots consist of sensory filaments, and if divided there is loss of sensation in the area to which the divided nerve sends its filaments. The spinal nerve formed by the union of the two roots is compound, containing both motor and sensory fibres; so are most of the larger branches which come off from it, but the two kinds of fibres become separated in the finer branches, some of these being made up of sensory and some purely of motor fibres.

45. Spinal Nerves.—If the spinal cord be cut across, its outside is seen to consist of white nerve matter, but within each half of the cord there is a crescentic mass of grey matter. The concavity of this crescent is directed outwards; the anterior horn of the crescent is turned towards the line of origin of the anterior roots, and the hinder horn towards the posterior roots. The fibres of the anterior roots arise as neuraxial processes from nerve cells in the anterior horn of grey matter. The fibres of the posterior roots are the neuraxial processes arising from the nerve cells in the ganglia of the posterior roots. Each of these cells sends off a process which divides into two branches, one passing into the spinal cord, the other continuing into the nerve. The connexions of the former of these, by which sensory impulses are conveyed to the cord, are very complex. Some ascend in the posterior column of the spinal cord to the medulla oblongata, and ultimately are connected by fibres, ascending in the crura cerebri, to the grey masses of the cerebral hemispheres. In the cerebrum these sensory impulses are translated into sensations of which we are conscious, but how this takes place we know not.

Not only does perception take place in some unknown manner in consequence of the reception of impressions by some regions of the cerebrum, but it is in the cerebral cortex also that the determinations of the will are translated into physical action and motor impulses are originated. These travel down certain of the fibres of the crus cerebri into the medulla oblongata. Thence they descend in the lateral column of the cord to the cells of the anterior horn, from which the motor nerves arise as neuraxial processes and convey to the muscles which they supply the stimulus which causes them to contract.

46. Reflex Action.—Besides these cerebral connexions there is a more direct communication between the posterior and the anterior roots of the spinal nerves. If the cord be cut across, and any of the areas supplied by the nerves which arise below the point of division be irritated, the muscles of that region will move. In this case the impulse is carried by certain complex connexions through the grey matter of the crescent to the cells of the anterior horn. When the action of the brain is suspended, as in deep sleep, local nerve stimulation will cause muscular movement in this way. For example, tickling the sole of the foot leads to the foot being withdrawn. This direct motor reaction following the excitation of a sensory nerve is called **reflex action**, and is independent of the influence of the will. Winking when the eye is suddenly exposed to a strong light, sneezing when the lining membrane of the nose is irritated, coughing when the larynx or trachea are stimulated, are all examples of reflex action. These actions take place without the conscious exertion of the will.

In the spinal cord and medulla oblongata there are definite groups of cells connected on the one hand with certain of the sensory, and on the other hand with certain of the motor mechanisms, and these are the centres of the several reflex actions of

ordinary animal life, such as respiration, circulation, swallowing, &c.

The rate at which nervous impulses travel has been determined by experiment to be about 120 feet per second. Pressure on a nerve-trunk interferes with its function, and if the nerve be sensory it produces painful sensations in the area which it supplies. Of this nature is the tingling feeling in the little and ring fingers produced by pressure on the ulnar nerve as it lies over the "funny bone" on the inner side of the back of the elbow between the two projecting bony points of the olecranon and the inner epicondyle. A similar sensation in the foot when it "goes asleep" is produced by pressure on the peroneal nerve on the outside of the back of the knee, due to sitting with the legs crossed. In both these cases it is to be noticed that the sensation is not referred to the place of pressure but to the area of distribution of the nerve. This phenomenon of referred sensation is sometimes curiously illustrated when after amputation of the thigh pains are felt in the toes, and if a stick be put in the hand of the patient to indicate the seat of pain he will touch the empty place where the foot should have been. The common and painful ailments of neuralgia and headache are usually examples of referred sensation of another kind, in which a cutaneous area at a distance is reflexly excited by irritation at some other part which is in some sort of nervous connexion with it. A bad tooth or a disordered stomach are common causes of headache; pain in the tip of the right shoulder is a frequent concomitant of disease in the liver; and in disease of the hip-joint, the pain is often referred to the knee, and not felt in the affected joint.

The nerve fibre is not a separate structure, but is the process of a nerve cell, and when this connexion is severed, as by cutting a nerve, the remoter part rapidly undergoes degeneration and

wasting. If, however, the two cut ends of a nerve are brought into contact and retained in position, reunion will usually take place in course of time.

47. PARALYSIS.—Paralysis is a condition in which the transmission of motor impulses is interrupted in some part of the mechanism between the grey matter of the brain and the muscle. In this condition we have a demonstration of the remarkable fact that the nerve fibres which supply the muscles of the right half of the body are connected with the left half of the brain, and *vice versa*. The motor fibres cross, or *decussate*, at the lower end of the medulla oblongata, but the sensory fibres cross within the cord and ascend on the opposite side. It follows from this, that if one-half of the spinal cord be cut across, motion will be lost in the leg on the cut side, and sensation will be lost in the opposite leg. If disease affect one side of the nervous centres above the medulla oblongata, that is, above both the motor and sensory decussation, motion and sensation will be lost on the opposite side.

48. CRANIAL NERVES.—From the brain itself there arise twelve pairs of nerves which are named **cranial nerves** to distinguish them from those that arise from the spinal cord. The foremost of these is the **olfactory nerve**, distributed to the mucous lining of the nose. This is the nerve of smell. The second is the **optic nerve**, which ends in the eyeball and is the nerve of sight. The third, fourth, and sixth are fine threads which supply the muscles that move the eyeball. The fifth is a large nerve which is the sensory nerve to the skin of the face, a portion of it also supplying the muscles of the lower jaw. The seventh pair of nerves supply the muscles which move the skin of the face, eyelid, lips, and cheek. The eighth is the **auditory nerve**, distributed to the organ of hearing. The ninth, which is named **glosso-pharyngeal**, is distributed to the membrane covering the back of the tongue.

It is the nerve of taste and supplies also some of the parts concerned in swallowing The tenth is called the **vagus**, or wandering nerve, from its long and devious course; it descends through the neck to the thorax and abdomen, and supplies the lungs and stomach: on this account it is also named *pneumogastric*. The eleventh, or **spinal accessory**, nerve takes a somewhat remarkable course: it arises for the most part from the lateral column of the spinal cord in the neck, but ascends through the foramen magnum into the cavity of the skull, which it soon leaves in company with the ninth and tenth nerves and the jugular vein. It is finally distributed to the superficial muscle of the back of the neck, the trapezius, and to the sterno-mastoid muscle which bends the head forwards. The twelfth cranial nerve is called the **hypoglossal**, and is distributed to the muscles of the tongue.

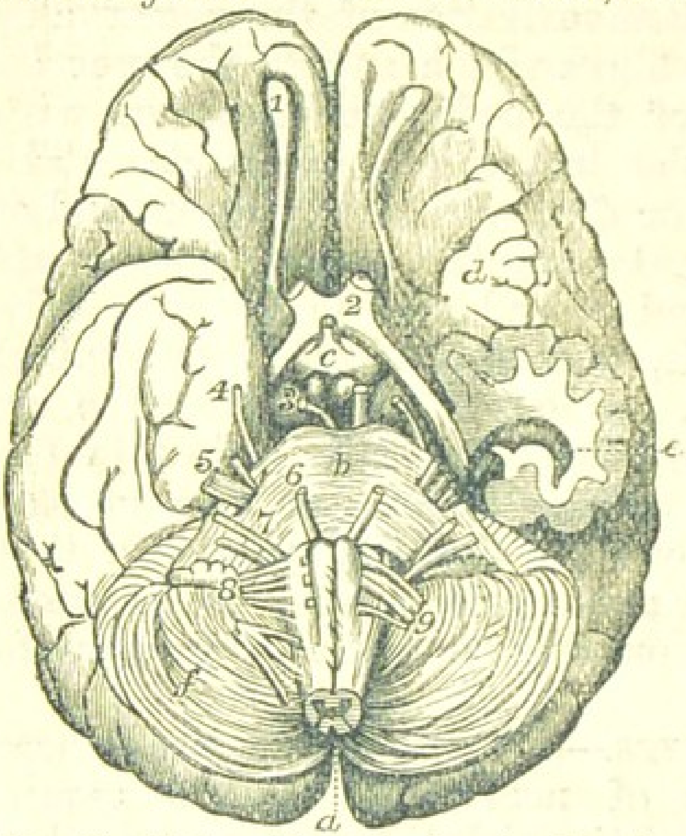

Fig. 48.—Under side of brain, showing the cranial nerves. 1, olfactory nerve; 2, optic nerve; 3, motor oculi; 4, trochleator; 5, fifth nerve; 6, abducens oculi; 7, facial and auditory nerves; 8. ninth, tenth, and eleventh nerves; 9, hypoglossal nerve; *a*, cut end of bulb.

