PHYSIOLOGY

OF THE HUMAN BODY

DR. ANDREW WILSON, F.R.S.E.
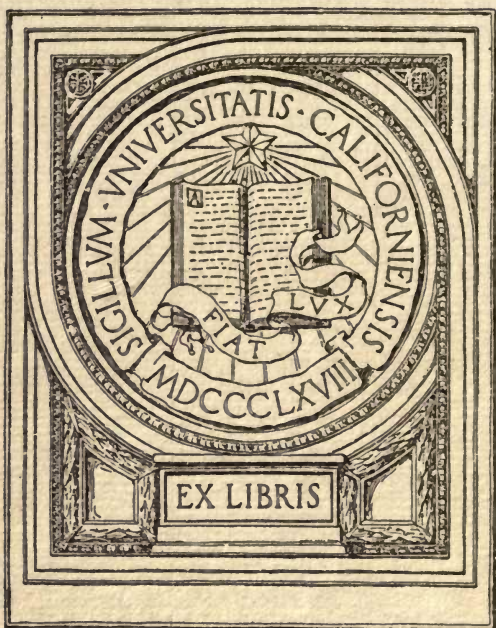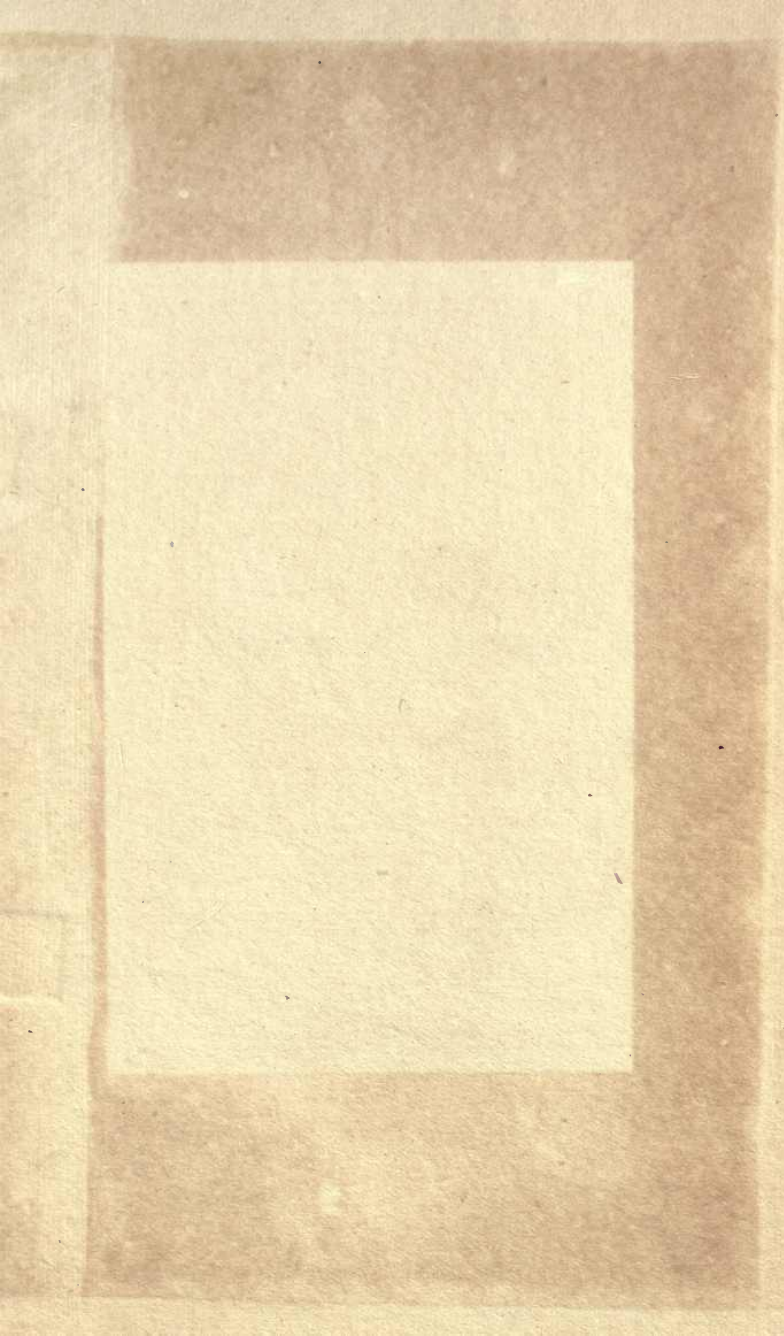
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Human Physiology
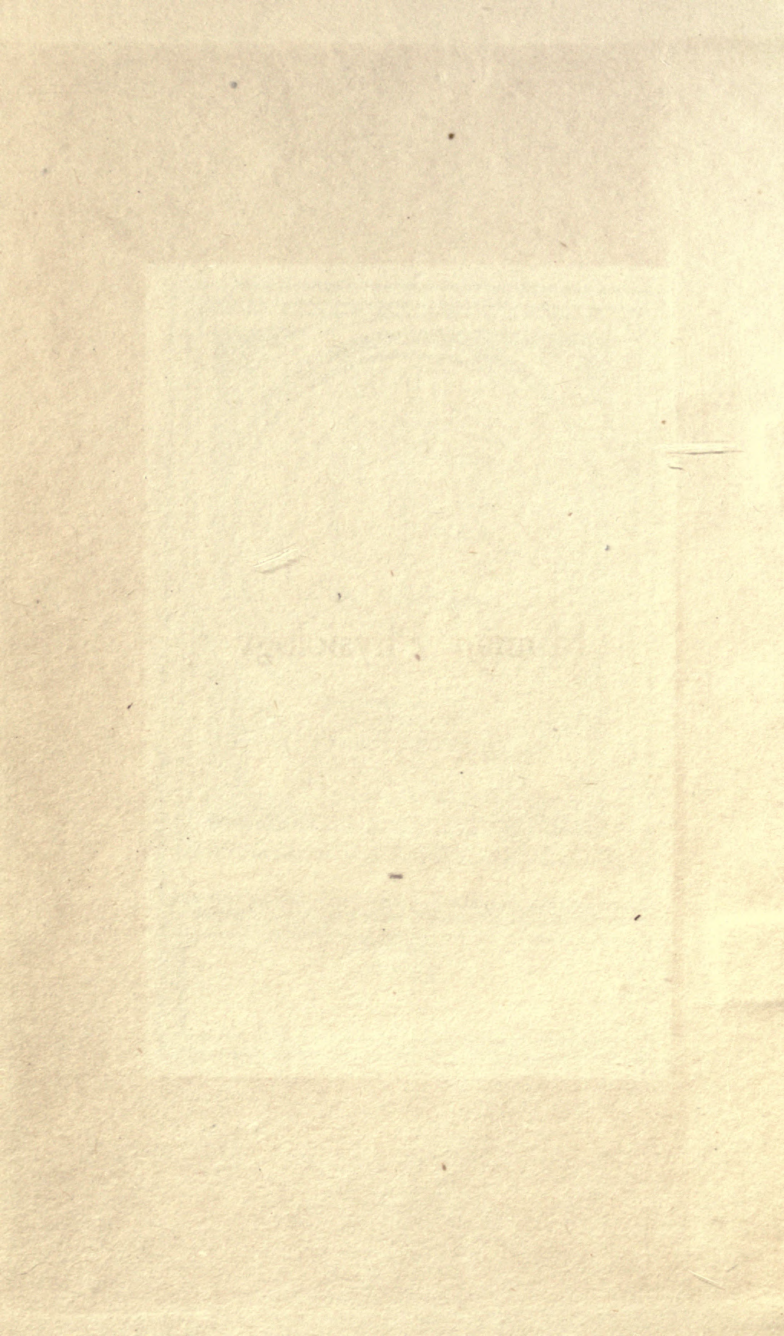
PHYSIOLOGY

A POPULAR ACCOUNT
OF THE FUNCTIONS
OF THE HUMAN BODY

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PREFACE

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THIS Manual is intended to familiarize the general reader with the outlines of the Science which deals with the body in action, and which describes the working of life's mechanisms. In its preparation the author has kept in view the possibility of the work being useful as a text-book for Senior Classes in Physiology at School. As the whole foundation of the knowledge of Health-Science must rest upon the basis afforded by an acquaintance with the body's functions, this volume may also appeal to students of Hygiene.

Human Physiology

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CHAPTER I

THE STORY OF THE BODY'S CONSTITUTION

INTRODUCTORY.—In investigating the history of a new country one naturally pays attention first of all to the constitution of the land and to the manner in which it is governed and its affairs regulated and controlled. Thus the nature of the government, the duties and privileges of citizens, modes of taxation, and even the past history of the people, are all items necessary to be studied before a full and complete knowledge of a country can be obtained. If we apply this comparison to the case of the human body we shall find many points of similarity between the two studies. It is impossible to gain an adequate idea of such a complex piece of organisation as is represented by the body of any animal of high rank, and more especially that of man, without first of all taking a broad and comprehensive view of its constitution. By constitution, in this sense, is implied the nature of its build and the manner in which its various duties and actions are performed and in which its life is regulated. Far more complicated than any mechanisms of man's own invention are those comprised within the limits of his own frame. Yet it is possible to gain a comprehensive and correct enough idea of our own constitution through considerations which for the

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most part must be directed to ascertaining first, man's place in nature; second, the particular build of the frame he owns.

Man's Place in Nature.—Man stands at the head of the animal kingdom, and as such becomes in turn the chief figure in the class of animals popularly known as "quadrupeds" and scientifically as "mammalia." In turn, this class forms one of the five divisions of the type of animals known as *Vertebrates*, or "back-boned" forms. In all of these animals the presence of a back bone or spine forms a distinctive feature, for even in the very lowest, represented by certain fishes, if a bony spine itself is not developed, we find in such animals a structure representative of the back bone itself. Man's superiority over all other members of his class, and therefore over all Vertebrates, is represented by features which really represent elaborations or evolutions of the structures found in his lower neighbours. For example, the bodies of all the back-boned animals are built on one and the same type. If we make a section, in the long direction of the body—of a fish, for example—we find that the skull and spine protecting the main centres of the nervous system—brain and spinal cord—occupy the back or dorsal region of the body. In the middle we find the digestive system, which is essentially a tube; whilst situated lowest we find the heart. Between the digestive system and the back bone there exists a second nervous system known as the *sympathetic system*, a structure typically represented by a double chain of nerve-knots or centres with connecting nerves. Now this plan runs entire and unbroken through the whole Vertebrate series of animals, from fish to man.

If the body of a man be similarly bisected, we note precisely the same arrangement of the great systems of his body. The back bone and skull lie in the back region, the digestive system occupies the centre of the body, and the heart lies below. Man, if placed in the same position as the fish or the dog and proceeding on his hands and knees, is seen therefore to represent a precisely similar type and build of body to that of all his vertebrate neighbours. The fact that man, as it has been remarked, is an animal which has taken to walking on his hind legs, makes no alteration in the disposition of those great systems of organs. When we speak of man's heart lying to the front of his body, we merely mean that it does so because he is a two-legged and erect animal, instead of being a four-legged and therefore horizontally placed creature. This remarkable uniformity of build of body in the case of back-boned animals is represented in the case of types of the animal kingdom of lower grade than the Vertebrates themselves, so that we awaken to the knowledge of the fact that each animal, whatever be its rank in the scale, does not show a body built on a type or plan peculiar to itself. On the contrary, it shares that plan with a larger or smaller number of other animals which constitute its so-called "type" or subdivision of the animal world at large. Man is therefore distinctly of the animal kingdom, and not outside it.

MAN'S SPECIAL FEATURES.—Whatever special features are found to characterise the human being are simply to be regarded as developments of the common type just described. In other words, we may safely assume that what is specially human reposes on the animal scaffolding peculiar to the

whole back-boned series. The characters specially distinctive of man are to be found in the equal and even balancing of his head on his spine (Fig. 1). The head of other animals has, so to speak, to be tied on to the spine—a feature well seen in the case of the horse, for example, where a very strong band of fibres constituting a *ligament*, literally ties the head on to the back bone. The balancing of man's head on his spine without effort has special reference to his upright position, as also has the particular conformation of his back bone. In the human spine we find a series of curves such as are found in no other animal, and these curves are specially adapted for the more perfect support of the head and body at large in the erect position which man of all animals can alone easily and perfectly assume. With regard to the curves of the spine, it may be noted that these appear in the child after birth, and are not fully completed until some time after the child has risen from the quadrupedal position in which it at first crawls to assume the erect and human posture. It is a

Fig. 1.—HUMAN SKELETON Showing adaptation to erect posture.

fundamental rule of science that structures with which we are born are those we share in common with lower animals, whereas conformations which appear later on in life, are to be regarded as specially human. We see the application of this doctrine in the case of the curves of the spine. Man develops these curves after birth in relation to his assumption of the erect posture, and such curves therefore must be regarded as distinctly human in character. Again, the shape of man's haunch or *pelvis*, and the manner in which the thigh bones are jointed thereon, indicate a distinctive adaptation to the erect posture, as also does the manner of articulation or joining of the end of the thigh bone with the leg. When we come to consider man's feet we again find a special modification for the erect posture. The sole of the foot is broadened out, and the heel bone is especially prominent—more prominent indeed in man, having regard to the length of the feet and size of body, than in any other animal. The heel bone, it will readily be understood, forms an effective fulcrum or support for the body in the erect position, and prevents any tendency to over-balancing in the backward direction. Such are a few of the anatomical characteristics peculiar to man. If we considered the case of man's brain and his mental attributes, we should discover other and even greater differences between him and his nearest animal relations. Although man's brain is built up on a general type which is found to run through the brains of all back-boned animals, he nevertheless has more highly developed than in any other creatures certain brain regions, especially the frontal or forehead region of the brain which is now recognised to be the seat of the higher brain

functions. Indeed, one might very well correctly express the opinion warranted by scientific considerations, that if we take into account man's mental powers alone, dependent upon the possession of a highly developed brain, these characters would entitle the human being to a kingdom to himself in the animal sphere.

OUR BODILY CONSTITUTION.—The complexity of the human body becomes resolved into a certain degree of simplicity, when we discover that under the single personality which a human being represents, there is included all the elements of a compound commonwealth. When the constitution of the body is closely scrutinised, we find that ultimately its component units become resolved into collections of microscopic bodies to which the name of *cells* has been given. In certain parts of the body it is true there are *fibres* to be found, these being represented by the muscles or flesh of the frame, by the ligaments of bones binding them together in the joints, and by the nerve fibres of which the nerves are composed, these last representing the telegraph wires of the body conveying messages to and from the external world. But as fibres themselves originate from cells, and, what is more to the point, *as the whole body to start with is developed from one single cell known as the ovum or egg*, we may readily understand how the cell may be taken as the typical unit of the whole body. Hence the history of cells forms the starting point for all satisfactory considerations which deal with the body's constitution.