Of these nerves all from the sixth to the twelfth arise from some part of the medulla oblongata; the fifth arises higher up, in the deep part of the pons; the fourth and third still higher, and the second springs from certain grey masses above the crura cerebri. The optic nerves of the two sides meet in the middle line below the brain and unite, forming

an X-like crossing in which 90 per cent. of the fibres take part, those of the right going for the most part to the left eye and *vice versa*. Disease of one optic nerve will, on this account, produce blindness of the outer part of the eye of the same side and of the inner part of the opposite eye.

The olfactory nerves arise from the front of the lower part of the cerebral hemispheres. The olfactory and the optic nerves differ in their development from the others, and are really direct outgrowths from the brain itself.

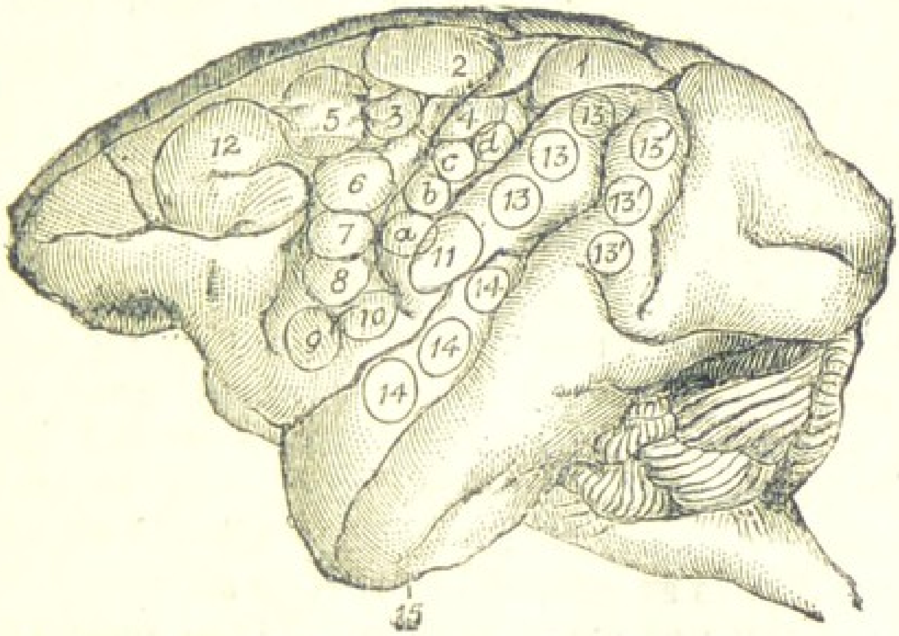

FIG. 49.—Left side of monkey's brain, showing the spots, stimulation of which produces muscular action. 1 and 2, in the thigh and leg; 3, in the tail and hind limb; 4, 5, 6, various parts of the arm and hand; 7, 8, 11, 12, face and head; 9 and 10, tongue; 13, eyeballs; 14, ear; 15, lip and nostril.

49. CEREBRAL LOCALISATION.—We as yet know nothing of the nature of the processes whereby the brain participates in mental or psychical action. By experiment it has been discovered that a large part of the side of the cerebral cortex is concerned in the production of the motor impulses whereby the voluntary muscles are set in action. The front part of this space in the neighbourhood of the left temple is concerned with the co-ordination of the several actions whereby thought is expressed by speech. In the monkey (fig. 49) this area is small (9), but

when stimulated it gives rise to motions of the tongue. Other regions of the cerebral surface posteriorly are connected with vision, smell, and hearing. The frontal lobes are probably those in which the psychical processes connected with attention, reasoning, and intellectual action take place.

Experiment has proved that the cerebellum is connected with the co-ordination of muscular actions relating to the performance of complex movements, such as walking, where many muscles must successively act in a definite order.

50. Nerve Endings.—We have seen that the motor nerves end peripherally in the muscular fibres ; there is a much greater variety in the method in which sensory nerves end, and these varying modes of termination are correlated with the nature of the impulses to which these endings are exposed.

The surface of the human body is placed in an environment of turmoil. It cannot move without coming into physical collision with some object solid or gaseous. The atmosphere around is in a continual state of motion, and that mysterious imponderable transmitter of finer vibrations named *ether*, which is supposed to pervade all space, is in a constant state of wave motion. These motions and waves, according to their rate of propagation and other physical conditions, affect one or other of certain specially sensitive nerve-endings in various ways.

For the recognition of the different varieties of these waves a certain physiological division of labour has taken place in the body. The vibrations of ether which are of the greatest rapidity are recognised as **light**, and the eye is set apart for their reception. For the recognition of **sound** waves the ear is adapted ; and for the perception of the impact of material particles there are nerve-endings distributed over the entire surface of the skin, within which the impressions of what is called common sensation take place. These nerves also take

cognisance of those ether waves of lower rapidity which give rise to sensations of heat. Certain areas of skin and mucous membrane have special functions in connexion with other varieties of sensation; on the fingers the sensory nerve-endings, which are called *touch corpuscles*, give us sensations which we can interpret into conceptions of form, texture, and consistence. This faculty we call the sense of **touch.** In the mucous membrane of the tongue there are nerve-endings which are affected by the contact of certain bodies of different qualities which give rise to sensations of **taste.** In like manner some parts of the nasal mucous membrane can appreciate and discriminate the contact of the odorous particles given off by certain bodies which give rise to sensations of **smell.**

By the perception of these various sensations we acquire all our knowledge of the outer world.

51. THE ORGAN OF COMMON SENSATION.—The **skin,** which is the superficial investment of the entire body, is the chief seat of common sensation. It is made up of two layers, a superficial, called **epidermis,** and a deeper, called **dermis.** The epidermis is built up of stratified epithelial cells, and differs much in its thickness in different regions, according to the amount of pressure to which it is exposed. On the heel it may become 1/18th of an inch thick, while on the eyelids it is only 0·008 in. New epithelial strata are constantly forming by the formation of new cells in the layer which lies in the middle of the epidermis; and the old surface cells are being continually dried, shrivelled, and shed. The average man loses of dried epithelium daily about 45 grains. The necessity of removing this effete epithelium by constant cleanliness is apparent. The scales of dried semi-detached epithelium are very favourable localities for the accumulation and growth of parasitic organisms, causing local irritation and sometimes more serious general disease. In the newly-formed cells of the epidermis pigment granules are fre-

quently developed, especially in some races of mankind. These are distinct in the new soft layer in the middle of the skin, and in the deepest layer which lies in contact with the dermis. As the cells shrivel and become opaque towards the surface the pigment granules become degenerated and ultimately disappear.

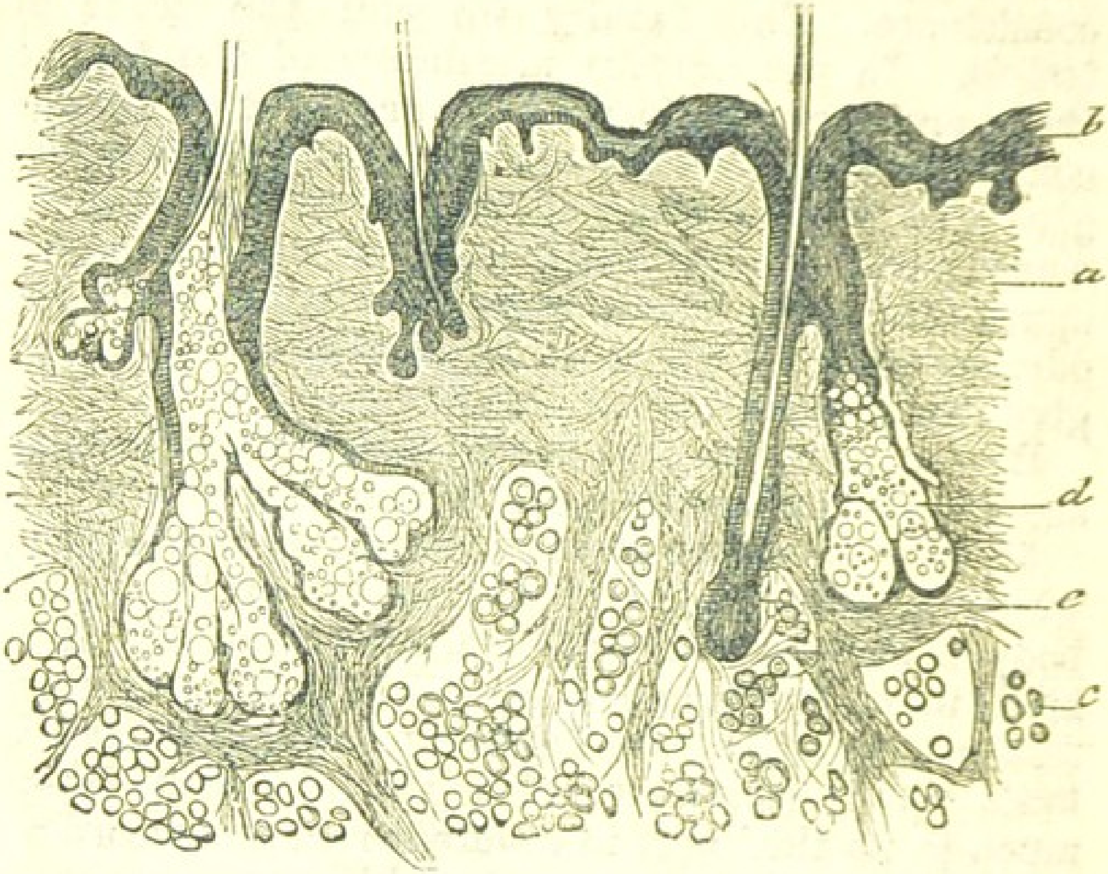

FIG. 50.—Vertical section of skin. *a*, corium or dermis; *b*, epidermis; the dotted line from *b* is about the level of the division of the stratum corneum from the deeper stratum Malpighii; *c*, fat cells; *d*, sebaceous glands; *e*, hair follicle containing hair bulb.

When a blister is applied to the skin the epidermis is divided by exuded liquid into two parts on the plane of this most actively growing stratum; the drier superficial layers, which are called the *stratum corneum*, is raised up over the fluid, while the deeper growing cells which form the *stratum Malpighii* lie beneath it. There are no blood-vessels in the epidermis.

The **dermis**, or **corium**, which underlies the epidermis, is made up of connective tissue. It is very dense and firm on the surface, which is very irregular, as it is beset with small cylindrical or

conical projections, which are called *papillæ*. It is richly supplied with blood-vessels, which make a fine network in its substance. From these vessels the lymph is derived which enters the epidermis and nourishes its cells.

52. Epidermal Processes.—Special processes of epidermis are found of two kinds. 1. Thickened dense layers, **the nails**, are formed on the back of the last joints of the fingers. These lie on unusually vascular patches of dermis.

2. Conical, solid, rod-like columns of epidermal cells are formed on the surfaces and summits of small vascular papillæ, which are sunk down at the bottom of cylindrical pits. These epithelial cell-columns are moulded by the pits and are gradually pushed up and made to project owing to the formation of new cells below them. To these fine cylindroid columns of epidermal cells the name **hair** is given. A hair is solid, composed of a superficial layer of longer, fibre-like cells, in which pigment granules are contained, and a central core of rounded cells. When the pigmented cells shrivel and air spaces form between them, hair becomes grey. There are often fine air spaces between the pigmented cells in red hair. A hair when put dry under the microscope appears as if tubular, but this appearance is due to optical refraction, as can be

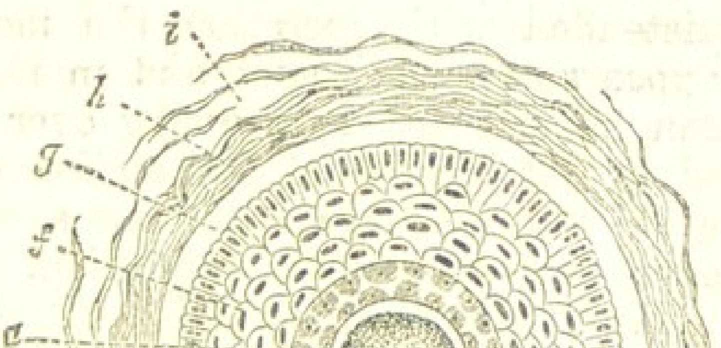

Fig. 51.—Transverse section of hair follicle and hair. *a*, medullary cells of hair; *b*, *c*, surface layers of hair; *d*, *e*, *f*, *g*, layers of epidermal lining of hair follicle; *h*, *i*, dermis around follicle

shown when the hair is embedded in a more highly refracting medium, such as Canada balsam.

Hairs can only be nourished at their bases by material derived from the floor and wall of their follicles. The lymph for this purpose comes from the blood-vessels in the papilla and its neighbourhood. If once the papillæ shrivel and waste, hair cannot be made to grow. Gentle stimulation, sufficient to increase the vascularity without causing too great congestion of the skin, is the only effectual means of encouraging the growth of the hair, and no application to the hair itself can have the slightest beneficial action upon its growth.

53. Dermal Glands.—There are two kinds of glands in the substance of the dermis. Of these one set, which are called **sebaceous glands**, are simple or branched pits that secrete a fatty matter for lubricating the surface. They usually open into the mouths of the hair follicles, though sometimes, as on the face, these glands are large and the hairs rudimentary. When these glands become over-distended with secretion the mouth of the duct appears as a black spot, and in this condition they can be emptied by pressing over them the mouth of a watch key. Inflammation of these follicles gives rise to the red pimply spots on the face so often connected with indigestion.

The mammary, or **milk glands**, are specially modified examples of sebaceous dermal glands.

The second kind of dermal glands are those that produce sweat. The **sudoriparous glands** are long narrow tubes which are coiled into rounded knobs in the substance of the dermis. From each of these the duct extends in a corkscrew-like manner to open on the surface of the skin. Sweat glands are especially numerous in some parts. On the palms of the hands there are about 800 in each square inch of surface. On the back of the shoulders they are much fewer, numbering only 180 to the

square inch. Altogether there are about $2\frac{1}{2}$ millions on the entire surface of the skin.

The fluid secreted by these glands consists of water containing a little sodium chloride, and minute quantities of a few other substances in solution. The quantity given off depends on the temperature and degree of moisture of the air, and may be increased by exercise and by copious draughts of liquid. Under ordinary circumstances an average man loses about 2 lbs. of sweat in the course of a day. The skin also gives off an appreciable quantity of carbonic acid, so that it may be regarded as an accessory respiratory organ. The free elimination of these substances is necessary to the maintenance of health, and serious consequences arise from interference with it. A boy who had been covered all over with gold leaf, in order to take the part of a cherub in a festival at Rome, died in consequence of this unintentional physiological experiment.

54. Cutaneous Sensibility.—Over and above the function of the skin as a protection, as a secretory organ, and as an absorbing surface, the skin is the seat of sensation, and contains, as has been already noted, many nerve-endings. Some of these are fine fibrils which end in blunted points between the cells of the epidermis. The largest nerve-endings, which are called **Pacinian corpuscles,** exist in the dermis of the finger tips. Upon these tactile sensation depends and the degree of delicacy of the sense of touch depends on the size and closeness of the corpuscles. It has been found that if the two sharp points of a pair of compasses are brought into contact with the skin the separate impression of the two points can be recognised when the points are 1/35th of an inch apart on the finger tips, but the points must be three inches apart before the doubleness of the contact can be detected by the skin of the back between the shoulders. According to the nature of the endings different forms of sensation are produced, such as simple sensations of contact

(common sensation), the sense of touch by which form and texture are discriminated, tickling, and temperature; and when the stimulus is of a nature to injure the nerve-endings the sensation of pain is the result.

Closely allied to these general sensations of the skin there are certain other sensations limited to distinct areas of the surface or of the mucous membrane. The irritation of the fauces or back of the throat due to dryness or certain saline stimuli produces the sensation of thirst. A similar stimulation due to want of food, affecting the nerves of the stomach, produces the sensation of hunger. Direct or reflex irritation of the fauces produces nausea.

55. Taste.—The special sensory nerves derived from the fifth and ninth pairs of cranial nerves distributed to the sides and back of the tongue end therein in bulbs not unlike the tactile nerve-endings. The bulbs recognise the differences of flavour of soluble materials put into the mouth, and the sense of recognition of these we call *taste*. We do not as yet know the physical basis of the distinction of which we are conscious between sweet and bitter, sour and salt bodies; but as the bodies must be in solution in order to be tasted it is probably due to a direct exercise of chemical influence on the end filaments of these nerves.

56. Smell.—The sense of smell is allied to that of taste, and is often confounded with it. It has its seat in the mucous membrane of the upper and back part of the nose, to which the olfactory nerve is distributed. The odorous material must be in the form of vapour or very finely divided particles in order to affect these nerve-endings.