THE CELL.—The modern conception of the cell is that of a microscopic speck of *protoplasm* or living matter which may vary from the 1-120th part of an inch in diameter—a size represented in the *ovum* or

egg—to the 1-6,000th or even the 1-10,000th part of an inch; dimensions of these last found in certain of the brain cells. Other cells (Fig. 2) may vary from the 1-200th part of an inch in diameter to the 1-25th part of an inch; but all cells, it will be understood, are microscopic objects, and can only be seen and studied by the aid of a microscope of fairly high power (Fig. 3).
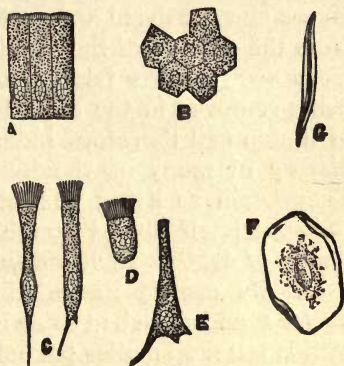
Fig. 2.—VARIOUS KINDS OF BODY CELLS

Including those found in mouth (F), windpipe (CD), digestive system (A), eye (B), and brain (E).

ABOUT CELLS.—The cell being thus a speck of protoplasm is, in its essential nature, a living thing. This fact must not be lost sight of, even with the knowledge that cells undergo in the course of

Fig. 3.—GOBLET CELLS
Found in the intestine or bowel.

their development special changes, many of them dying and perishing, to be replaced by other cells, whilst others again may become more or less hardened and take part in the formation of bodily structures which can scarcely be called vital in their nature. The cells which compose the *epidermis* or outer layer of the skin, for example, are produced from the upper surface of the under-skin. As layer after layer of these

cells is formed and pushed upwards, the outermost layers become dried and scale-like, and are given off from the surface of the skin in large numbers, being worn away by the friction of our clothes, and also being removed in the act of washing. The history of a skin cell therefore indicates in a measure the history of many of the living units of our body. They begin as living vital structures, and pass, as the body itself does, through a stage of decline and finally of death. Included in the living substance of a cell we usually find a solid particle termed the *nucleus*, and attached to or imbedded in the surface of this latter a smaller particle termed the *nucleolus*. These are highly important structures, which, however, need not further be alluded to in the present instance, save to remark that they are closely connected with the production of new cells. Many cells, in addition, possess a cell wall or boundary-membrane, although this last item does not appear to be an essential characteristic of many of the living units of our frames.

THE WORK OF CELLS.—Recognising the cell as a living structure in its most typical aspect, we must further note that every important organ and tissue of our frame is composed of cells. Naturally, as in a State there are different grades of citizens, some performing work of a higher grade than others, so in our bodily constitution, we find that whilst the whole duties of the body are performed through the work of these wonderful cells, there naturally appear variations in the relative importance of our living units. The cells which compose the outer layer of the skin are thus relatively unimportant as compared with, say, the cells of which the liver is composed, or when compared with those which

manufacture or secrete the gastric juice of the stomach, those which manufacture the sweetbread juice, or those which secrete the saliva of the mouth (Fig. 4) or the tears supplied by the tear glands of the eyes. More important still, in respect of the duties they perform, are *nerve cells*, those which constitute the units of the nervous system (Fig. 5) or governing system of the body, amongst which fall naturally to be included the *brain cells*.
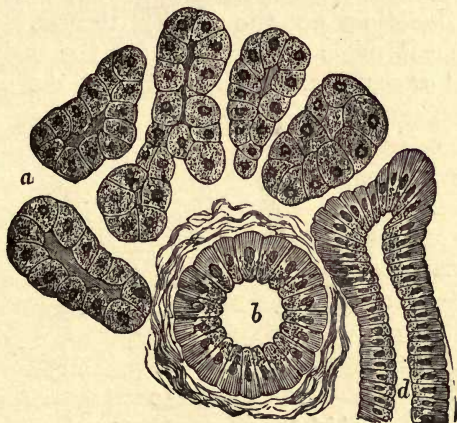
Fig. 4.—SECTION OF SALIVARY GLAND
Showing cells lining the duct (b), and others situated in the gland substance.

We may regard the living matter of which nerve cells are composed as representing the highest form of protoplasm which is known. If we are to judge the character of living matter by the duties it performs, it is obvious that the living matter of a brain cell, engaged in the work of bodily government, must be of a vastly superior character to that which devotes its energies to the manufacture of bile or

of sweetbread juice.   Hence the relative importance of cells is a point to be kept in mind, although we must not lose sight of the fact that all cells are in their way necessary and important, each discharging its own duty in the maintenance and upkeep of the frame of which it forms part.   The work of cells is identical with the work of the body at large. They may be said to represent the workmen of the frame whether their labour is devoted to supervising its nutrition, to governing its interests, or to assisting in building up the bodily tissues.   Everything that is made in the body for the body's use, secreted or manufactured in fact from the blood as
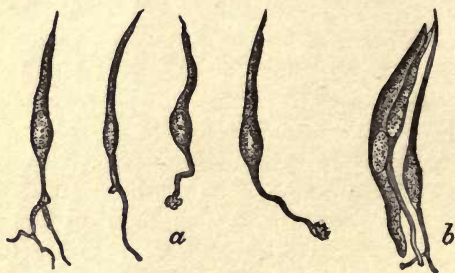
Fig. 5.—CELLS
In which the nerves of taste end.

the raw material, has to be regarded as representing the work of cells.   In the earlier stages of bodily development the whole frame is represented by a mass of cells.   Where strong structures in the shape of bone, muscle-fibres, ligaments and the like have to be developed, we meet with such structures directly originating from cells themselves.   The broad view which may be taken therefore of the constitution of the human body is that of regarding it as a really compound, or, as we might term it,

a colonial organism. It masks its compound nature under the guise of a single living personality, but the Ego which every man represents in himself is a compound thing, and can only be maintained as a single personality through the direct co-operation of the millions of different cells of which his body is built up. Such a broad view of matters serves to convey to us an adequate idea of the constitution of the living frame. If we extend our glance through the animal and plant worlds at large, we may discover that the same remarks apply to all other living organisms. The very lowest animals and plants consist each of a single cell. The animalcule in the pool and the yeast plant respectively illustrate this fact. When we advance beyond these lowest organisms we find that the single-cell state gives rise to the many-celled condition. Hence the lowest animals and plants are termed *unicellular*, whilst other and higher forms are termed *multicellular*. On this basis we may recognise that man stands at the head of the *multicellular* animals, not the least interesting fact involved in this statement being that already noted which teaches us that our wonderful frame arises, like that of all other animals and plants, from a single cell. It is, in fact, the wonderful multiplication of this single cell we term the *ovum* or *egg* into all the other cells of the body, which constitutes one of the most remarkable facts of living existence.

THE BODY'S CHEMICAL COMPOSITION.—A word regarding the *chemical* composition of the body may be added here. There are to be discerned in man's body some fourteen *elements*, all of them common to the world at large. They are represented by oxygen, carbon, nitrogen, hydrogen, lime, potash, soda,

sulphur, iron, phosphorus, magnesium, and other less familiar substances. Our elements therefore present nothing distinctive. These elements combine, moreover, to form *compounds*. Some of the latter (water, common salt, phosphate of lime, chalk, etc.) are also common in the world around us; but other compounds, formed by the elements noted (protoplasm or living matter, fat, starch, sugar, etc.) are peculiar to animals and plants. It is this power of building up the latter class of compounds which distinguishes living beings. The body of a man, taking it at 100, is composed of—water, 61'0 per cent; minerals, 5'5; bony matter, 18'0; starch and sugar, 0'1; and fat, 15'4.

CHAPTER II

THE STORY OF OUR FOODS

THE DEMAND FOR FOOD.—To nourish ourselves is the first duty we perform on entering the world, and it is the last we discharge on leaving it. All through life exists the necessity for finding our daily bread. Nor is this a feature peculiar to man alone. The fungus growing on the wall, the lofty tree, the animalcule in the pool, and the higher animal, through their whole existence must be fed. Indeed, if one were to try to discover the sharpest line of demarcation which might be drawn between the world of life and that of non-living matter, we should find it in this perpetual demand for food on the part of the animal and plant. Growth of a kind is certainly represented in the world of non-living matter. A stalactite or lime pillar depending from the roof of a cave will grow, but it enlarges its size simply by additions to its outside surface, and stoppage of this process of *accretion*, as it is called, has little or no effect on the stability of the object. The case is very different with a living being. Not merely is a constant supply of food demanded, but the material taken as nutriment is received into the interior of the organism, and has to undergo a process of digestion whereby it is assimilated and ultimately changed into the substance of the living being itself. In this latter respect we again perceive a very striking difference between living things and

things that are inorganic or non-living in their nature. A geranium growing in a pot illustrates equally with man the necessity for a constant food-supply. The plant will draw from the air so much carbonic acid gas, which is absorbed by its leaves. By its roots it will take up from the soil water, minerals, and also a certain amount of ammonia; these items constituting the food of the green plant. The failure to supply any of these items will result in the death of the plant from a want of nourishment, and if we turn to the animal the same remark applies. Its food is certainly different from that of the plant, but whatever be the kind of nourishment necessary for the animal, that nutriment must be supplied, otherwise, like the plant deprived of water and other food, the existence of the animal will assuredly come to an end.

WHY WE EAT OUR DINNER.—Associated with this demand for food, another consideration crops up in the shape of the inquiry why food-taking should represent a necessary duty of the living being at all. From a social point of view we might argue that had we been differently constituted, a very large number of our fellow-beings might find existence a somewhat easier matter than it proves to be. There is a constant struggle on the part of many human beings to obtain food; hence, if the duty of getting food were removed, their existence might prove a less arduous period than is represented to-day. It is easy to show that the inexorable laws of nature, which have to be obeyed lest the penalty of disease and death come upon us, are founded upon a very plain and distinctive feature of the living constitution. An answer to the question, "Why do we want our dinner?" is perhaps not so easily or satisfactorily supplied as

might be imagined. To say that we eat because we are hungry and drink because we are thirsty, only doubles the difficulty which before was single; for the inevitable inquiry would follow in the shape of the question, "Why are we hungry and why are we thirsty?"

THE ANSWER.—A comprehensive view of life, founded upon scientific knowledge, teaches us that our body is a machine that is always working. It requires very little thought to convince us of the truth of this statement. When we go to sleep, for example, and seek to recuperate our worn-out forces in the repose of the night, our heart, even though its work lessens, still continues to beat; our chest rises and falls in the act of breathing; and certain organs of our body, such as the liver, although their work is slowed down, continue to act through the watches of the night. There are certain of our brain cells, which, representing the night shift of the workmen of the nervous system, keep watch and ward over our destiny. Thus, even in sleep the work of the body is not suspended. Its bodily work is continued with increased force during our waking life, and, in addition, we are then face to face with another fact, namely, that the work we have to do in the world is superadded to that represented by the mere bodily labour of maintaining our life. We are therefore encompassed and environed by a continual atmosphere of bodily work and labour. It is of course an undeniable axiom that all work means waste. The waste attending the work of any ordinary machine is represented in two forms. In the first instance, there is waste of the actual machinery itself: the substance of the machine undergoes wear and tear. But there is also a constant

expenditure of its *energy*, which we may define as *the power of doing work*. Obviously, if the machine's work is prolonged to a certain extent, it will require to be supplied with additional material out of which it will repair its own waste, and from which it will derive a new store of working power. In the case of an ordinary engine, the power of doing work is derived from the combustion of coal and the conversion of water into steam, whilst there is also to be considered a certain amount of actual wear and tear of the engine itself. Both sources of waste have to be reckoned with, and have to be made good by repairs to the engine and by a constant supply of coal out of which its energy is developed. Now, our bodies are closely related to the engine in respect of their work and repair. Our frames do not merely demand food in order that the waste of the body may be repaired and replaced by new material, but they also require nutriment that they may develop new supplies of energy for the work they have to perform. In these considerations is found the answer to the question, "Why do we eat our dinner?" We take food—in other words—because out of the material thus supplied we repair our bodily waste, and we develop new stores of working power.

ABOUT FOODS.—Bearing the comparison with the engine in mind, we naturally divide the foods on which we exist into two chief classes. These may be described as, first, *body-building* or *tissue-forming foods*, otherwise called *nitrogenous foods;* and second, *energy-producing foods*—these last being also termed *non-nitrogenous* articles of diet. This division is a perfectly natural one. A "nitrogenous" food is one which includes the element *nitrogen* in its composition. The presence or absence of this

particular element makes all the difference in the world in the character of a food. For as the living matter or protoplasm of our bodies is a nitrogenous substance, and as protoplasm is one of the most important elements demanding repair, these foods therefore come to represent in the most typical fashion our body-building items. If we make out a list of the substances on which we subsist, we shall find them to consist of (1) water, (2) minerals, (3) starches and sugars, and (4) fats. These represent the non-nitrogenous foods, while the (5) nitrogenous foods complete the list. Water and minerals are in one sense "body-building" items, because, as we shall see, water enters into the composition of every tissue and fluid of our frame, whilst minerals also play an important part both in building and in maintaining the welfare of the body. Nitrogenous foods, on the other hand, are represented by various principles contained in many foods derived both from the animal and plant worlds, such foods containing other substances in addition to their nitrogenous matters. As examples of the nitrogenous class we may take *albumen*, represented by the juice of meat and white of egg; *casein*, represented by the curd of milk; *gluten*, found in flour and vegetable matters at large; and *legumin*, specially found in peas, beans, and lentils. These principles are associated, as has been noted, with other foods. For example—in peas, beans, and lentils, we also find starch, a certain amount of fatty matter, and minerals along with water, which last we may take for granted is found in foods of all descriptions. Gluten, found in bread, is associated with starch, a small amount of fat, minerals, and water. Beef and other forms of flesh-building

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albumens also contain fat and minerals with certain other substances. We thus see that in ordinary modes of feeding we do not take as a rule any food singly or by itself, but in combination with a number of other substances combined with it. It is needful to remark that whilst the distinction between foods which go to build up and repair the bodily substance and those which supply us with energy or working power is a very real one, nevertheless no sharp boundary line can be drawn in practice between the two classes of substances. It is known that under certain circumstances the body-building foods may yield a certain amount of energy, and some physiologists have argued that fat itself may discharge the duties of the tissue-forming items, although this latter view has not received universal support. The probability is that the functions of the two foods are interchangeable in some degree, but that in the ordinary healthy individual their functions are more or less limited to playing the parts just detailed in the nutrition of the body.

ABOUT WATER.—The human body consists by weight of two-thirds of water; and this fact, surprising as it may be, does not reveal the whole importance of water as a food. A constant supply of this fluid is required not merely to give to the tissues their proper composition, but a further supply is needed to replace that which is perpetually being used up in the body and excreted by the lungs, skin, and kidneys. Furthermore, water is demanded for the purpose of every vital action, and it is also necessary for the solution of our solid foods so that they may be presented to the digestive organs in a shape which favours their easy assimilation. The importance of water as a food is also

revealed by the fact that on water alone (and of course on air, which is really part of our food supply) a man may exist for periods varying from twenty to thirty days or more, whereas, if deprived of water and solid food as well, his existence would probably end in from six to seven days. Water is thus the only food which will maintain existence for a considerable period, having also regard to the air breathed. The quantity of water contained in the various organs and tissues of the body is very great. In the blood 90 per cent of water exists, and even in the brain-substance a very large amount of water is contained.

MINERALS.—Our mineral food-supply amounts on an average to about one ounce per day. The minerals demanded for nutritive purposes are represented by phosphate of lime, which is of extreme importance in early life, seeing that it forms the material from which bone derives its hardness. Common salt, or *chloride of sodium*, is a necessity of life, and appears to be required not merely for the purpose of digestion in the stomach, but also seems to be in other ways a necessity for the body, the blood itself containing a fair amount of this mineral which is given off or excreted in almost every fluid of the body, ranging from the perspiration to the tears. Other minerals required for the support of the body include potash—this mineral being apparently of much importance seeing that a lack of it gives rise to the serious trouble known as *scurvy*, which is inevitably associated with errors in diet. This disease of old was well known in connection with ships making long voyages, the sailors being fed on salt meat in the absence of fresh meat or vegetables. The salt meat alone could not be regarded as the

cause of the scurvy outbreak, but the lack of potash
in the meat.   When proper food is supplied contain-
ing potash, scurvy disappears.   Vegetables contain
potash, as also do fresh meats and potatoes; and the
remarkable fact was noticed that in Irish famines
where the sufferers had little else than potatoes to
eat, though the people were starving and emaciated,
no scurvy appeared.   Minerals thus enter intimately
into the compositon of the body, and are demanded
as an essential part of our diet.

THE ENERGY-PRODUCERS.—The energy-producing
foods are fats, starches, and sugars.   Fats stand
out distinctively as heat-producing foods, but it is to
be noted that a food which is capable of producing
heat is also capable of developing energy or working-
power.   Probably the starches and sugars are more
effective as energy-producers than fat, because they
are specially supplied to the muscles; but the typical
diet must include a supply of both items, greater
working power being developed from the combina-
tion of fats, starches, and sugars, than from the
taking of one of these foods only.   Fat is an
extremely important item in our diet.   It is not
merely required as part of our bodily substance,
being formed out of starch and sugar chiefly, but
likewise seems to play an important part in assisting
the digestion of other foods, whilst it is especially
the food of the nervous system.   Starch and sugar
are derived from the vegetable world, which may
also yield us forms of fatty food in the shape of oils.
These two classes of foods, starches and sugars on
the one hand, and fat on the other, are closely
related in chemical composition.   It is curious to
note that the body possesses the power of convert-
ing starchy foods into fat.   This is well seen in the

case of obesity or corpulence, the diet treatment of which excludes starches and sugars from the dietary to as great an extent as possible, whilst the amount of fatty foods need not be reduced to the same degree. The liver appears to be an organ in which the transformation of starchy foods into fats specially takes place. When geese and ducks are artificially fed upon maize (which contains a very large proportion of starch), and are prevented from taking due exercise, the livers of the birds become masses of fat, which are used in the preparation of the familiar *paté de foie gras* of Strasburg.

OUR NOURISHMENT.—One of the first rules for healthy nutrition which may be deduced from what we have learned regarding foods, is that both classes of foods are required for the due nutrition and support of the body, and this for the reason that the one class of foods discharges different functions in the frame from the other. The body-building foods are not required in anything like the proportion of the energy-producing ones. The comparison between the engine and the body again holds good. The engine in the performance of its work consumes far more coal and water, as sources of energy-production, than it requires iron for repairs, although it must be confessed the human engine is somewhat more imperious in its demands for the daily repair of its substance than is the machine. The comparison, however, holds good so far in that day by day we must consume a far larger amount of work-producing foods than of those which contribute to renew our bodily substance. Thus it has been calculated that the proportions required in the case of an adult man of the two foods are represented by one of nitrogenous or body-building substance to

four or four and a half of the energy-producing foods. We thus consume a far greater amount of starchy food and sugar than of albumen, casein, or any of the other foods which repair the tissues. In the case of hard work the proportions of both have to be slightly increased, but still the working foods must naturally assume a predominance. Nature teaches us much the same lesson when we investigate the composition of the foods which she especially employs for the nourishment and building of the young animal. The composition of milk shows us a perfect combination of the two classes of foods for the purpose of body-building and for energy-production. Milk contains not merely casein or curd for the formation of tissue, but likewise supplies fat and sugar of milk, which represent energy-producing substances, in addition to water and minerals. The case of the egg is similar. Out of a few teaspoonfuls of yolk and white the body of the bird is built up, this body exhibiting a complexity of structure not far behind that of our own frames. In the egg we find albumen, fat, water, and minerals; the combination necessary for the building of the body being essentially that which in after-life is also required for the body's support.

FOOD-TAKING IN PRACTICE.—We have seen that most of the articles of diet we consume, with the exception of such foods as water and minerals, contain both classes of substances in varying proportions. The experience of mankind, apart from scientific teaching, has led him to the practice of taking foods in such combination and in such proportions as usually on the whole best conduce to the nourishment of the body. In such combination of foods we receive the due proportions of the

different substances required, such proportions not being offered by one food taken by itself. Thus, white fish is largely deficient in fat, and with this article of diet some form of fatty sauce is usually taken; whereas on the other hand, fish represented by salmon, herring, and eels, containing a fair proportion of fat—eels especially containing much fat —do not require the addition in question. Salads are made more nutritious by the addition of eggs and oil; and a rice pudding, deficient in fat, is made a very much more nutritious article of diet by the addition of eggs and milk. In the same way foods which are apt to be somewhat tasteless are rendered more savoury by certain additions being made to them. Thus with fowl, salt food in the shape of ham or bacon is taken; and the familiar combination of salt beef and greens is, in its way, to be commended—the greens containing potash and thus tending somewhat to modify the salt of the beef. The value of green vegetables, it may be stated, does not consist in their affording much nourishment, but in their supplying us with the minerals, especially potash, which we have seen to be a necessary constituent of the blood. Even when we toast bread we cause it to undergo a change which converts so much of its starchy contents into sugar. We thereby assist the action of the saliva of the mouth, the duty of which is to convert starch into sugar as will be afterwards shown. Such habits in the taking of food, as has been said, have originated as the result more of experience than of scientific wisdom, but science has at least supplied reasons why such combinations are beneficial, and in this respect has given a powerful sanction to the adoption of rational modes of feeding.

DIFFERENT DIETS.—A question has often been asked regarding what has been called "the perfect way in diet." Science speaks here with no uncertain voice regarding the great law which underlies the feeding habits of mankind. Certain persons maintain that vegetarianism represents the ideal mode of feeding. Some of the advocates of this system subsist on milk, eggs, and cheese, and are not therefore to be regarded as rigid adherents to their doctrine. Others again subsist on vegetable matters entirely, whilst some extreme advocates of vegetarianism reject most starchy articles and advocate a diet which consists largely of nuts. It may be said that there is no perfect way in diet except that which suits the individual and is adapted for maintaining him in perfect health. The great law which underlies nutrition is that man can practically subsist on any kind of food, and that it is climate, or, in other words, his position on the face of the earth which determines the particular articles of diet on which he subsists. Thus in the northern regions of the world meat is largely consumed, and in the far north the diet is almost exclusively of a fatty order, as represented in the habits of the Esquimaux. Here the teaching of nature has again been followed, for fat is a typical heat-producing food, and the inhabitants of the Arctic regions therefore obtain from their diet a source of heat which external nature has largely denied them. In the south, on the other hand, man tends to become more or less a vegetarian and fruit-eater, because the land he inhabits grows fruits in profusion, and vegetables are cheap and easily obtained. In the temperate climates of the earth man becomes a mixed feeder, although certain nations, it is true,

consume more meat than others. The British nation has been credited with a larger consumption of meat food than that represented in any other people. At the same time it must not be forgotten that, with the exception of those who dwell in the extreme north, every nation consumes a fair amount of vegetable matter, and the quantity of meat consumed cannot, save under exceptional circumstances, be regarded as excessive. Further, meat is not by any means to be despised as a body-building food, seeing that, although it is an expensive diet, at the same time a little meat contains a large amount of body-building substance, and above all forms an easily digested food. Indeed, one of the strongest arguments against a purely vegetarian diet is found in the facts: first, that such a diet is apt to be indigestible; and second, that a far less proportion of nutritive substance is absorbed from a purely vegetarian diet than from a mixed dietary in which meats and vegetable foods are both represented.

EXPERIMENTS IN FEEDING AND WORK.—It is always interesting to trace the history of scientific discovery and to note the manner in which definite conclusions regarding any special subject have been arrived at and formulated. The main principles of the science of foods and feeding having been detailed, it is on these latter grounds important that we should become aware of the manner in which it was demonstrated that whilst the nitrogenous foods are to be regarded as body-builders the non-nitrogenous foods—starches and sugars—fall to be considered the sources of our energy or working-power. In the days of Baron Liebig, the famous chemist, foods were classified as "body-builders" (or tissue-formers), and "heat-producers." The

fats, starches, and sugars were classified under the latter category, but the production of heat was not then associated in the minds of scientific men with the development of energy. In other words, food which was regarded as a heat-producing element was dissociated from any other of the special functions we know it to discharge when consumed in the body. Liebig taught the doctrine that the work of the body was done on nitrogenous food. He assumed, for example, in the action of a muscle fed by such foods, that the muscle used up its substance, and in other words developed its power of movement or work out of the consumption of its own material. This view held the scientific field for many years, until various circumstances seemed to raise doubts in the minds of physiologists regarding the correctness of Liebig's views. Hence arose the necessity of further experimentation. This was carried out chiefly by Continental scientists who practically demonstrated in a manner which left nothing to be desired that Liebig was mistaken, and that, as the modern doctrine of food-usage in the body teaches, the nitrogenous foods are the typical body-builders, whilst the non-nitrogenous foods are those which represent the coal or source of energy of the human machine.

THE DEMONSTRATION.—A series of experiments made by two Swiss observers stands out prominently as illustrating the nature of the researches which gave information of paramount importance regarding diet to the world at large. Their experiments were made at the Faulhorn Mountain in Switzerland. They endeavoured by practical work—taking themselves as the subjects of the experiments—to discover the nature of the foods which were

specially consumed in the act of bodily work. Estimating the height of the Faulhorn Mountain as 10,000 feet, the basis of their experimentation took the shape of the investigation of the amount of bodily waste given off by a man, weighing 140 pounds, climbing the mountain. This of course represented a measured piece of work: the raising of a man's own weight (140 pounds) 10,000 feet high. Paying attention to the amount of waste matter which was given forth in the accomplishment of this task as compared with that excreted at rest, they arrived at certain definite conclusions. We have to bear in mind that as the two classes of foods are used up in the living body, two different kinds of waste are given forth as the result. The nitrogenous foods give off waste chiefly by the kidneys, this waste material being represented by a substance known as *urea*, which represents in itself the final stage, so to speak, in the breakdown of nitrogenous substance in the body. On the other hand, the waste of the non-nitrogenous foods is represented by substances given forth from the lungs, skin, and in part by the kidneys. These are in chief, *heat, water*, and *carbonic acid gas*. The problem being thus fairly defined, the two experimenters carefully calculated the amount of waste of the two kinds specified during their periods of rest and during their climbing of the mountain respectively. The result was the discovery that the amount of urea, that is, the waste of nitrogenous food, did not materially alter whether they were at rest or whether they were engaged in their active exercise. On the other hand, the waste of non-nitrogenous kind increased very materially during their periods of activity, and decreased during their

time of inaction. These experiments, repeated and verified, clearly showed that the nitrogenous waste bore no proportion whatever to the amount of exercise or work performed, and that whereas the non-nitrogenous waste did bear a very distinct relationship to work, it became clear that the non-nitrogenous foods represent the true source of energy. In this way the doctrine was firmly established that it is on fat, starch, and sugar, that our active bodily work is performed, whilst nitrogenous foods became settled in their proper place as tissue-producers and repairers of the bodily waste which to a certain extent is perpetually represented in our frames.

AN INTERESTING TABLE.—An interesting table was compiled by the late Dr. Frankland, the eminent chemist, on the results of the experiments just described. He calculated the quantity, the cost per pound, and the actual cost of the food, which, if perfectly consumed and utilised within the human body, would supply it with energy enough to raise a man's weight (140 pounds) 10,000 feet high. The following items represent the chief particulars of the calculations thus made:—

	lbs.		Price per lb. d.		Total Cost. s.	d.
Bread ...	2·345	...	1½	...	0	3¾
Oatmeal ...	1·281	...	2¼	...	0	3½
Potatoes ...	5·068	...	1	...	0	5¼
Beef Fat...	0·555	...	10	...	0	5¼
Cheese ...	1·156	...	10	...	0	11½
Butter ...	0·693	...	1·6	...	1	0½
Lean Beef	3·532	...	1·0	...	3	6½
Pale Ale ...	9 bottles ...		0·6	...	4	6

From this table it appears clear that the non-

nitrogenous foods come to the front as energy-producing substances. The popular idea that the best food on which to feed a man having a fair amount of physical work to do is beef-steak or other form of meat, is shown to be erroneous. The meat is valuable enough as a tissue-former, but as shown by Dr. Frankland's table, the working-power which the meat affords can only be got out of the fat it contains; and in the case of lean meat a large quantity of this substance would require to be eaten to afford the necessary supply. These researches also teach us economy in the use of food. The combinations of food already alluded to are economical in that one food supplies what another food lacks. A man fed on a proper quantity of bread and meat would diet himself more economically than if he took meat alone, or bread alone—economically, that is, in respect of his obtaining sufficient material for his support. The bread and meat together in suitable quantities would supply him with both body-building food and with energy-producing food in the shape of the starch of the bread, as well as the fat of the meat. If he took meat alone to gain sufficient working-power, he would over-load his body with nitrogenous matter to obtain the bare amount of fat for energy-production. If, on the other hand, he elected to subsist on bread alone, he would greatly over-load himself with starch in order to obtain just sufficient body-building substance found in the gluten of the bread. Teachings of such a kind are of great importance to the nation as showing forth the basis of economical feeding and as tending to prevent the large amount of waste of food which, it is to be feared, is too commonly represented in our midst.

CHAPTER III

THE STORY OF DIGESTION

WHAT DIGESTION IS.—A common notion regarding the nature of digestion is that which defines it as the work of converting food into blood. This is an entirely erroneous definition. Food is not converted into blood, but is changed by digestion into such a form that it can be added to the blood and be readily incorporated with that fluid with which in due season it becomes identical. It might truly be said that in many respects the food we eat presents a certain chemical resemblance to the blood itself, but whilst digestion involves certain actions of a physical kind, it is also represented by a series of chemical aspects wherein the elements of the food are recombined after being in many cases split up or dissociated, and thus made available to renew and repair the vital fluid. The blood, a topic to be hereafter treated, may be regarded as the common currency of the body out of which all the tissues of the body take precisely the nourishment which is adapted to renew and repair their vitality, so that in one sense the blood has been well described as being a kind of fluid epitome of the body itself.