Taste and smell exercise a marked effect in helping us to discriminate the different kinds of material which we take as food. As a rule, bodies which smell and taste agreeably stimulate the secretion of the several digestive fluids, while those that are unpleasant interfere with these secretions. There is

thus practical physiological advantage, as well as æsthetic satisfaction, in foods which are cooked so as to taste and smell pleasantly, and *vice versa*.

57. Hearing.—A more complex apparatus is required for the recognition of those finer vibrations which we denominate sound waves. These are vibrations of the particles of the air, which alternately approach and recede from each other at different rates. When this rate is rapid the note heard is a high one, if slower the note is lower. Such differences are named differences of *pitch*. The waves also differ in amplitude; when this is greater the sound is said to be loud, when smaller it is said to be faint.

Sound waves are seldom pure and simple. With each principal wave there are usually a number of

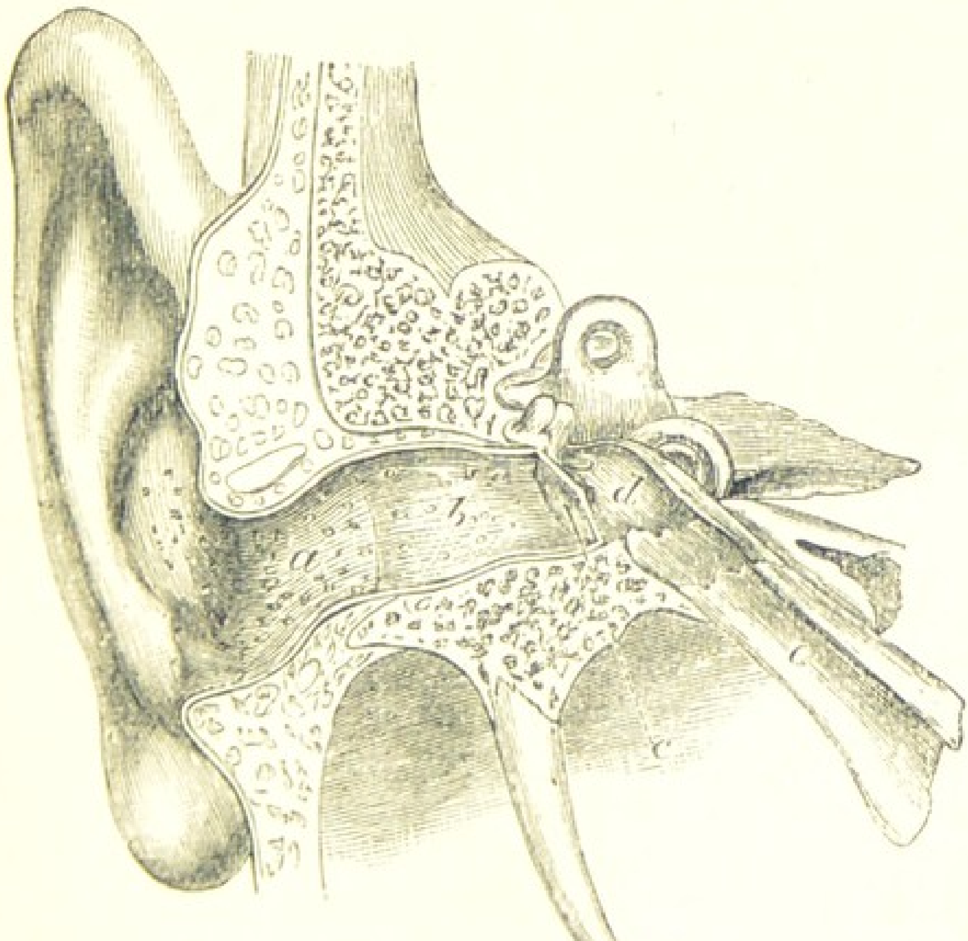

Fig. 52.—Vertical section through organ of hearing, showing the external ear, the gristly (*a*) and bony (*b*) ear tube; *c*, membrana tympani; *d*, cavity of tympanum, above and internal to which is the internal ear; *e*, Eustachian tube, whose opening is shown in Fig. 7.

smaller dependent secondary waves of greater rapidity which are known as *over-tones*, and the quality of a sound depends on the number and nature of these. If they bear no proportion to each other the resulting sound is a noise, but if they have certain definite numerical relations to each other the sound is a musical tone. Sound waves of any pitch travel in air under ordinary conditions of temperature at a rate of 1,100 feet per second.

The ear is an apparatus whereby we recognise not only the existence of these vibrations but also their pitch, amplitude, and quality. It consists essentially of three parts, the outer ear or sound-collecting apparatus, the middle ear or sound-transmitting apparatus, and the inner ear or sound-recognising organ.

The **outer ear** consists of two parts, the crumpled, skin-covered plate of cartilage, which we call the **auricle**, or pinna, and the tube or **meatus**, which passes from this to the middle ear. The bottom of the meatus is closed by a thin membrane, the **membrana tympani.** If this were a uniformly stretched membrane, like a drum-head, it would have, when made to vibrate, a certain peculiar tone of its own. This is prevented by the attachment to the membrane of a little bone, the **malleus**, or hammer, owing to which the membrane is pulled inwards at one spot, so as to appear of a widely conical form. This mode of arrangement produces a different degree of tension at different parts of the membrane, and on this account, as the self-tone produced by the vibration of a membrane depends on its uniform tension, there is no such self-tone produced by the vibration of the membrana tympani. The malleus is attached to a second bone, the **incus**, or anvil, and this to a third stirrup-shaped bone, the **stapes.** This chain of bones transmits the vibrations from the membrana tympani to the internal ear, and at the same time the attachment of the malleus to the membrana tympani acts as a sort of

damper on the free vibration of the membrane. The cavity in which these bones lie is called the **tympanum**, and is placed in the temporal bone. It is filled with air, which gains access to it from the pharynx through a narrow passage, the **Eustachian tube.**

On the inner wall of the tympanic cavity there are two openings, the *fenestra ovalis* above, which is blocked up by the base of the stapes, and the *fenestra rotunda* below, which is closed by a little membrane. By these the vibrations are communicated to the third part of the apparatus, the internal ear, the organ in which the varieties of sound are appreciated and discriminated.

The **internal ear** consists of three parts:—1. A **vestibule** or central cavity, a hollow in the temporal bone, which is one of the hardest bones of the skull.

Fig. 53.—Membranous labyrinth of internal ear. *a, b, c,* the semi-circular canals; *d,* utriculus; *e,* sacculus; *f,* canal joining sacculus to (*g*) cochlea.

From this there pass off three semi-circular canals above and behind, and a coiled, snail-shell-like organ, the **cochlea,** in front. Within the vestibule are two membranous sacs, which are not only filled with liquid, but float in a surrounding liquid within the bony cavity. From one of these there passes off into each semi-circular canal a fine tube, which in like manner is filled with liquid and floats in an external liquid. From the front of one of these sacs there passes a fourth tube, which is spirally

coiled in the cochlea and fastened along its outer wall. This tube is also filled by a liquid and is supported on a bony shelf, above and below which is also a liquid.

On the membranous sacs and tubes of the labyrinth the filaments of the eighth cranial nerve end in peculiar filaments. Those in the cochlea form a remarkable layer within the membranous tube of the cochlea, and to this layer the name **organ of Corti** is given. These nerve-endings are affected by the waves in the liquids which surround them, in a peculiar way as yet unknown. The nerve stimulations, carried to the cerebrum by the auditory nerve, are translated into conscious sound-sensations in a region of the cerebral cortex near its base.

The human ear cannot detect musical tones which are produced by fewer than 16 vibrations in the second, and the highest audible tone is that produced by some 40,000 vibrations. The low A of the grand piano is a note of 27·5 vibrations and the high C^5 has 4,224 vibrations.

Deafness, or the incapacity to recognise sound, may depend on the blocking up of the meatus by the waxy secretion of the cutaneous glands of its lining membrane (the *ceruminous glands*), or on imperfection in the conducting apparatus or membrana tympani, or lastly upon disorganisation of the inner ear. The plugging of the Eustachian tube at its throat-end may also cause temporary or partial deafness by interfering with the adjustment of the air enclosed in the tympanic cavity, and so with the freedom of vibration of the membrane.