THE DIGESTIVE SYSTEM.—It is possible to form a simple, and at the same time correct, idea of the nature of any digestive system ranging from that of the lowest animal, in which such a system appears, onwards to that of man himself. Any digestive

system is really a tube running through the body of an animal, having the mouth as its anterior or front opening, and the *anus* or terminal aperture of the intestine or bowel, as its posterior opening. Digestion may be described as the journey of food
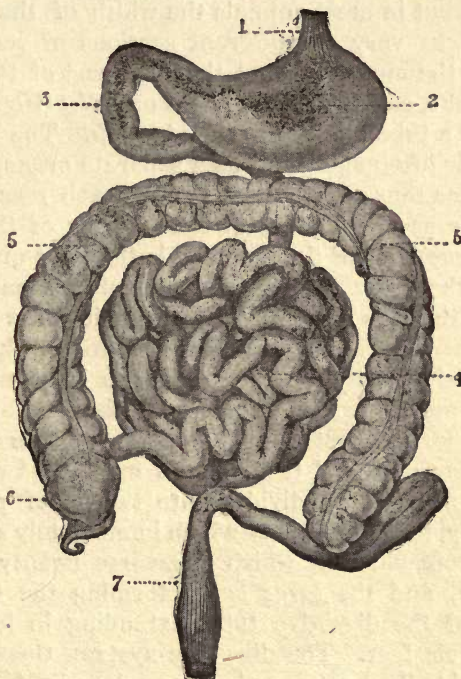

Fig. 6.—GENERAL VIEW OF DIGESTIVE TUBE
(1) gullet, (2) stomach, (3) beginning of intestine, (4) small intestine, (5) large intestine, (6) cæcum with appendix, (7) rectum.

along this tube, the nutriment in the course of its travels being acted upon by various fluids or secretions poured upon it and so changed and resolved

for its ultimate destination, namely, the blood current. In animals of simple organisation the digestive system presents itself as a tube and nothing more. In a worm, for example, it exhibits pretty much the same calibre from one end to the other, but in most animals the width of the tube is found to vary in different sections of its length. From the mouth we find the first part of the digestive tube, called the *œsophagus* or *gullet* (Fig. 6) leading as a tube directly to the *stomach*. The stomach itself is often spoken of as a separate organ, and the idea has thus arisen that the stomach resembles a bag or sac depending in the interior of the body. The true view of the stomach is that it is merely an expanded part of the digestive tube; expanded, in order that the food may remain in it for a time so that certain important changes, to be hereafter chronicled, may be effected upon it. Succeeding the stomach we again come upon the tubular part of the digestive system. This portion is termed the *intestine* or *bowel* (Fig. 6). In man it is twenty-six feet long, and is divided into two chief portions, namely, the *small bowel* which immediately succeeds the stomach, and which measures twenty feet in length, and the *large bowel* forming the terminal part of the digestive tube, extending in length to about six feet. The digestive system, therefore, is undoubtedly a tube, as has been described, with the stomach as an expanded part thereof.

DIGESTIVE GLANDS.—The length and complexity of the digestive system show a distinct relation to the food upon which an animal subsists. The rule may be remembered that vegetable-feeding animals possess longer and more complex digestive systems than do those which live on a carnivorous or flesh

dietary. Thus a cow's digestive system, or that of a sheep, is more complex than that of the lion and is also much longer. The hen or pheasant, living on grain, possesses a more intricate digestive apparatus than the eagle or the gull, and the same rule applies to the difference between the digestive system of those insects which live on vegetables and those which are carnivorous in habits. It has already been noted that as food passes along the digestive tube certain secretions or fluids are poured upon it, such as have the result of chemically and otherwise altering and changing it so as to fit it for ultimate addition to the blood. These digestive fluids or secretions are provided by certain organs termed *digestive glands*. We may figure these glands as attached to the sides of the digestive tract, and as communicating in each case with the tube by means of a special *duct* or *tube*. The first series of digestive glands to be encountered are the *salivary glands*, or those of the mouth. They pour upon the food the saliva or "water" of the mouth, the action of which on the food will be presently described. When the food has passed into the stomach the *gastric glands*, or those imbedded in the wall of the stomach, pour out upon the food the *gastric juice* which is the special secretion supplied by the stomach in order to discharge its special functions in the act of digestion. When the food leaves the stomach it meets with other two secretions, one—the *bile*—being poured upon it from the *liver*, and the other—the *sweetbread juice*—coming from the *pancreas* or *sweetbread*, organs situated in close proximity to the stomach itself. The food finally passes into the bowel, and having been mixed with the bile and sweetbread juice is further

subjected to the action of the secretions provided by the glands of the small intestine (*intestinal glands*) which appear to play some part or other in digestive action, the exact duty of the secretion of the bowel being as yet imperfectly understood. We are now in a position to review the general conception of the digestive system which, as has just been stated, is a longer or shorter tube possessing an expanded portion known as the stomach. Digestion is the journey of food along this tube, and is accomplished through the action of certain secretions or fluids contributed by the digestive glands placed at the sides of the tube, such secretions being poured upon the food at different stages on its journey.

THE DIGESTIVE JOURNEY.—Simplifying thus our view of the process of digestion we may divide the digestive journey into three stages. The first of these concerns what happens to the food in the mouth, the second deals with digestion in the stomach, and the third and last stage notes the changes which the food undergoes in the intestine. Following upon digestion itself we find another function or duty, that of *absorption*. This latter action is devoted to the conveyance from the digestive system into the blood of digested food which remains in the intestine, although, as we shall note, a certain amount of the digested food leaves the digestive system and passes into the blood at a stage considerably earlier than that representing the close of the digestive work.

DIGESTION IN THE MOUTH. — That digestion really commences in the mouth is a fact not generally appreciated. Many persons speak of digestion as if that function was discharged by the stomach alone. As a matter of fact, and curious

though the circumstance may appear, the stomach has really very little to do with the digestion of food at all, that is, when compared with the bulk of the digestive work at large. The action of the stomach is no doubt highly important, but it does not by any means include those actions through which the larger amount of the diet is converted into a form ready to be assimilated by and into the blood. The first digestive work accomplished in the mouth is division of the food by the teeth. This is an extremely important action, but one unfortunately too much neglected by the vast majority of people. The proper division of the food by the teeth is essential for the healthy performance of digestion, first, because the stomach cannot digest masses of food; and second, because unless food be thoroughly divided by the teeth it cannot be thoroughly mixed with the saliva which is in itself an essential for the perfect digestion of starchy foods. Returning presently to consider the teeth themselves, we may illustrate the axiom that digestion begins in the mouth, by considering the duties performed by the saliva or "water" of the mouth. This fluid is furnished by three sets of glands. Of these glands, one set exists in front of the ears, these being known as the *parotid glands*. The other two pairs, called *sub-maxillary* and *sub-lingual glands*, are situated in the floor of the mouth. Each pours its secretion into the mouth through a special tube or duct, the saliva representing a "secretion" as it is termed, manufactured by cells. The essential units in the salivary glands are living cells, which, from the blood supplied to the glands, elaborate or manufacture the particular secretion afforded by these organs. Each cell in this way may therefore be

regarded as a little chemist, seeing that secretion implies not merely a separating from the blood of certain products already formed therein, but also an actual process of manufacture out of the raw material represented by the blood of the new substance or fluid.

ABOUT SALIVA.—This fluid in the case of the salivary glands is a colourless fluid consisting very largely of water and containing minerals, while its chief constituent is a substance or ferment known as *ptyalin.* Upon the presence of ptyalin depends the particular action which the saliva discharges in the work of digestion. To saliva is assigned the first step in digestion, namely, that of converting the starch we eat into a form of sugar known as *grape sugar.* This is accomplished by the action of the ptyalin ferment, and we are therefore taught the lesson that the starch consumed so largely as food, is intended by nature to pass to the stomach, not in the form of starch, but in that of a sugar. It may be remembered that all throughout digestion this rule holds good. Starch, as such, is practically useless to the body. It may be, as we shall see, stored up in the liver in the form of starch, but when required for bodily purposes to be applied to the tissues as a food, and especially to the muscles as an energy-producing substance, it must be presented in the form of sugar. Another point worthy of importance, because possessing a distinct bearing on the nourishment of young children, is the fact that ptyalin does not appear in the saliva of the child until it attains the age of seven or eight months. Prior to this age it is therefore incapable of converting starch into sugar, nature making up for the want of starch by placing sugar ready made in the

milk. To give a child under the age specified any foods containing starch is therefore to supply it with material which is not merely indigestible, but may be regarded as being the cause of a large amount of the infant mortality due to erroneous feeding.

THE TEETH.—The importance of attending to the care of the teeth and of preventing tooth decay by daily attention in the way of brushing the teeth and
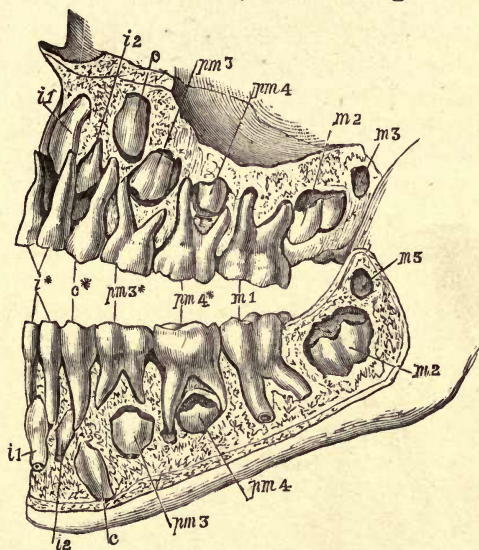

Fig. 7.—TEETH OF THE FIRST SET
Showing the second teeth in course of development.

cleansing the mouth, scarcely requires to be inculcated here. At the same time, the duty of preserving the teeth by all means in our power is one the importance of which should be early impressed on the minds of the young by way of avoiding tooth decay and tooth degeneration which are only too

conspicuous features of our age. The importance of thoroughly dividing the food by the teeth has been already insisted upon. Two sets of teeth (Fig. 7) exist in man, and in most of his neighbour animals. The first teeth are known as "milk teeth," and number twenty; the second set possessing twelve additional
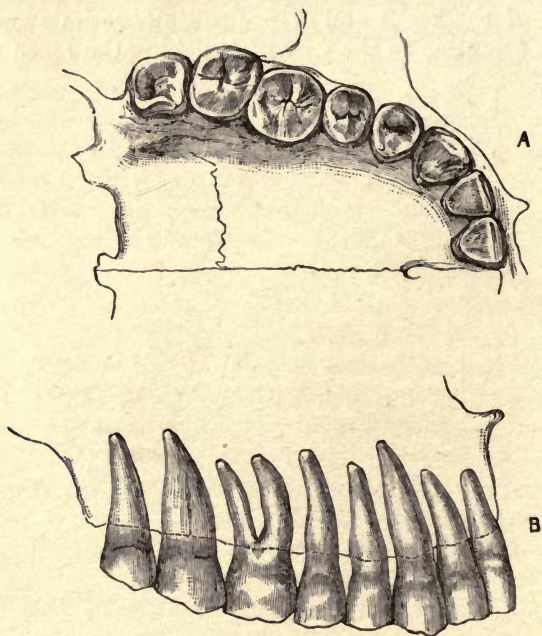

Fig. 8.—TEETH OF ONE-HALF OF UPPER JAW IN POSITION
Seen from above (*a*), and from the side (*b*).

teeth, and therefore numbering thirty-two. In each jaw the same number and the same arrangement prevail (Fig. 8). There are four front teeth or incisors, two canine or eye teeth, four premolars or bicuspids, and finally six molars or back teeth in each jaw.

The last molars in the jaw receive the name of "wisdom teeth," owing presumably to their late development. The six molars in each jaw are not preceded by any teeth in the milk set, the presence of the twelve molars thus accounting for the difference in number between the teeth of the second and those of the first set. The bulk of each tooth is composed of a substance called *dentine* or *ivory*, which is very different from bone and of much denser texture. The top of each tooth is coated with a still harder substance termed *enamel*, whilst at the root we find a third substance somewhat resembling bone in structure and known as *cement*. The teeth, it may be added, are typically skin-structures, that is to say, they correspond closely with nails and hairs in their mode of origin and development, seeing that they originate from the delicate skin layer,

Fig. 9.—THE HUMAN TONGUE
Showing the papillæ or organs of taste.

which, folded inwards at the mouth, constitutes what is popularly known as the gum or mucous membrane.

SWALLOWING.—Divided by the teeth and mixed with the saliva, the food is ready to be swallowed. This action is somewhat complicated in its nature. It may be briefly described as consisting first in the work of the tongue (Fig. 9) in gathering particles of food from all parts of the mouth and gullet into small masses or boluses suitable for swallowing or
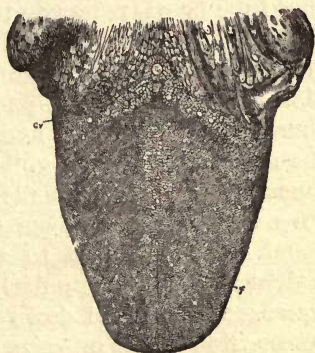
deglutition, as the action is scientifically termed. The tip of the tongue is next placed to the roof of the mouth and the food-mass tilted backwards to be received and grasped by the upper part of the throat known as the *pharynx*. This is a muscular bag which is drawn up to meet the food, the hinder nostrils at the same time being closed to prevent the escape of any fluid from the channel of the nose. The food passing still backwards, reaches the upper part of the windpipe where we find the entrance to that tube or passage-way to the lungs guarded by a lid-like structure known as the *epiglottis*. This structure, when swallowing is naturally performed, closes over the windpipe entrance, and the food therefore passes over and behind the windpipe into the upper part of the gullet. The gullet itself is a muscular tube whose walls are closely approximated save during the passage of food to the stomach. Food does not pass to the stomach by its own weight as is often popularly supposed, but is rather squeezed or pressed down into the stomach by the contraction of the muscles of the gullet which act in wave-like fashion, ultimately forcing food through the front opening of the stomach, called the *cardia*, into that organ. Choking, we may perceive, will be caused by any action (such as speaking or coughing) which interferes during the process of swallowing with the perfect closure of the epiglottis protecting the entrance to the windpipe.

THE STOMACH.—In man, the stomach (Fig. 10) is a pear-shaped expansion of the digestive tube, the large end of the pear lying to the left side of the body. From the narrow end of the pear-shaped bag the bowel is given off, this junction between the stomach and the bowels being found on the right side of the

body where the liver is situated.   Roughly speaking,
if we take the stomach as the centre of the organs
contained in the abdomen or belly, we find the liver
(Fig. 11) lying to the right, the spleen to the left, and
the sweetbread or pancreas below and in front of the
stomach.   The stomach, like the rest of the digestive
system, has three coats or coverings.   There is first
of all a somewhat tough outer coating (serous coat)
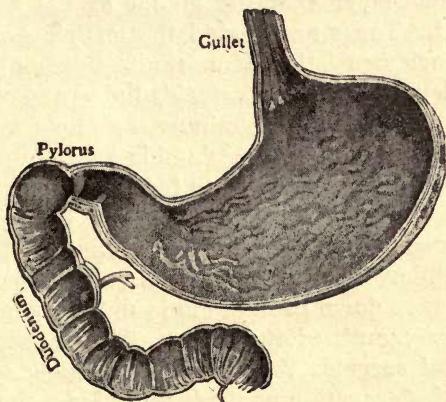giving shape to the tube.   The middle coat is a

Fig. 10.—THE STOMACH
Showing interior and commencement of bowel.
The sweetbread duct is shown opening into the bowel.

muscular coat composed of involuntary muscular
fibres, or in other words of fibres which are not
directly under the command of the will as are the
muscles of arms, legs, and other parts of the body.
The function of this muscular layer of the digestive
tube is naturally to propel the food along its course,
whilst in the case of the stomach the duty of the
muscular coating is to cause movements of the
stomach to take place so that the food will be made

to circulate within it and so become thoroughly mixed with the secretion which the stomach pours out upon it. The inner coating of the stomach, or *mucous layer*, as it is called, is that which comes in contact with the food. This mucous layer is continued onwards into the intestine as it appears upwards in the gullet. The glands it contains naturally differ according to the various functions discharged at different parts of the tube. It is in this mucous layer that the glands of the stomach are found. These are named the *gastric* or *peptic glands*, each consisting of a minute tube embedded in the substance of the stomach's lining and opening into the stomach by a minute aperture through which the secretion of the gland is poured upon the food. Again we come face to face with the work of cells, for the makers of the gastric juice of the stomach are microscopic cells which line the tubular glands. Microscopic research has also shown that the cells deep down in the glands differ from those nearer the mouth of the tubes. The gastric juice each gland secretes therefore seems to undergo a process of elaboration as it advances from the lower part of the tube until it is poured into the stomach.