58. Sight.—The reception and appreciation of the subtlest of ether vibrations, the waves of light, are the work of the most delicate of our sense organs, the **eye**, which is placed for protection in a conical bony cavity in the front part of the skull. This cavity is named the *orbit*. The **eyeball** is a globe measuring about an inch in diameter; it rests posteriorly upon an elastic fatty cushion, and is cap-

able of being moved in different directions by seven muscles, which are connected to the brain by three cranial nerves. There is a remarkable co-ordination in the action of these muscles, owing to which the two eyes cannot move independently of each other, but must be turned so that the axes of the eyeballs remain nearly parallel to each other. When one eye is raised or depressed the other is likewise moved in the same direction, and when one eye is turned outwards the other is spontaneously turned inwards.

The anterior surfaces of the eyes are protected by the eyelids, the lining membrane of which (called the **conjunctiva**) is continued as a thin transparent layer over the front of the eyeball. The continuity of this layer from lid to eyeball can be seen by drawing down the lower lid as far as possible,

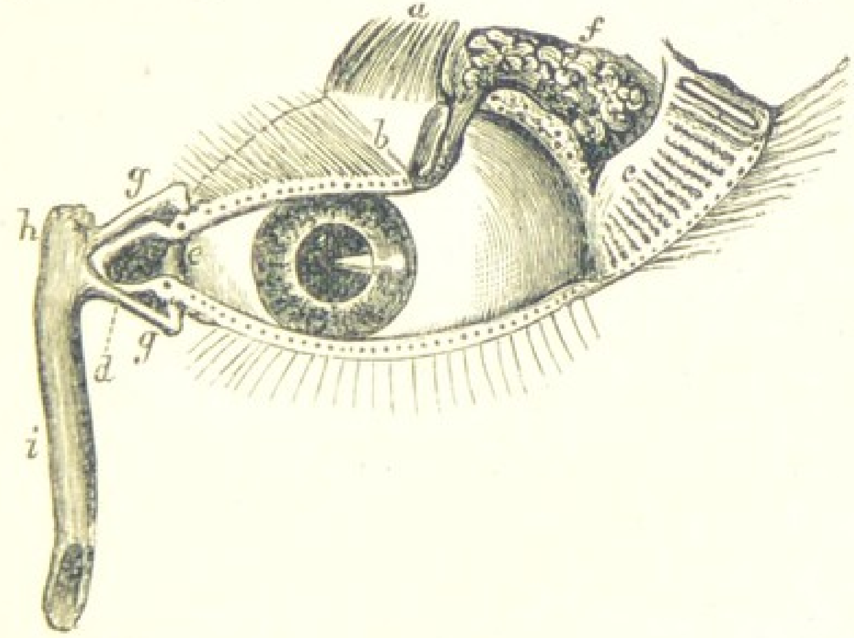

Fig. 54.—Tear apparatus. The upper lid is vertically divided and its outer part everted to show *f*, the lacrymal gland; *a*, elevator muscle of the upper eyelid; *b*, margin of upper lid with eyelashes; *c*, Meibomian glands opening along the margin of lid; *d*, lacrymal caruncle; *e*, plica semilunaris; *g*, canaliculi whose mouths, the puncta, are represented as two black dots; *h*, lacrymal sac; *i*, nasal duct.

when the angle of reflexion of this membrane can be seen. The surface of the conjunctiva is moistened by the secretion of the **lacrymal** or **tear gland**, a small body about as large as a bean, placed at the

upper and outer corner of the orbit close to the outer part of the upper lid. The tears are poured out through many fine ducts on the conjunctival surface, bathing the opposed surfaces of the lids and the eyeball, and are then received by two minute drainage holes, the **puncta lacrymalia**, which communicate with the lacrymal sac at the inner corner of the eye-socket. From thence the tears descend into the nose by the **nasal duct.** The puncta can be easily seen, on the inner extremity of the margin of each lid, close to the innermost hairs of the eyelash.

In the front of the eye is a circular transparent window, the **cornea**, through which we can look into the dark interior of the cavity of the eyeball. Behind this cornea is a coloured circular curtain, the **iris**, which may be brown, hazel, blue, or grey, according to the amount of pigment present in it. The irides of the inhabitants of tropical countries are generally deeply pigmented; those of more northern and colder countries have less pigment and are usually either blue or grey.

In the centre of the iris is a round hole, the **pupil**, through which the deeper parts of the eye can be seen. The size of the pupil varies during life according to the brightness of the light to which the eye is exposed, as the iris is a muscular curtain which acts reflexly under the stimulus of light. If one stands in the dark corner of a room turned away from the light and examines his own eyes in a hand-mirror, the pupils will be seen to be enlarged. By walking towards the window and so exposing the eye to brighter light the iris expands and its central aperture appears to contract. The iris is of use in stopping off the circumferential rays of light which pass through the cornea. It takes some time for this self-acting apparatus to work, and therefore we are dazzled when we pass from a dark room into a lighter one, until the pupil becomes diminished to the necessary size.

Conversely when we pass from a light room into a darker one we cannot see until the pupil has become commensurately dilated.

The structure of the eye may be most easily understood if we procure the eye of a bullock or a sheep from the butcher and dissect it with a sharp pair of scissors. The cornea being cut through,

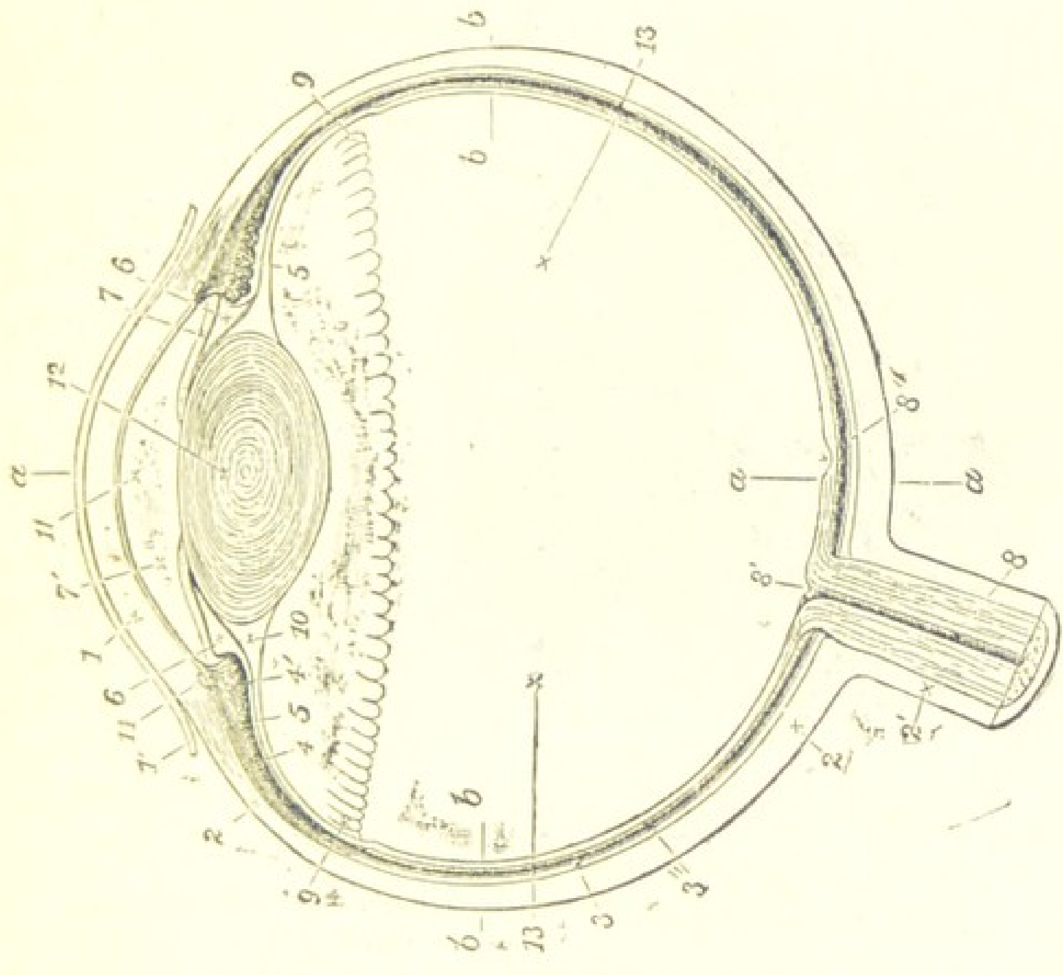

FIG. 55.—Diagram of a horizontal section through the eyeball. 1', conjunctiva; 1, cornea; 2, sclerotic; 3, choroid; 4, 4', ciliary processes and muscle; 5, suspensory ligament of (12) the lens; 7, iris; 8, optic nerve; 8', entrance of central artery and blind spot; 9, anterior limit of retina; 7', 11, aqueous humour in the anterior chamber of the eye; 13, vitreous body; *a-a*, antero-posterior axis of eyeball; *b-b*, transverse axis.

a watery fluid, the *aqueous humour*, is found in the space between the cornea and the iris. This interval is called the *anterior chamber*.

The outer coat of the rest of the eyeball is a very firm white layer of fibrous tissue. This is named the **sclerotic**. Into the back of this a white cylin-

drical cord, the optic nerve, enters. This in the ox-eye is about as thick as a quill. Around this the muscles of the eyeball are inserted into the sclerotic, and anteriorly the sclerotic and cornea are firmly united together. The portion of the sclerotic covered by conjunctiva which can be seen anteriorly around the cornea is called the white of the eye.

If the eye be placed in a basin of water and the sclerotic cut round with a sharp-pointed pair of scissors, a soft black layer is exposed. This membrane, which is called the **choroid**, contains numerous vessels, and is continued anteriorly into the iris, around the margin of which it is folded into many fine radiating folds, the *ciliary processes*. In the bullock's eye there is a bright metallic greenish layer, the *tapetum*, on a large part of the choroid, which is absent in the human eye.

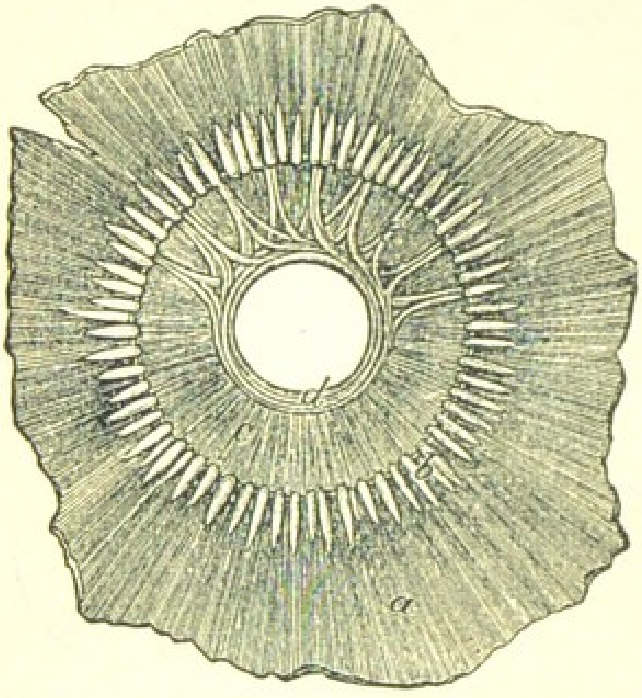

FIG. 56.—View of the back of the iris (*c*), with the surrounding ciliary processes (*b*) and portion of the choroid (*a*); the circular muscle of the pupil is shown at *d*; the radiating fibres at *e*.

When the choroid is divided, a semi-transparent, whitish, very soft layer is brought into view. This is the nervous layer, the **retina**, and is the terminal expansion of the optic nerve. It is spread over a bright and perfectly clear gelatinous mass which fills up the chief part of the eyeball. This is called the **vitreous body**.

In microscopic structure the vitreous body consists of an exceedingly fine meshwork of connective tissue whose interstices are filled with fluid. In its

anterior part just behind the iris there is embedded in it a transparent bi-convex **crystalline lens.** This can be detached by tearing the delicate membrane which covers it, and by which it is attached to the ciliary processes.

The function of the eye is to receive and appreciate the images of illuminated objects. Every opaque object upon which rays of light fall reflects light from each point on its surface. Of the rays which fall on the cornea, the iris stops off those that fall near the circumference, admitting through the pupil the central rays. These pass through the crystalline lens, by which the pencils

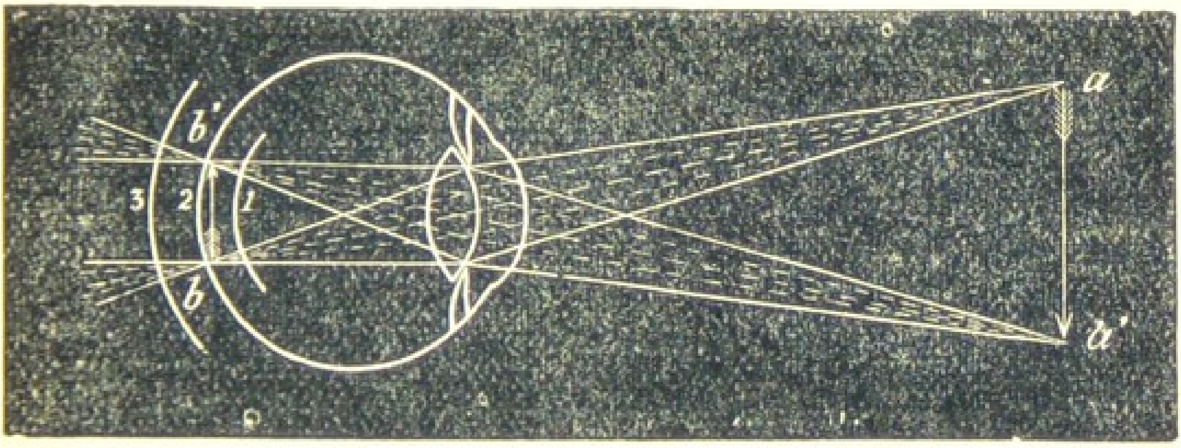

FIG. 57.—Diagram showing the course of the rays of light from two luminous points *a* and *a'*; the rays from *a* are collected by the lens and brought to a focus at *b*.

of rays diverging from each spot on the illuminated object are made to converge to a focus upon the retina.

The outer layer of the retina consists of very complex and minute rod-like bodies, arranged with their ends directed towards the pupil so that each focal point is upon the extremity of several of these rods. The rods are affected in some unknown way by the stimulus of the light, and the reception of this stimulus affects the filaments of the optic nerve whereby the impressions are conveyed to the brain.

All spots of the retina are not equally sensitive, the most sensitive region being the central spot, which is in the living eye of a yellow colour. It is

upon this *yellow spot* that the rays fall which are reflected from objects held straight before the middle of the eye.

There is on the inner side of this yellow spot a small circular area which is blind. This is the place at which the optic nerve enters the eye, and at which there are no rods. Its blindness can be proved by closing one eye and looking steadily at the small a in the adjoining figure. The other letters will also be visible at the same time. If now the page be brought slowly nearer to the eye while the eye is kept steadily looking at the small a the large A will disappear at a certain point, reappearing when the book is brought still nearer.

a o A x

On the reappearance of the A it will be noted that it comes into view from the inner side, the x being seen before it. If now we move the book back towards its original place the A will again disappear, coming again into view from the outer side when the o is seen before it.

59. ACCOMMODATION.—The crystalline lens is highly elastic and is not always of the same degree of convexity, but by the action of certain muscular fibres in the ciliary processes its outer layer can be

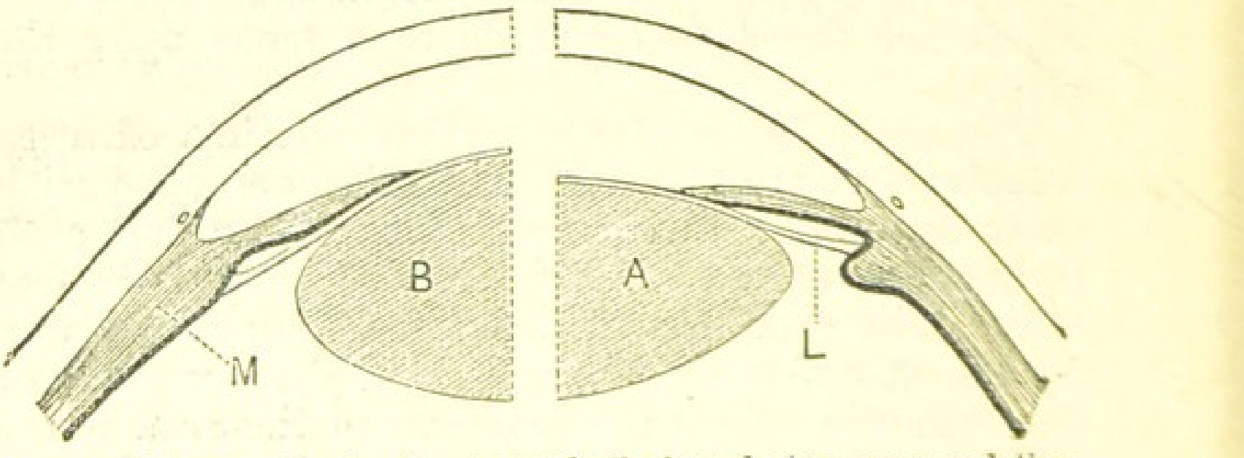

FIG. 58.—Diagram showing the change in the lens during accommodation. On the right side the lens is arranged for distant vision, the muscle is relaxed and the ligament L is tense, so flattening by its compression the front of the lens A; on the left the muscle M is acting, and this relaxes the ligament and allows the lens B to become more convex, and so fitted for the vision of near objects.

acted upon so that its curvature becomes altered. This changes the focal length of the lens, and thereby the eye can be accommodated for vision of objects which are at different distances. If we look out of a window at a distant object while a pencil is held up about 12 inches from the eye, so long as the gaze is directed to the distant object the image of the pencil is blurred. If then we look at the pencil the image of the distant object becomes indistinct. The ciliary muscular fibres are relaxed when the eye is focussed for distant vision, but they are in action when the eye is being used for examining near objects.