GASTRIC JUICE.—The gastric juice of the stomach is a fluid of much importance. It exercises, as we shall see, a very definite action upon certain foods. We find it to consist of *water*, *minerals* (amongst which common salt bulks somewhat largely), an acid called *hydrochloric acid*, and a special ferment found in no other secretion of the body and known as *pepsin*. The digestive action of gastric juice is no doubt specially due to the action of the pepsin and the acid, but at the same time we cannot afford to ignore the part which may be played in such action

by the minerals and likewise it may be by the water represented in the secretion. The cubic capacity of the adult human stomach is about five pints and a very considerable amount of gastric juice is elaborated and secreted in the course of a single day's digestive work. It is interesting to note that the first accurate analysis of gastric juice was obtained from the case of Alexis St. Martin, a Canadian trapper, who early in the nineteenth century suffered from a gunshot wound which penetrated his side. This wound healed somewhat too perfectly in the sense that a flap was left in the man's side, and by lifting this flap the interior of the man's stomach could be inspected. His medical attendant, Dr. Beaumont, recognised that this was an exceptional opportunity for investigating the process of digestion. He accordingly obtained samples of gastric juice for analysis and likewise made many experiments with the view of ascertaining the times occupied in the digestion of various foods. Cases of analogous nature have since occurred, and have thrown much light on the work of the stomach in digestion. It may be briefly said that vegetable foods are found to require a longer time for digestion than purely animal diet; whilst of animal foods, fish, tripe, and fowl appear to be more readily digested than meat; and amongst meats, mutton seems to be more easy of digestion than beef and pork.

THE STOMACH'S WORK.—Before food enters the stomach its lining membrane is of a pale pink hue. On the entrance of food a rush of blood takes place to the walls of the stomach in order to supply the raw material out of which the gastric glands may elaborate and manufacture gastric juice. Accord-

ingly, the interior of the stomach may literally be said to blush on the entrance of food. The gastric juice is poured out upon the food, and the stomach's movements, of which in health we are unconscious, serve thoroughly to mix the food with the secretion of the organ. It would appear that the food is made to circulate within the stomach in a somewhat figure-of-8 fashion, and this again would appear to proceed during the whole period that the food remains in the stomach. The hinder aperture of the stomach, or that which leads into the intestine, is known as the *pylorus* (Fig. 10), the aperture by which food enters the stomach being termed the *cardia*, as we have already noted. The pylorus is kept closed by a valve-like muscular arrangement which exists in that situation, and it is only when the proper time arrives for the food to pass out into the intestine— that is, when digestion in the stomach has been completed—that this muscular ring uncloses, and the subsequent contraction of the stomach forces the digested material into the bowel.

WHAT THE STOMACH DIGESTS.—Allusion has already been made to the work of the stomach, in respect that the amount of its labours is inferior to that discharged by, say the bowel or intestine. Hence we now arrive at the interesting fact that there is only one class of foods upon which the stomach can exert any decided action. These foods are the *nitrogenous ones*, represented, as we have seen, by albumen, casein, legumin, gluten, and the like. They represent of course the typical body-building elements. As by far the larger proportion of our daily meals consists of non-nitrogenous starch, sugar, and fat, it therefore follows that the stomach's share in the work of digestion is relatively

small; if small, however, it must be regarded as nevertheless of high importance. It is not denied that a certain minor action on non-nitrogenous starches and sugars may be exerted by the stomach, but the all-important part of its work is the action which it exerts on nitrogenous articles of diet.

PEPTONES.—The gastric juice thoroughly mixed with the food, and leaving practically unaltered the sugar contained in the food and any starch which may have escaped the action of the saliva of the mouth exerts its power, as we have seen, on nitrogenous articles of diet. Coming in contact with albumen or any other foods of this class it converts them into bodies known as "peptones." One of the chief differences between a peptone and the food it previously represented is that, as a peptone, it can easily pass through the walls of the stomach and be absorbed by the bloodvessels. The peptone possesses other characteristics, but this last is the special feature to which attention may here be directed. The result is that the peptones leave the stomach and pass as described into the bloodvessels of the organ. They then find themselves in the veins of the stomach which join a very large vessel known as the "portal vein," returning blood from the whole of the digestive organs. In tracing the course of the portal vein we find that it disappears into the liver, so that the liver is the direct destination of the peptones which it has been the business of the stomach to separate out from the rest of the food; these peptones, as we have seen, representing the changed nitrogenous articles of diet which have been consumed. What happens to the peptones in the liver will hereafter be described, but it should be noted that already from the stomach

we have the absorption into the blood of certain highly important articles of food. It would almost seem as if nature taught us the lesson that the nitrogenous foods required for body-building purposes are of high importance, and, as such, have to be more readily and quickly passed into the circulation; the starches, fats, and sugars, on the other hand being less important, and requiring to wait for digestion in the bowel or intestine. The stomach may be regarded in this sense as a kind of half-way house on the digestive journey in which the progress of the food is for the time being arrested in order that the nitrogenous foods converted into peptones should be passed onwards into the liver, there to be further dealt with and fitted for their ultimate destination, namely the blood current.

THE LIVER.—The third stage of the digestive journey may be said to commence with the passage of the food from the stomach into the intestine or bowel. Immediately the food enters this portion of the digestive tube it meets with *bile* from the *liver* (Fig. 11) and *sweetbread juice* from the *pancreas* or *sweetbread*. These two secretions are poured upon the food practically at the same point, the duct or tube from the sweetbread frequently joining that coming from the liver. The liver is the largest organ of the body, weighing between three and four pounds, and lying to the right of the stomach sheltered beneath the lower ribs of that side. Essentially the liver is a great colony of "hepatic" or liver cells, the diameter of each cell averaging the 1-1,000th part of an inch. Into the liver there passes from the great portal vein already mentioned, a continuous supply of blood returned from the digestive organs at large. This blood, as we shall see, is laden

with the products of digestion in the shape of foods
absorbed from the intestine.   On the under surface
of the liver lies the *gall-bladder* which is a store-
house of bile.   As the liver is perpetually secreting
bile, and as this fluid is not constantly demanded for
digestive purposes, it is stored in the gall-bladder
whence a special duct, joining that coming from the
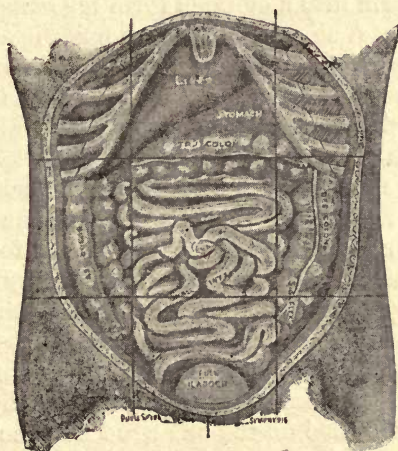liver, conveys it to the bowel.   The duties of the

Fig. 11.—FRONT VIEW OF DIGESTIVE
ORGANS in *situ.*

liver are at least threefold.   A common conception
of this organ is that it makes bile and does nothing
else.   This is a highly erroneous supposition,
because the making of bile represents, if it may so
be termed, the least important labour of the organ.
As it has well been put, the water discharged from
the engines of a steamer does not represent the
work of the vessel, but merely the result of that
work.   The secretion of bile similarly represents in

reality a kind of waste product, only a product which is made useful in the economy of the body.

THE LIVER AND PEPTONES.—The first duty of the liver is to deal with the peptones or changed nitrogenous foods which we have seen to be conveyed to it from the stomach. The liver cells deal with these peptones and exert a certain chemical action upon them, the effect of which is to change them into a suitable form for being added to the blood. A somewhat curious point in the history of peptones refuses to be noted. If peptones themselves were allowed to pass into the blood unchanged from the liver, they would give rise to symptoms of body-poisoning, and there seems little reason to doubt that many cases of so-called bilious disorder are really due to interference with the liver's work in this respect. That our food, otherwise of perfectly healthy character, may therefore injuriously affect us if proper chemical changes are not effected upon it is obviously a remarkable fact of our constitution. The liver in this respect might be compared somewhat to a filter which stands between the food on the one hand and the blood on the other. It is a fact of some interest in relation to the liver's work that actual poisons taken into the body may be detected in the liver more readily perhaps than in any other organ of the body, the liver exercising here, the same filtering action such as it discharges naturally in the process of digestion.

THE LIVER AND SUGAR.—The second duty of the liver is that of dealing with the sugar-foods which represent either sugar taken as such, or starches which we have seen are converted into sugar by digestive action. From the intestine sugar is absorbed and carried to the liver by the portal vein. In

the liver this sugar appears to be converted into a starchy substance known as *glycogen*, or *animal starch*. Stored up in the cells of the liver, it would seem that this starch is ultimately reconverted into sugar, and paid out to the blood by the hepatic vein which represents the great outlet of the liver into the circulation. Here we might compare the liver to a banker who receives the cheques and drafts of his customers, and pays out money that is required in the form of ordinary currency which can be used to pay the customers' workmen. Some doubt has been cast upon the liver's work as affecting a source of sugar-supply for the body at large, and the muscles especially. It has been contended that the sugar which is stored by the liver is converted into fat, and that any escape of sugar from the liver is to be viewed as an unnatural process. This view, however, has received but slight support from physiologists at large. It seems to be refuted by the fact that the hepatic vein, carrying blood away from the liver, contains a larger proportion of sugar than any other vein in the body. If the sugar-supplying duty of the liver be upheld, it is not necessary to reject the idea that the liver may also form fat from the starch it stores up, for we know that starchy foods tend to produce fat and are therefore forbidden to corpulent persons. The probability is that the liver discharges both duties. It gives off sugar, and it may form fat; the former action being vastly more important than the latter. A proof of the liver's manner of dealing with sugar is afforded by the disease known as *diabetes*. In this disease there is an excess of output of sugar from the liver, as well as a certain want of action on the part of the sweetbread, the functions of which

will be presently described. The result is an excess of sugar-supply inducing a much enfeebled condition of body, associated with kidney-trouble, represented by a very much increased flow of urine. The origin of this disease is still undetermined, but it would appear to arise from some defect in the working of the nervous system taking the shape of a lack of control over the liver and its sugar-producing functions; a duty carried out by some nerve centre specially devoted to the regulation of the function in question.

THE BILE.—Bile is to be regarded as waste matter which the cells of the liver have separated from the blood. The liver may thus be ranked with the skin, lungs, and kidneys, as an organ which tends to deal with a certain proportion of the waste which is inseparable from the wear and tear of life. Bile is a dark greenish-coloured fluid of a complicated character. It is, as we have seen, a waste product made useful. Poured on the food, it exerts a special digestive action on the fats of the food, breaking down the globules of the fat, emulsifying them and thus rendering them more readily incorporated with other foods and also more readily absorbed. Bile also exercises on the food a certain antiseptic action preventing the food in the intestine from undergoing injurious changes, whilst a third function, that of stimulating the movements of the intestine, may be attributed to it. We see a lack of this stimulating action, when, on account of the deficiency of bile, constipation becomes a marked symptom amongst other signs of digestive irregularity.

THE SWEETBREAD.—The *sweetbread* or *pancreas* lies below and in front of the stomach. It is an organ in shape somewhat resembling a dog's tongue,

the tip of the tongue lying to the right side of the body. The duct or tube of the sweetbread leads into the intestine, and may join the duct of the liver itself. The sweetbread is an organ devoted to the secretion of the sweetbread or pancreatic juice, manufactured from the blood supplied to the cells of the organ. It is a clear fluid of complicated composition. At least four different ferments are contained in it. These are represented first by a substance known as *trypsin* which acts on the nitrogenous foods so that any of these foods which have escaped the action of the gastric juice of the stomach will be altered and changed into peptones in the intestine. A second ferment is that known as *amylopsin*, this substance acting as does the ptyalin of the saliva and changing starch into sugar. Here, again, we meet with an expedient of nature whereby starchy foods which may have passed unchanged into the intestine will be acted upon and duly converted into sugar by the sweetbread secretion. A third ferment, called *steapsin*, acts on fats, and therefore must assist the work of the bile, whilst a fourth ferment is known as *rennin*, this last curdling milk. The sweetbread secretion derives its importance from the fact that it is the only digestive fluid which can act upon all kinds of food, nitrogenous and non-nitrogenous alike. Recent researches seem to show that the sweetbread also manufactures what is called an internal secretion not meant to be poured upon the food, but to be passed into the blood. It is supposed that this latter ferment tends to destroy or otherwise to change or utilise sugar which has passed into the blood. Hence in cases of diabetes, already mentioned, it is supposed that where this internal secretion of the sweetbread fails

to act, the excess of sugar in the blood is likely to attain great dimensions and thus to constitute a very serious phase in the history of cases of diabetes.

ABSORPTION.—We have now arrived at the close of the digestive journey. Reviewing the stages through which the food has already passed, we have noted that a considerable amount of the nutriment
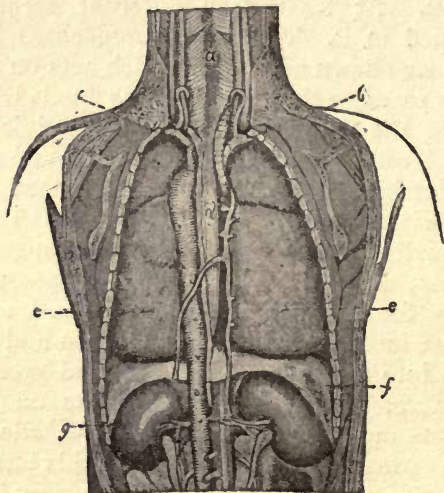

Fig. 12.—SECTION OF BODY

Showing (*a*) windpipe; (*b*) junction of thoracic duct; (*c*) junction of right duct with vein in neck; (*d*) aorta, or main descending artery; (*e e*) lungs; (*f*) diaphragm; (*g*) kidney.

has already been conveyed into the blood. Thus peptones early left the stomach and reached the blood through the liver, supplying nitrogenous foods to the circulation and thus placing them quickly at the service of the body. Sugar from the intestine, we saw, passes up the portal vein and is dealt with

by the liver. At the close of digestion the food, which receives the name of *chyle* (it is called *chyme* when it leaves the stomach), must therefore consist largely of fats, and this is found to be really the case. The chyle is a fluid resembling milk in appearance. It is absorbed from the intestine by a delicate series of vessels which take their origin in little projections on the walls of the intestine called *villi*. Passing through the cells forming the outer wall of these projections, the chyle is conveyed by the absorbent vessels already mentioned to a tube termed the *thoracic duct* (Fig. 12) lying on the left side of the spine. Received into this tube, the chyle is passed upwards, and ultimately we find the thoracic duct ending in a large vein at the root of the neck on the left side (Fig. 12). At this point we may regard in one sense as situated the junction between the food and the blood. The absorbent system of vessels, however, has other duties to discharge in addition to that of bringing chyle from the digestive system to the blood. All through the body we find delicate absorbent vessels termed *lymphatics* (Fig. 13). They are found to carry a clear fluid known as *lymph*. This fluid really represents colourless blood, and the lymphatics receive this lymph as the overflow of the blood which has escaped from the finest bloodvessels of the body so as directly to nourish the most minute structures of the body. As the absorbent vessels carry this lymph back to the thoracic duct and to a smaller and neighbour duct situated at the right side of the spine (Fig. 12), the ultimate destination of the lymph is seen to be the blood current, and into the blood stream it is ultimately poured. The body is thus seen to be nourished from two sources, first from the food we eat, and second from the lymph, which,

representing the excess of blood-supply, is gathered up from every part of the frame and returned to the circulation. What are known as *lymphatic glands* exist in various parts of the body, and are connected with the lymphatic system of vessels or *absorbents* as they are also called. We find these glands prominent in the sides of the neck, in the arm-pits (Fig. 13), in the groin, and in other parts of the
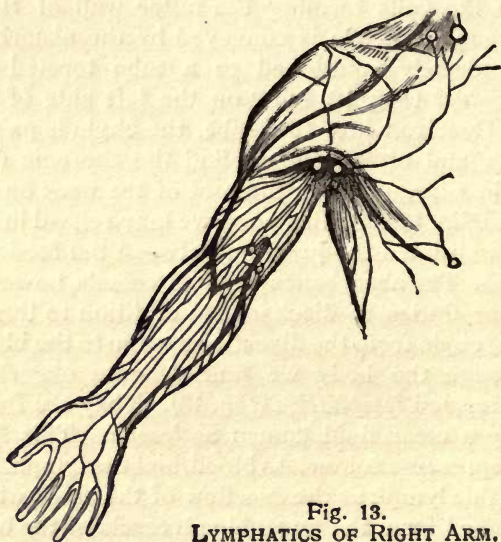

Fig. 13.
LYMPHATICS OF RIGHT ARM.

body. Lymph passes through them on its way back to the circulation, the duty of these glands being to elaborate it and thus to fit it more perfectly for being added to the blood by way of assisting in the repair and renewal of that fluid.