An ingenious experiment was devised two centuries ago by a Jesuit named Scheiner to demonstrate the process of accommodation. Make two pinholes in a card nearer each other than the diameter of the average pupil, that is about 1/16th of an inch apart, so that you can, with one eye, look through the two holes at once. Attach this card at the end of a board into which 10 inches from the card a needle is fixed, while a second needle is inserted in the same line but 18 inches away. Close one eye and with the other look through the holes at the needles. When you look at either needle one image of that object is seen and two images of the other; that is, the lens is so focussed that the rays from the needle looked at are made to converge to one point, and therefore the curvature is such that those from the other needle do not similarly converge. If when the eye is fixed on the needle nearest to it the right hole be closed by another card, the right image of the distant needle will disappear, and *vice versa;* but if while the eye is fixed on the farther needle the right hole be closed, it is the left image which vanishes. This is owing to the fact that when the lens is focussed for near vision its convexity is increased, and, in consequence, the rays from the distant needle have been brought to a focus prematurely and have again begun to

diverge before reaching the retina, those on the left hand side being cut off, and *vice versa.*

60. Defects of Vision.—If the eyeball be a little longer than usual in its horizontal axis the rays of light collected by the lens from an object held 12 inches in front of it will converge to a focus in front of the retina, and will have begun to diverge before reaching that membrane. In such a case the object must be brought nearer the eye in order that vision may be distinct. Such an eye is called *myopic*, or short-sighted, and this defect is corrected by interposing a concave eye-glass between the object and the eye, which by giving a certain increased degree of divergence to the rays which enter the eye causes the focal point to be farther from the lens. The opposite condition of the eye is called *hypermetropia*, or longsightedness. In old persons the eyeball tends to flatten, the lens loses its elasticity, and the ciliary muscle becomes impaired in its function. In consequence of these changes the focal length of the lens becomes excessive and the range of accommodation lessens. Convex glasses are required to compensate this senile condition, which is named *presbyopia.* Spectacles to remedy these defects were first used by Alessandro Spina in the 14th century.

In some cases the curvature of the refractive surfaces in the eye is unequal in different directions; the cornea is often more curved vertically than horizontally, and in consequence the rays of light which enter the eye in the vertical plane are collected to a focus sooner than those neighbouring rays which enter in other planes. There is consequently not a true focal convergence of all rays from a given point, and the image produced is blurred. In such a case a horizontal line has in order to produce a definite image to be brought nearer the eye than is needful in the case of a vertical line. This defect, which is called *astigmatism*, is corrected by the use of a lens which is the segment of a cylinder, whose curves make the correction necessary to compensate

for the varieties in curvature of the transparent media of the eye. The ordinary healthy eye is usually astigmatic in a small degree, the cornea being more convex in the vertical than in the horizontal direction. On this account, if two lines of equal thickness be drawn, one vertical, the other horizontal, at a certain distance from the eye the latter appears thicker than the vertical.

The crystalline lens is made up of long fibre-shaped epithelial cells, arranged so that their extremities meet around a triradiate axis. Owing to some slight inequalities of the curve in any one segment of the lens, there is generally a slight amount of irregular astigmatism observed in looking at a luminous point, such as a star or distant gas lamp, which in consequence appears rayed. This optical illusion accounts for the conventional representation of a star.

61. Mechanism of Vision.—The method whereby the undulations of light are converted into nervous impulses is as yet obscure. It cannot be by the production of mechanical vibrations in the rods of the retina, but is most likely by the production of some chemical change in the pigmentary matter in and around the rods or cones. It has been shown by experiment that if an animal be killed in the dark and its head fixed in front of a window, the pattern of the window is imprinted on the retina as a bleached area. By the use of a solution of alum as a mordant a picture of this kind has been fixed for a time as a species of photograph.

The eye takes cognisance of impressions of light with extreme rapidity; an electric spark which lasts only 0·000,000,868 of a second is distinctly visible. The impression lasts a certain time, hence when a cord with a burning end is twirled round rapidly it gives the appearance of a circle of light. There are many well-known illusions, such as the zoeotrope and kinetoscope figures, which depend on this persistence.

Light rays vary in their wave-lengths and therefore in their rates of vibration, and they produce upon the retina effects which vary with these physical differences. Light rays with a wave-length of 0·000,315 of an inch and a vibration rate of 481,000,000,000,000 vibrations in a second give the sensation of red colour, while waves of 0·000,016 of an inch in length and a rapidity of 764,000,000,000,000 per second give the sensation of violet. Intermediate wave-lengths and rates of vibration give rise to colour sensations of orange, yellow, green, blue, and indigo. The appreciation of these different kinds of light probably depends on the existence in the retina of several elements which are differently affected by different kinds of light. It is believed by some that there are three different materials which are respectively capable of being stimulated to the highest degree by red rays, green rays, and violet rays, but which are susceptible to lower grades of stimulation by other colours. If light be of a certain degree of intensity, or consist of certain combinations of rays of several wave-lengths such as red and green, the sensation produced is that of white light.

All parts of the retina are not equally sensitive to rays of different colours. In a healthy eye colour-perception is only complete in the middle area of the field of vision; around this is an area in which the red rays cannot be perceived, and outside this there is a marginal zone, in which no colours can be perceived. It has been found by experiment that about 2·7 per cent. of persons have the central field of their retina also insensible to red rays, so that they cannot discriminate red from green; a smaller percentage have no power of discriminating colours. This condition, which is named *colour-blindness*, can be tested by the use of skeins of worsted of various colours, which have to be matched or discriminated.

62. After-Images.—When objects are kept for a

short time before the eye and then removed the visual impressions which persist are called after-images. In the case of very bright bodies these appear as illuminated spots, and are called *positive after-images*, as when one looks at the sun or an electric light. In other instances the after-images are *negative*, appearing dark where the originals were light, and *vice versa*. When coloured objects are looked upon and the eyes turned to a white surface the after-images are complementary in their colours, red being replaced by green, violet by greenish-yellow, and so on.

The retina is more sensitive after a period of rest in darkness, as the visual pigments become restored.

As is well known the image formed on the ground glass plate in a camera is inverted, and from its construction the same must be the case in the eye. The perception of the image in its proper position is a process which takes place in the area of the cerebrum with which the optic nerves are ultimately connected. Direct mechanical stimulation of the optic nerve gives rise to sensation of light, and a flash of light is seen when the optic nerve is divided. The *phosphenes* or sparks seen when one receives a blow on the eye are sensations of this order.

63. Binocular Vision.—The two eyes are so arranged and their motions so co-ordinated that light rays from each illuminated point of an object fall upon exactly corresponding points of the two retinæ, so that by a psychical process they become blended into one image. If we hold up a finger between the face and a distant object and closing the right eye look at it with the left, then closing the left eye look at it with the right, the finger will appear to have moved to the left. This depends on the fact that the points of view of the two eyes are not exactly the same. If, closing the right eye, one holds a card edgeways before the left eye so that only its margin is visible, it will be found that if the

left eye be closed and the right eye opened a portion of the right side of the card comes into the field of vision. Binocular vision has thus the advantage that it enables us to see a certain larger amount on each side of one object than could be seen by one median eye, and so we get a perception of depth and a capacity of judging distance, as well as an extension of the field of vision. A *stereoscope* is an instrument in which two pictures, each representing the view taken from the view-point of a single eye, are optically combined, and the impression of solidity is in this manner obtained.

64. Composite Co-ordinated Actions.—Hitherto we have proceeded by a progressively synthetical method, reviewing each function and organ. But in the living and acting body the several life processes do not take place independently. There is an active co-operation of many parts in each action. For example, in walking the muscles are set in motion by motor impulses from the cerebrum acting through the cells of the anterior horn of the cord. These impulses to the several co-operating muscles are co-ordinated by the cerebellum, and governed in direction by the perception of distance by the eye.