THE SPLEEN.—The spleen situated to the left side of the stomach may be regarded as a " blood gland," and as therefore closely related in its nature

to the lymphatic glands which have already been described. It is one of the ductless glands of the body, that is to say, it possesses no tube or duct issuing from it like the liver or sweetbread, and therefore does not elaborate any secretion to be poured into the digestive tube or other system of the body. But the spleen is well supplied with bloodvessels. A very large artery enters it and a very large vein leaves it, so that a continuous current of blood is always passing through this organ. It is found that the blood leaving the spleen has a larger number of white cells or corpuscles than the blood which enters it, so that we may regard the spleen as a manufactory of the white corpuscles in question. Furthermore, it would seem that in the spleen the old worn-out red corpuscles of the blood are disposed of, because examination of the spleen substance seems to show these corpuscles in all stages of breakdown. Some authorities are of opinion that the spleen also aids in the manufacture of red corpuscles, although these latter are known to be elaborated in other organs of the body. The spleen, it may be added, is capable of being removed from the body of animals without their existence being materially impaired. The explanation is to be found in the idea that, as the spleen is really a lymphatic gland, its absence is compensated for by the work of the other glands of the system to which it belongs.

CHAPTER IV

THE STORY OF THE HEART

THE CIRCULATION.—In order that the nourishment obtained from the food should be duly placed at the service of every organ, tissue, and cell of the body, it must be duly circulated through the frame. This function we find accordingly to be performed through the medium of the heart as a central pumping engine, and by the bloodvessels or tubes which are directly or indirectly in communication with the heart itself. The blood, as the common currency of the body, must find its way to every nook and corner of the system, and we shall note that a very perfect mode of distribution of the nutrient fluid is secured by the arrangements to be presently described as existing in the shape of the heart and bloodvessels. It is of importance to note in the first instance that it is a "circulation" of blood we are dealing with, and not a mere flow. The difference between these two things is obvious. If we stand on the banks of a river and watch the water passing us, we note that the water will not return again, but will flow to the sea or lake in which the river ends. Circulation, on the other hand, implies a return of that which is circulated to the starting-point, or at least includes a journey or cycle which tends in a sense to repeat itself. In the case of the distribution of blood through the body, the idea of a circulation is really represented; for if we

could trace one blood particle from any portion of
the circulation we should find that in course of time
it would return to the starting-point, and this
circulation would continue until the particle was
worn out or otherwise disposed of.   The meaning of
this circulation and the purpose it is intended to
serve become clear when we reflect on the manner
in which the body has to be nourished, and the
necessity which exists for the waste matter to be
carried to the organs devoted to its excretion or
removal from the body. ⁄ Pure blood is sent out by
one side of the heart (the left) to nourish the body,
and is everywhere circulated through the tissues.
In order, however, to allow the outgoing stream of
blood to reverse its course, it passes into vessels
which carry it away from all parts of the body and
which end in the *right* side of the heart.   This latter
side propels the blood to the lungs, where it is puri-
fied.   The blood, in its return journey, has gathered
impurities and waste matters from the tissues, and
it is these matters which in greater part are excreted
by the lungs, the skin, and kidneys, the liver, as
we have also seen, bearing its share in this work.
The purpose of the circulation of the blood may be
summed up in the statement that the blood so
distributed provides nourishment for the body, and
in its early history provides material for growth.
In the second place heat is distributed through the
body by the medium of the blood, whilst in the third
place material is provided to the various glands for
the purpose of enabling them, as we have seen, to
manufacture the various fluids or secretions of use
in the body.   A fourth use of the circulation is to be
found in its acting as a drainage system, in that, when
loaded with waste matters it is returned to the lungs

in order that the results of the bodily wear and tear with which it has become encumbered should be duly excreted.

THE COURSE OF THE CIRCULATION.—The course followed by the blood in its circulation may be appropriately described at the present stage of our enquiries. Pure blood, returned from the lungs, enters the *left auricle* (Fig. 14) of the heart, which is the smaller and upper chamber of that side, t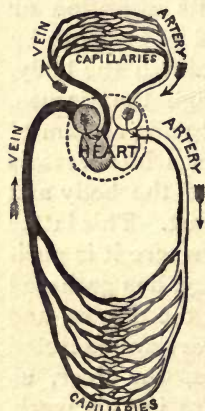he auricle acting as a receiver of the blood. From the auricle the blood passes directly to the *left ventricle*, this last being the pumping chamber, and by the contractions of this cavity of the heart blood is sent throughout the whole body conveyed by the arteries. Becoming impure in the body the blood is returned to the *right auricle* of the heart, whence it passes to the *right ventricle*, which in turn sends it to the lungs for purification. From the lungs the purified blood passes to the left auricle, and once more resumes its circulatory journey. In connection with the circulation we have to note the *bloodvessels* or tubes which are employed to distribute blood through the body.

Fig. 14.—DIAGRAM OF THE COURSE OF THE CIRCULATION

Impure blood is represented by the black tint.

ABOUT THE BLOODVESSELS.—The *arteries* (Fig. 14) are bloodvessels which are in direct communication with the left side of the heart, and into them the left ventricle is perpetually pumping pure blood for

conveyance over the body. An artery is a vessel possessing a fairly well developed coating of muscular fibres in its walls. It is therefore a more or less elastic tube, and offers little resistance to the wave of blood propelled along its length at each stroke of the heart. The muscular coating of the artery, serving to produce the contraction of the tube, assists the work of the heart, and it is the pulsation which is set up by the wave of blood propelled in part by the contraction of the blood-vessels themselves which gives rise to the phenomenon known as the *pulse.* A "pulse" can be found in every artery of the body, but it is most definitely felt at the wrist about an inch or so above the base of the thumb on that particular side of the arm where an artery called the *radial artery* lies near
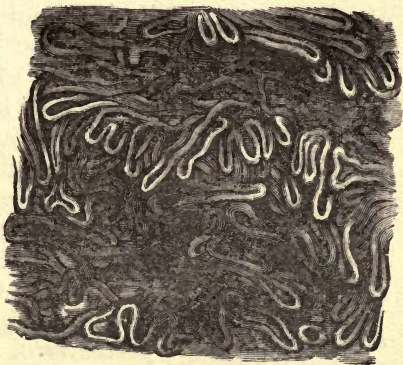

Fig. 15.—Capillaries of the Skin.

the surface of the body. To count the pulse is of course a familiar and convenient fashion of ascertaining how fast the heart is beating. If we trace any artery sufficiently far in its course we find it to divide and sub-divide until we reach branches so fine that they can only be seen by aid of the microscope. A very perfect view of these finest divisions of the arteries called *capillaries* (Fig. 15) can be obtained by observing the web of a frog's foot under

the microscope. These capillaries are the finest bloodvessels of the body, and convey the blood to the most minute cells and tissues. The blood itself passes through the fine walls of the minute bloodvessels, and thus comes directly in contact with the parts it is intended to nourish (Fig. 16). This fact has already been noted in the section dealing with the work of "absorption." The circulation is, however, continued beyond these finest bloodvessels onwards into another and different set of vessels known by the name of *veins*. Thus arteries end in capillaries, and veins begin in them. As the veins leave the further parts of the body they tend to become larger and larger, receiving branches in their course, and at last ending in two large vessels which return blood from the lower and upper parts of the body respectively, these large veins entering the right auricle of the heart. Another large vein, the *portal vein*, as we have seen, returns blood from the digestive organs and carries it to the liver for purposes already mentioned. We have thus three sets of bloodvessels concerned in the distribution of blood through the body, namely arteries, capillaries, and veins. The blood is naturally pumped by the force of the left side of the heart through the system of arteries and capillaries, the flow of blood slowing down in the capillaries just as the force of a river current is much lessened when

Fig. 16. — CAPIL-LARIES AND BODY CELLS

The blood fluid passes through the capillary walls and nourishes the cells.

the river begins to flow out over level ground into
a larger number of small channels. The circulation
in the veins, that is, the return of the blood
to the right side of the heart, is due to various
causes. There is first of all the force of the blood
which is perpetually being sent out from the left
side of the heart, each oncoming rush of blood, so to
speak, forcing onwards, and, in the case of the lower
part of the body, upwards, in the veins, the blood
which has preceded it. Again, the muscular move-
ments of the body compressing the veins, assist the
return of the blood, any tendency to backward flow
being prevented by the presence in these vessels of
pocket-like valves. The mouths of the pockets open
towards the heart, so that whilst blood easily passes
in that direction, any back-flow fills the pockets,
which, meeting in the middle, offer an obstacle to
regurgitation of the blood.

THE BLOOD.—With regard to the chemical com-
position of the blood we find that it contains a large
proportion of water, so much nitrogenous or proteid
matter held in solution, this matter being derived
from the food, and a certain amount of mineral
matter in addition. Blood when drawn from the
body gives us an idea of its physical characteristics
and composition, for it then separates ultimately
into two parts, the clot which falls to the bottom of
a vessel, and a layer of straw-coloured liquid which
rises above. This liquid is termed *serum*, the clot
consisting of the corpuscles of the blood which are en-
tangled in a substance apparently developed when
the blood is removed from the body, and known as
"fibrin." An old experiment taught that if fresh
blood from an animal was switched with willow
twigs it did not clot. The reason for this change in

the behaviour of the blood is explained by the fact that the switching removes fibrin from the blood, this substance being found in the shape of whitish jelly-like threads attached to the twigs. Blood, therefore, may be said to consist of two parts, a fluid part to which the name of *plasma* is given, and solid parts represented by the *corpuscles* of the blood which are of two kinds, *red* and *white*. The plasma of the blood may be regarded as the real blood, for it contains the substances which are essential for the nourishment of the body. The corpuscles, however, have also their highly important uses. A speck of blood pressed between two thin plates of glass and examined microscopically, shows the clear plasma of the blood liquid, whilst floating in it are innumerable corpuscles (Fig. 17). Blood may be regarded therefore as really a clear fluid, seeing that the blood liquor, or "plasma," is itself colourless. It owes its red colour to the immense number of red blood corpuscles which float in the blood liquid. Blood might in this way be compared to water in a ditch in summer which appears green in colour to the eye. It is not really green, because if some of this water be viewed in a tumbler the clear water itself is seen, and the green colour is then perceived to be due to the infinite number of small green plants which float in it. So with the blood; its colour is due to the immense number of red corpuscles, and it is only when the blood is microscopically treated as described, that the eye is capable of

Fig. 17.—BLOOD CORPUSCLES.

(*a*) red corpuscles in rouleaux; (*c* and *d*) white corpuscles.

perceiving the clear fluid in which the corpuscles float.

THE BLOOD CORPUSCLES.—Two kinds of *corpuscles*, it has been noted, exist in the blood, the red and the white. The red (Fig 18) are far more numerous than the white, the proportion on the average being 1 white to 600 or 700 red, although after meals the proportion of white corpuscles appears to be increased, but soon apparently lessened down to the amount just stated. The size of a red corpuscle may be set down on the average at about the 1-3,200th of an inch in diameter; a white corpuscle is somewhat larger, about the 1-2,500th of an inch across. Very important differences are to be noted between the white and red corpuscles. not merely in respect of their nature, but
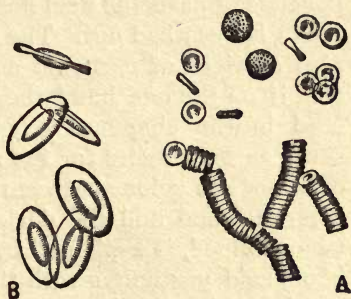

Fig. 18.—DIFFERENT RED BLOOD CORPUSCLES.

(*a*) those of man; (*b*) those of a frog oval and nucleated, that is, having a central particle.

also with reference to the duties they perform. The red corpuscles contain a substance called *hæmoglobin* which contains a very appreciable amount of iron. This substance may be regarded as therefore giving colour to the blood, and the value of iron administered as a blood tonic, therefore finds in the fact just related full justification. The hæmoglobin of the red blood corpuscles readily combines with oxygen gas, the all-important element we breathe in from the atmosphere, this gas being readily parted

with to the tissues; for in the absence of oxygen no vital action can be performed and no other food utilised. We thus discover that the great function of the red blood corpuscles is that of acting as the oxygen carriers of the blood, so that this gas may be perpetually conveyed to every tissue of the body. The red blood corpuscles discharge yet another duty. It has been shown that the blood gathers waste material from the tissues, this waste representing the result of bodily wear and tear. A part of this waste consists of carbonic acid gas, which, conveyed to the lungs, is breathed out. The red blood corpuscles are also carriers of carbonic acid gas to the lungs, so that if on the one hand they act as distributors of food in the shape of oxygen, on the other they serve as scavengers for the removal of waste. The difference in colour between the light red of pure or arterial blood and the darker colour of impure or venous blood, is explained by the fact that when carbonic acid gas unites with the hæmoglobin a darker hue is produced.

Fig. 19.—A White Blood Corpuscle of Man
SHOWING HOW IT ALTERS ITS SHAPE.

THE WHITE CORPUSCLES.—The white corpuscles are microscopic bodies of very different nature from the red. Each white blood corpuscle is in fact *a living cell*, and as such, possesses a kind of semi-independent existence in the blood in which it lives. Studied under special conditions by the microscope, a white blood corpuscle is seen to move through the

contraction of the protoplasm, or living matter of which it consists, across the microscopic field (Fig. 19). If it comes in contact with any solid particle, the living body of the white blood corpuscle will surround and engulf the atom, and in many cases will devour or dispose of it. This action introduces us to the real function of the millions of white blood corpuscles contained in the blood of a single person. They may be described as the sanitary police force of the body. It is known that when foreign particles, especially in the shape of germs, gain admittance to the tissues, a rush of white blood corpuscles takes place to the point of infection. They are capable of pushing their way through the thin walls of the finest blood vessels and of thus coming face to face with the enemy that has literally invaded their gates. A battle takes place between the invaders and the defenders, and in many cases, though not in all, the white blood corpuscles by massing together and bringing their serried array well to the front, are able to dispose of disease germs and like particles which otherwise would tend to inflict injury in the shape of disease upon the body. Occasionally, however, defeat awaits these wonderful little defenders of the living domain. In the latter case, when defeated, they die, and the frame thus lies at the mercy of the invading microbes. A study of the process known as *inflammation* has revealed other curious facts regarding the white blood corpuscles. When inflammation occurs we find in that process, not one of disease as is commonly supposed, but rather an action which represents the body's attempt to defend itself against invasion of disease producing germs. The white blood corpuscles or " phagoctyes " as they are also called, issue forth from the minute bloodvessels in large numbers, and the symptoms

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of inflammation really represent the signs of con-
flict which is being waged in the bodily domain. If
the white corpuscles be defeated and the inflammation,
instead of being allayed and subsiding, proceeds to
the length of suppuration, (that is the formation of
pus or *matter*), we discover that "matter" really
consists of the dead bodies of the defeated white cor-
puscles. As such it may constitute, like the soldiers
left dead on a battlefield, a source of danger to the
territory around, and may set up disease in other
parts of the body. Such is the history of the white
blood corpuscles which practically in all animals thus
appear to discharge the duty of a sanitary force, ever
on the alert to combat invasion of the body by disease-
producing particles.

THE HEART.—By a somewhat circuitous route we
have at last returned to the central system of the cir-
culation, the heart itself. Any heart, from that of the
insect to that of man, may be described as a hollow
muscle. It is hollow to receive blood, and it is mus-
cular that it may contract to expel that fluid in the
proper directions. There is thus no mystery about
the heart and its action. The same form of energy
by which we move our fingers, arms, or legs, repre-
sents the force which circulates the nutrient fluid
through our frame. A glance at the heart of a bul-
lock in a butcher's shop will at once show us that its
substance is similar to the animal's flesh. Both are
composed of muscle with this difference that the
heart is composed of *involuntary muscle fibres*, that
is, it acts independently of the will, whereas the or-
dinary muscles of arms, legs and so forth, are termed
voluntary because they can be brought into action
when we desire movements to be performed. At the
same time, the heart can be affected, as will be seen,

by and through the medium of the nervous system, with which it exists in very close and intimate relationship. A plain but sufficiently correct idea of the heart may be gained by comparing it to two semi-detached houses. In other words the heart is completely divided into two sides. As there is no possibility of the tenant in one of the houses visiting his neighbour through the partition wall, so no blood can pass directly from one side of the heart to the other. Each side of the heart, as we have seen, consists of two chambers, called *auricle* and *ventricle*, and we have also noted that it is the duty of the left side of the heart to propel pure blood everywhere through the body, the function of the right side being to send impure blood brought to it by the veins to the lungs for purification. Having regard to the duties performed by the two sides of the heart we see that the left side (Fig. 21) has by far the greater share of the work to do. Hence, as might be expected, the left heart is the much stronger side of the two, its muscle being three or four times the thickness of that of the right side.

THE WORKING OF THE HEART.—In studying the manner in which the heart works we find that the two auricles contract together, and the two ventricles similarly act in unison. Each cavity of the heart has to dilate to receive blood, the auricles from the bloodvessels pouring blood into them, and the ventricles from the auricles themselves. The expansion or dilatation of the cavities receives the name *diastole*, whilst when each cavity of the heart contracts, that is, grows smaller, it naturally sends out its blood; the act of contraction being known as *systole*. Returning for a moment to the course of the circulation, we must bear in mind that as each auricle

contracts it sends blood below into its corresponding ventricle. As each ventricle contracts, the blood is sent out in the one case (left) to the body, in the other case (right) to the lungs. Having regard to these actions there dawns upon our minds the
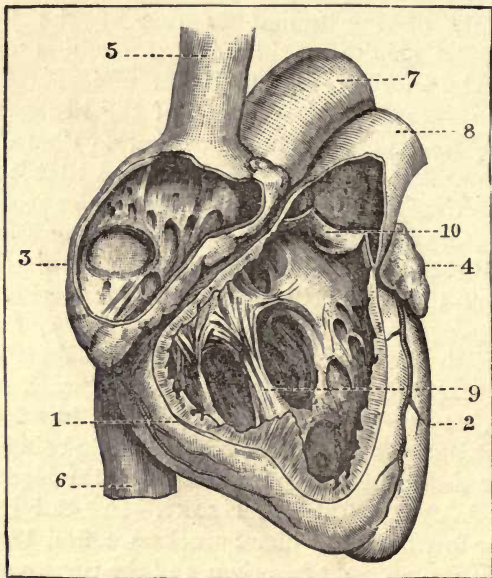

Fig. 20.—SECTION OF HUMAN HEART (right side).

(*1*) wall of right ventricle; (*2*) left ventricle; (*3*) right auricle; (*4*) appendix; (*5 and 6*) great veins opening into auricle; (*7*) aorta; (*8*) pulmonary artery leading to lungs showing valves (*10*); (*9*) cords of the tricuspid valve between auricle and ventricle.

necessity for some contrivance by way of preventing any reflux or back-flow of the blood in the wrong direction. When each ventricle contracts to send blood to the lungs or body, so much of the blood if not

duly prevented might return into the auricle. This reflux is prevented by the valves of the heart (Figs. 20 and 21) which constitute one of the most interesting points connected with the structure of that remarkable organ. There are two valves on each
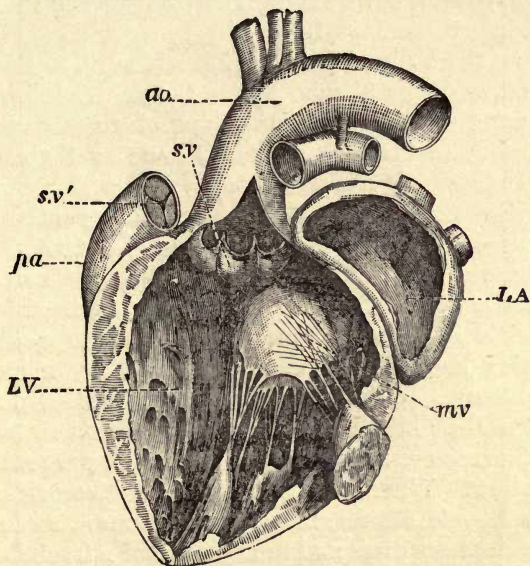

Fig. 21.—LEFT SIDE OF HEART OF MAN.

(*la*) left auricle; (*lv*) thick wall of left ventricle: (*mv*) mitral valve; (*pa*) pulmonary artery, and (*sv'*) its valve; (*sy*) semilunar valve of aorta (*ao*).

side of the heart, each valve being more or less a replica of its neighbour on the other side. On the left side we find a valve between the auricle and ventricle called the *mitral* or *bicuspid* valve (Fig. 21 *mv*), the neighbour valve on the right side being called the *tricuspid* valve (Fig. 20, *9*). Each of these valves may

be described as consisting of flaps of the heart's lining membrane, two flaps existing on the left side, and three on the right. These flaps hang down into the cavity of the ventricle, to the walls of which they are attached by thin yet strong cords (Fig. 20, *9*.) When blood passes downwards from the auricle into the ventricle, these flaps, falling down, are pressed closely against the walls of the ventricle and so allow the free downflow of the blood. When the ventricle is filled, the work of an instant, the flaps of the valves are floated up on the top of the blood so that their edges meet accurately and are brought into perfect apposition (Fig. 22, *a*), thus forming a complete partition for the time being between auricle and ventricle. The function of the cords attached to the flaps can now be understood. As the blood under the flaps of the ventricle is pressing upwards before the ventricle empties itself, these cords attached to muscular prominences on the walls of the ventricle (Figs. 20, *9*, and 22, *a*) pull the flaps down in opposition to the upward pressure of the blood and thus prevent any backflow. When the blood has left the ventricle and the ventricle dilates, the flaps once more assume a dependent position, and thus permit of a fresh flow of blood from the auricle above to the ventricle below. The action of these valves has been not inappropriately compared in a rough way to the effect of running water into an empty pond. The leaves of the duckweed lying in the pond are floated up by the inrush of the water, and in a similar fashion the flaps or valves are raised so as to constitute a perfect temporary partition between the two cavities of the heart. The other valves of the heart exist at the entrance to the great bloodvessels leaving each ventricle. They are called *semilunar valves* (Fig. 20, *10*) and consist

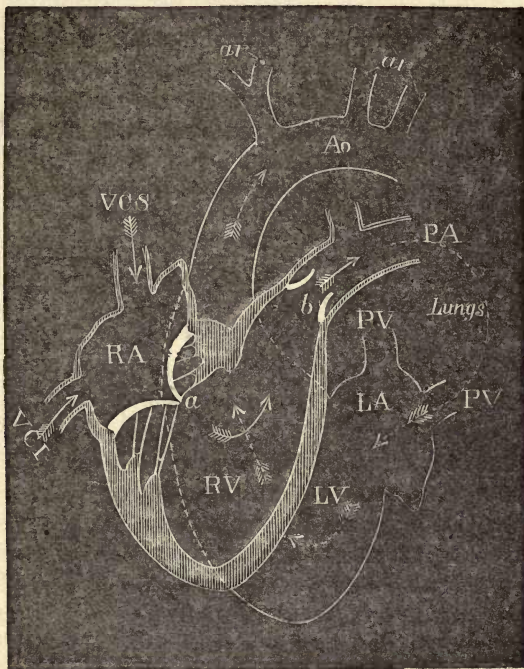of three pockets placed in a circle around the blood-vessel. The edges of these pockets being crescentic

Fig. 22.—DIAGRAM OF THE HEART'S ACTION.

The tricuspid valve (*a*) is shut, and the semilunar **valve** (*b*) is open to allow blood to pass to lung. The valve (*a*) keeps blood from passing back into the auricle (*ra*). From the lung purified blood returns to the left auricle (*la*) by the pulmonary veins (*pv*) passes into the **left** ventricle (*lv*) and out to the body through the aorta (*ao*). (Note the cords which in the valve (*a*) prevent **the flaps** from floating up into the auricle.)

in shape have given rise to the term "semi-lunar" or "half-moon" shaped. These valves are somewhat

similar to those already described as existing in veins. The mouths of the pockets open away from the ventricle, and the passage of blood from the ventricle into the blood vessel is therefore unfettered (Fig. 22 *b*), because the blood rushes past the mouths of the pockets. If, however, any back flow or reflux of the blood takes place, the pockets fill and their edges meet in the centre and oppose a barrier to the regurgitation of the blood whose flow they regulate.

The Heart's Beats.—If we place our ear over the heart of an individual we become conscious, after a little accurate observation, of two distinct sounds. These sounds it will further be observed show a certain rhythm in that they proceed in pairs. The first sound is long and loud, the second is short and sharp. The sounds as heard may be imitated fairly by pronouncing the words "lŭbb" and "dŭp." It is of great importance to note the meaning of these sounds, inasmuch as in the case of the physician his power of diagnosing heart trouble must depend largely on his familiarity with these sounds in health and in disease. The first sound appears to be caused by the action of the valves between the ventricles, whilst certain authorities are of opinion that the mere contraction of the ventricles also aids in producing it. The second and shorter sound is undoubtedly produced by the closure of the semilunar valves. The marvellous feature connected with the work of the valves of the heart is that of their instantaneous action, and moreover in their perfect working, it may be, during a long lifetime. What takes even a limited space of time to describe is accomplished in the heart instantaneously, these valves acting practically as often as the heart beats.

Does the Heart Rest?—Oliver Wendell Holmes in one of his poems, speaking of the work of the heart, says:—

> "No rest that throbbing slave may ask,
> For ever quiv'ring o'er his task."

This poetically expressed opinion, that of an anatomist and physiologist by the way, is very far from the truth.   No organ of the body works perpetually. Even if its action, as in the case of the liver, is more or less of a continuous character, there are nevertheless periods during which the action is lessened and slowed down, and in this way a period of comparative rest is represented.   In the case of the heart it may be said that it rests practically as much as it works, its periods of rest being equal to those of its activity. It can be shown that if we suppose one single round of the heart's work to be represented by a circle, an accurate division of this circle would show that each interval between the sounds corresponds exactly to the sounds themselves in extent.   The sounds we have seen proceed in pairs.   The first sound is succeeded by a short pause, the second sound next occurring.   A longer pause exists between the second and the next first sound representing the beginning of the next pair of sounds.   Measured accurately the duration of the pauses equals the duration of the sounds.   Rest is therefore in the case of the heart equal to work; only the heart is in the position of a workman whose duties enable him to take short spells of rest between short spells of labour.   The amount of energy expended in the circulation of the blood by the heart has been accurately measured.   Knowing the force which the heart exerts in a single round of its duties it is a mere matter of multiplication to arrive at an estimate of the amount of work performed

by the organ in say twenty-four hours. This amounts to what in scientific language is called one hundred and twenty foot-tons of work. Put in plain language this statement means that if all the work expended by the heart in twenty-four hours could be gathered up, concentrated, and applied to a huge lift, it would raise one hundred and twenty tons one foot off the ground.

THE HEART AND THE NERVOUS SYSTEM.—It is a familiar fact of life that the movements of the heart are influenced by our emotions. The poet speaks of the " pulse of hope," and it is undeniable that when an individual is happy, contented, and healthy, his heart beats freely and with vigour. On the other hand, the play of a different emotion, such as grief, acts in the opposite direction. The heart beats then become of a slower character, and the circulation is carried on less vigorously. The heart is well under the control of the nervous system, but it is necessary, in order fully to appreciate the relations between the two sets of organs, to remind ourselves that in addition to the brain system, composed of the brain itself, the spinal cord, and the ordinary nerves of the body, a second nervous system exists in the shape of the *sympathetic system* which lies in front of the spine. This latter system controls actions in the body which are independent of the will, and amongst other duties it performs, it is responsible for controlling the ordinary work of the heart. Four sets of nerves are concerned with the heart and its regulation. Imbedded in the substance of the heart we find masses of nerve cells belonging to the sympathetic system, termed *cardiac* or *heart ganglia.* These represent the heart's own little government system, so that we might very well compare the organ to a territory like

the Isle of Man which illustrates the Home Rule
principle in that it possesses its own House of Keys,
regulating its local affairs. These ganglia are respon-
sible for keeping the heart duly at work. The muscle
of the heart requires to be stimulated to action like
every other muscle of the body, and so we discover
that the sympathetic system, represented by these
detached parts in the heart substance, will duly super-
vise and control the ordinary actions whereby the
the blood is circulated. Connected with the heart we
find a branch of the sympathetic system passing
into the heart and connecting itself with the cardiac
ganglia just mentioned. Also from the brain sys-
tem a branch of a very large and important nerve
known as the *vagus* is also connected with certain of
the ganglia of the heart. The meaning of that ap-
parent dual control over the heart's action becomes
clear when, as the result of experiment, it is shown
that whilst the sympathetic nerves stimulate the
action of the heart and quicken it, the vagus nerve
acts in the opposite direction and tends to slow the
heart's movements. We thus discover that provision
is made for the perfect control of the heart in health.
If circumstances arise when it is necessary for the
heart's work to be increased, the sympathetic nerve
will effect this end. If, on the other hand, the heart
requires to be slowed down, the vagus nerve will then
come into play.