One of the most interesting and complex of these processes produced by the co-operation of many parts is that whereby we speak, and as in its perfection this mechanism is peculiar to man its study forms an appropriate conclusion to our survey of human functions.

65. Voice and Speech.—The **larynx** or organ of voice is an irregular box made of five cartilages and placed at the top of the windpipe below the back of the tongue. If the tongue of a sheep be procured from the butcher this organ will be found appended to its root. The upper opening into it is guarded by an upright curved plate of elastic cartilage, the *epiglottis*. In front and below this is the **thyroid** cartilage, formed of two plates of gristle joined together anteriorly at an angle. This is the body

which can be felt in the human neck, much larger in the male than in the female, and consequently called the "Adam's apple." Below this is a ring-like cartilage, the **cricoid**, on the back of which stand up two pyramidal cartilages with their tips slightly recurved, the **arytenoids.** Looking down into the larynx through the triangular upper opening, whose base is at the epiglottis and whose sides are folds which pass from the lateral margins of this to the arytenoids behind, we see that the cavity is narrowed to a slit-like chink on the level of the bottom of the thyroid cartilage. This chink, the **rima glottidis**, is bounded on each side by a projecting elastic band, which passes from the thyroid to the base of the arytenoid, and which, like the rest of the interior of the larynx, is covered by mucous membrane. The margins of these bands, which form the edges of the rima glottidis, are sharp and are called the **vocal cords.** Five pairs of small muscles can alter the relative positions of the thyroid and arytenoid cartilages, and so can make the vocal cords vary in tension and in the size of the interval between them. When the arytenoids are slightly rotated outwards and separated by an interval a clear space is formed, through which the air in ordinary breathing passes in and out silently. When, however, the arytenoids are approximated so that the whole current of the air in expiration has to pass

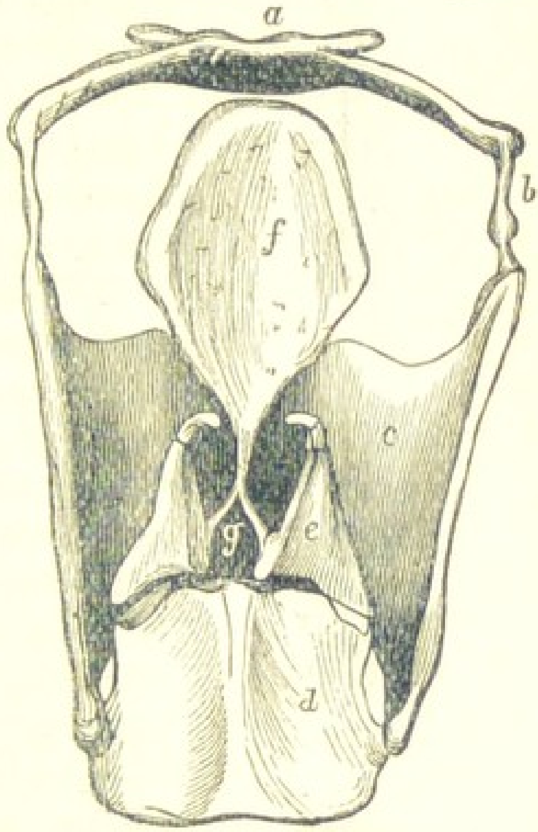

FIG. 59.—The cartilages of the larynx, back view; *a*, hyoid, or tongue bone; *b*, thyrohyoid ligament; *c*, thyroid cartilage; *d*, cricoid cartilage (represented in section in Fig. 7); *e*, arytenoid cartilage; *f*, epiglottis; *g*, opening of glottis.

between the sharp edges of the vocal cords, these are made to vibrate and produce a note whose pitch varies with the length and tension of the cords. The sounds thus produced are the *vocal sounds* The range or compass of the human voice is considerable; the deep bass F corresponds to a note of 42 vibrations in the second, the high soprano A is a note with 1,708 vibrations.

The sounds produced by the vibrations of the human vocal cords are not pure tones; with each there are also produced many over-tones, and upon the number and nature of these the quality of the individual voice depends.

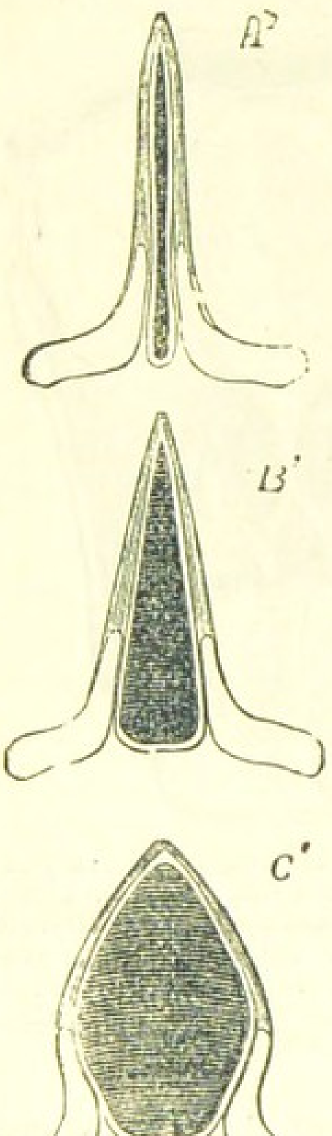

FIG. 60.—Diagrams of the shapes of the chink of the glottis in different states of the vocal cords. A′, as in singing; B′, in easy respiration; C′, in forced respiration.

The sounds of the voice produced in the larynx pass out by the mouth. This mobile chamber acts as a resonating cavity, and according to its shape it modifies the sound, intensifying some over-tones and damping others. The five vowels U (pronounced as *oo* in *poor*), O, A (pronounced as *a* in *far*), E (pronounced as the *a* in *mate*), I (pronounced as the *ee* in *meet*), are essentially sounded as notes of different pitch, each separated from its neighbour by an octave, and their distinctive characters depend on the differences in shape of the resonating mouth chamber through which they pass.

The positions of the tongue, teeth, and lips modify still further the vibrating current of air, and the breaks and alterations thus caused engrafted on the vowel sounds are called *consonants*. Speech consists of the succession of vowel sounds

produced in the larynx and modified in transmission through the mouth, together with the consonantal noises produced in the mouth itself. To each simple combination of vowel and consonant we give the name *syllable.* In the production of each syllable there is a complex co-ordination of muscular action in the chest, the larynx, and the mouth, set agoing and controlled by the central nervous system. By education we learn to correlate a certain mental concept with the result of the physical effort to produce a certain succession of syllables, and by a concurrent education of the ear we are able to associate the same concept with a similar sound when we hear it produced by the speech-organs of another. In this manner speech becomes the medium for the conveyance of thought from one to another. The region of the brain in which some part at least of the mechanism of the psychical portion of this process is seated is a small area of the brain underlying the left temple. Injury or disease of this part of the brain is attended with *aphasia*, or incapacity of speaking, even though the articulating mechanism be uninjured.

66. Life and Death.—We have seen that while the body continues to live its protoplasm is in a continual condition of decomposition and recomposition. If these processes exactly balanced each other life might last indefinitely, but we find that soon after the body has attained its full size the amount of restoration of protoplasm following metabolism begins to diminish. Much of the protoplasm becomes altered into what are called the formed tissues, fibrillar connective tissues, cell walls, &c., in which it no longer undergoes the same amount of metabolic change and consequently ceases to be a source of energy. A time comes when the amount of energy liberated falls short of the minimum necessary for the maintenance of the life-processes, and the result is *death.* Somatic death is the loss of the unity of existence of the body as an organism, and depends

essentially upon the stoppage of the action of the heart. The tissues and individual cells continue to live and undergo metabolism until their properties are gradually lost from want of nutrition. With somatic death the physical life of the individual ceases. Meantime, however, from the living tissue of the body other living beings have sprung, and the protoplasm of the child has been directly derived from that of the parent, so that although the life of the individual rarely exceeds the allotted span of threescore years and ten, there is a real sense in which the protoplasm of the earliest ancestor of our race lives still in his descendants, and will continue to live as long as the present condition of the world lasts.

This, however, is only one of the many inscrutable mysteries with which the study of man in the concrete brings us face to face. As physiologists our province is limited to the one part of human nature, the phenomena of his material body. The sister science of Psychology introduces us to phenomena, quite as real as those with which we have dealt, but of an entirely different order, which though linked to physiological processes can in no wise be identified with them.

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