THE RELIEF OF THE HEART.—So far a very com-
plete nervous control is exercised over the central
organ of the circulation. There yet remains, however,
a fourth nerve which demands attention. This nerve,
it was discovered, instead of conveying orders from
the central nervous system, carries messages in the
reverse direction. In other words, its purpose is to

give warning to a particular part of the nervous system situated in the brain of necessary modification to be made in the heart's labours. Thus, if the right side of the heart particularly be somewhat fagged in its work, and if heart fatigue begins to be represented, a message passes along this fourth nerve, to which the name of *depressor* or *relief nerve*, may be given. The message is conveyed to the nerve centre which regulates the bloodvessels, The result of what may be called an appeal for help or relaxation of its duties on the part of an overworked heart, received by this centre, is at once reflected or sent forth to the bloodvessels of the body and especially to the large bloodvessels in the neighbourhood of the heart itself. The result is that these vessels are made to expand widely, and as it is obviously easier for the heart to propel blood through wide channels than through narrow and contracted ones, relief as in the case of sudden fatigue of the heart is thus obtained. No better example in the whole body of an accurately acting and self-governing mechanism can be obtained than that just described whereby the heart contrives to gain relief under conditions of strain and stress.

CHAPTER V

THE STORY OF THE LUNGS, SKIN AND KIDNEYS

THE WORK OF THE LUNGS.—The function of breath-ing, or *respiration* as it is also termed, is discharged in the body with a double aim in view. Even a casual study of our breathing movements reveals at once the fact that by the one movement, *inspiration* or breathing in, we inhale air from the atmosphere, and by the succeeding and opposite movement of *expira-tion* or breathing out, we exhale air from the lungs. A very casual examination of the difference between the air breathed in and that breathed out further serves to show that the two movements represent two distinct phases of the work of the lungs. We breathe in atmospheric air, the composition of which will be presently noted, whilst we breathe out in addition to the air, somewhat altered in its composition, certain other matters representing part of our bodily waste. By inhaling air we supply the body with the oxygen gas, which has already been noted to be essential for all the processes of life, this gas being conveyed with the pure blood circulated through the body to every cell of the frame. On the other hand the matters breathed out from the lungs include air which shows a far larger proportion of *carbonic acid gas* than the air breathed in, whilst the exhaled air is found like-wise to be loaded with *watery vapour* and also *to be much warmer* than the air which is inspired. We thus learn in the first place regarding the duties of

the lungs that whilst inspiration is really the act of feeding the tissues with oxygen, expiration is an action devoted to ridding the body of part of the inevitable waste which attends the continual work of life. If we breathe through a tube into a bottle of lime water we find clear evidence that carbonic acid gas is given forth after each act of expiration. For the water becomes milkier the longer we breathe into it, and ultimately a white precipitate falls down in the bottom of the vessel, this substance being chalk. It has been formed by the addition of carbonic acid to the lime of the water, chalk being chemically known as carbonate of lime. To demonstrate that the air given from the lungs is warmer than the air we breathe in, is an easier matter still. We have only to breathe on a cold pane of glass to notice the obscuring of the service, whilst such a simple experiment also proves to us that water is exhaled in the breath in the form of vapour which condenses on the glass, a phenomenon familiarly seen in every crowded railway carriage, the windows of which are closed. The function of breathing has therefore to be defined as a double one in which the nutrition of the body is served in the first instance, and the waste of the body partly excreted in the second.

ABOUT AIR.—The air we breathe is a mixture and not a chemical compound of two gases, *oxygen* and *nitrogen*. Roughly speaking there are about twenty-one parts of oxygen to seventy-nine parts of nitrogen in a hundred parts of air. Absolutely pure air has this composition, but ordinary air, which may for practical purposes be regarded as pure, contains in addition other elements. A certain amount of carbonic acid is comprised in all air save the very purest, but where the quantity of this gas does not amount

to more than four parts in 10,000 of air, the purity of the air may be taken for granted, that is, having regard to its being safe for breathing. When on the other hand the quantity of carbonic acid gas mounts up, as it does in close and confined places, the air then becomes deleterious to health. In ordinary air a variable amount of watery vapour is always found, and in very pure air, especially that of the mountain and the sea, *ozone* occurs, this last being a very active form of oxygen presumed to have stimulating effects on the body, and therefore credited with giving to mountain air and that of the ocean, their invigorating properties. The air in addition contains a certain amount of suspended matter in the form of invisible dust. This dust becomes visible under certain circumstances as when a beam of electric light is sent under certain conditions through air, and we can realise the immense amount of floating dust which ordinary air may contain when in a darkened room we see countless motes and beams dancing in the track of a beam of sunlight passing in through a clink in the closed shutters. Much of this dust consists of mineral matter, but a certain proportion has to be ranked under the head of *organic matter*, that is, matter either itself alive or derived from living bodies. The living dust of the atmosphere is represented by *germs* or *microbes* of various kinds, many of them harmless, some of them undoubtedly disease-producing. A certain amount also of dead material is represented in the air, consisting of the worn out cells and particles derived from animal and plant bodies. It may be added that from the lungs with each breath there is also expelled, in addition to heat, water and carbonic acid, a certain amount of organic matter representing the worn out tissues and particles

brought from all parts of the body, and in part
derived from the lungs themselves.

VENTILATION.—One of the great problems of human
life is to secure an adequate and a constant supply of
pure air. This task is much more difficult than
might at first sight be supposed. Our rooms and
abodes as constructed in modern times rarely pre-
sent facilities for securing free and perfect ventila-
tion, that is without exposing us to injurious draughts
and so exposing us to risks of cold and chill. The
problem of ventilation can only be adequately solved
in a scientific fashion by mechanical means whereby
through the use of ventilating fans fresh air is
brought in and the foul air expelled. Such means
are, of course, not applicable to ordinary dwellings,
and therefore we have to fall back in the latter case
on simple and crude expedients, represented by the
opening of windows or the fixing of ventilators which,
however well they may act in theory, rarely come up
to the expectations of their inventors in the matter of
practice. One of the most simple fashions in which
a room may be ventilated at practically no cost at
all, is that of raising the bottom sash of a window
four or five inches and of placing in the open space a
bar of wood on which the lower sash rests. The
result of this arrangement is to raise the top of the
bottom sash above the bottom of the upper sash.
Air comes in between the two sashes with much less
draught than is the case when the window is simply
drawn down from the top. Outlet ventilators may
be placed near the ceiling, the ordinary form of these
ventilators allowing air to pass out into the chimney,
whilst the smoke is prevented by a valve arrange-
ment from entering the room. Such ventilators, how-
ever, only act when the pressure of air in the room

is greater than that represented in the chimney. The open fireplace, although an extremely wasteful appliance in the matter of coal consumption seeing that a very large proportion of the heat passes up the chimney, nevertheless possesses the advantage of assisting materially the ventilation of a room. A current of air passing up the chimney displaces so much of the air in the room which is renewed from the outside, and thus a certain circulation of air is maintained.

AIR QUANTITIES.—Allusion has been made to the difference between the composition of the air breathed in and that expired. We may assume that the air inspired contains in one hundred parts about twenty-one parts of oxygen, seventy-nine parts of nitrogen, and ˙04 parts of carbonic acid. On the other hand air which is breathed out has naturally its oxygen diminished owing to so much of the gas having been absorbed by the tissues, the amount being about fifteen parts. The quantity of nitrogen does not alter, this gas being inert, and serving apparently for the purpose of diluting the oxygen; whilst the carbonic acid given forth is naturally increased and is represented by other four parts in the hundred parts of air. Summing up the differences between air breathed in and air breathed out, we may say that the air breathed in contains much oxygen, little carbonic acid, a certain amount of watery vapour, and is of the temperature of the surroundings. That which is exhaled on the other hand contains less oxygen, more carbonic acid, is of the temperature of the blood from which it has passed, this temperature being 98˙4 degrees, and in addition contains a certain amount of the organic matter already noted. In a rough way it may be said that the air we expire contains five per cent less

oxygen, and five per cent more carbonic acid than the air inspired. The amount of oxygen consumed in twenty-four hours by an adult has been estimated at about eighteen cubic feet, this applying to a man at rest. The amount of carbonic acid gas given out might be figured forth from the carbon contained in a piece of charcoal weighing about nine ounces, whilst the amount of water given forth from the lungs in a day on the average may be set down at about half a pint. Concerning the amount of air inhaled at each breath thirty cubic inches may be regarded as the average quantity taken in at each inspiration. A like amount will be given forth with the outcoming breath, but by taking a deep breath an additional hundred cubic inches may be drawn into the lungs, this additional amount being expelled along with the thirty cubic inches represented as taken in by an ordinary inspiration. The amount inhaled in quiet breathing (thirty cubic inches) is called in scientific language, *tidal air*, from the suggestion that it represents the quiet inflow and outflow of the tide. The additional hundred cubic inches taken in a deep breath constitute *complemental air*, the corresponding amount expelled being called *supplemental air*. It must be noted, however, that over and above the deepest breath we can give forth, a certain amount of air remains in the lungs. This amounts to about one hundred cubic inches. It is termed *residual* or *safety air*, for the reason that it is required to prevent the chest and lungs from collapsing through the pressure of the external air.

BREATHING BAD AIR.—A great lesson in public and personal health may be taught us by the knowledge obtained regarding the necessity for securing a supply of pure air in order that our health and

physical welfare may be conserved. The story of the Black Hole of Calcutta is familiar to all. The results of breathing and re-breathing foul and fetid air contaminated by the waste products of human beings, received on that occasion an object lesson of historical kind. Other incidents have occurred to show the marked influence which a highly polluted atmosphere exercises in inducing effects of a serious nature leading to ill-health, and in extreme cases to death. Whatever difficulties exist in the way of procuring fresh air, it is at least something to realise its importance in the maintenance of health. One of the reasons for the large amount of public apathy which exists regarding the necessity for securing a pure air supply, is due to the fact that the effects of breathing polluted air are generally slow and insidious in their action on the body. We rapidly become accustomed to a foul atmosphere, and thus fail to appreciate the harm which is being done by our inhaling it. The experiment of Claude Bernard is well worth bearing in mind in connection with this topic. He placed a sparrow under a bell jar of a size calculated to contain sufficient air to keep the bird alive for three hours. At the end of the second hour a fresh sparrow was introduced into the jar, this second bird at once collapsing and dying on account of the impurity of the atmosphere produced by the first bird, but amidst which atmosphere the latter could live for another hour. This experiment, it is true, does not find its exact counterpart in humanity, but none the less is the grave lesson taught us that a supply of pure air is even more necessary for the preservation of health than pure food and pure water, in respect at least, that we are always breathing, whilst we are not perpetually eating and drinking.

THE LUNGS.—The lungs, two in number (Fig. 23), are contained in the cavity of the *thorax* or *chest*. This cavity is bounded by the spine and ribs behind, and by the breast bone and cartilages or gristly ends of the ribs in front. It is a highly elastic part of the skeleton, the elasticity being due largely to the presence of the rib cartilages just noted. The need for
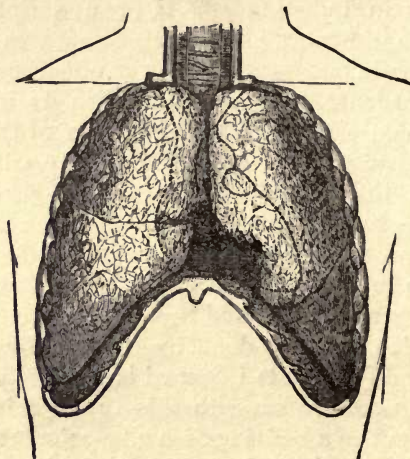

Fig. 23.—THE LUNGS IN POSITION VIEWED FROM THE FRONT.
They rest on the diaphragm or midriff. The heart is shown in outline.

elasticity can be appreciated when regard is had to the constant movements the chest exhibits in the act of breathing. The lungs are suspended freely in the chest and communicate with the cavity of the mouth and with the air by means of the *trachea* or *windpipe* (Fig. 24) at the upper part of which we find situated the *larynx* or organ of *voice* (1). The windpipe is kept open and patent by the pressure of gristly rings which can easily be felt in the front of the throat.

Free movement of the neck is thus permitted, whilst the passage of air to the lungs continues uninterruptedly. The heart lies between the lungs (Fig. 25), a situation admirably adapted for the easy maintenance of the close relationship we have already noted to exist between the two organs. The chest is lined
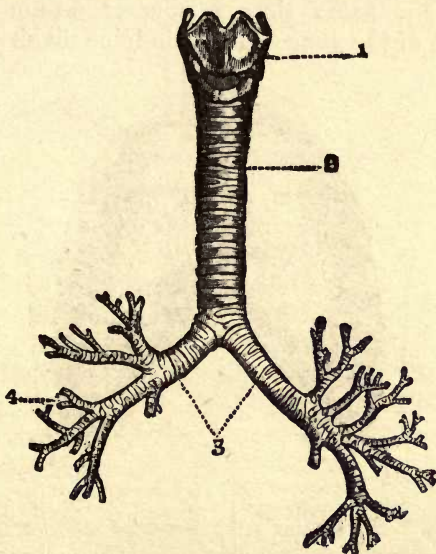

Fig. 24.—LARYNX OR VOICE BOX, TRACHEA AND BRONCHI.

(1) larynx; (2) windpipe or trachea; (3) bronchial tubes or main divisions of windpipe in lungs.

and the lungs covered with a delicate smooth and glistening membrane called the *pleura*. In the movements of the lungs in breathing it is therefore the layer of the pleura covering the lung which moves smoothly on the layer lining the chest. A little fluid secretion is perpetually thrown out between the

two surfaces of the pleura and undue friction is thus obviated. With regard to the structure of a lung it may be described as a bag of *air cells*. If we follow the track of the air breathed in we may readily become acquainted, not merely with the actual destination of the air, namely the blood current, but also gain at the same time a correct notion of the structure of the lung. The windpipe divides at the
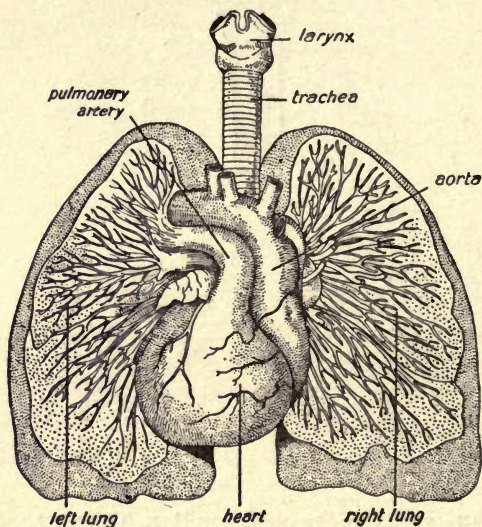

Fig. 25.—THE RELATIONS OF HEART AND LUNGS.

root of the neck into two main branches, each called a *bronchus* (Figs. 24 and 26). The main division passes into the lung of its own side and immediately begins to divide and sub-divide into smaller and smaller branches which are known as *bronchial tubes* (Fig. 26). The windpipe and bronchial tubes are lined by a delicate membrane which exhibits a special feature of its own in the fact that its cells each

possess a microscopic fringe of lash like threads of living matter. These are known as *cilia*. They are in a state of constant movement and serve to waft up towards the mouth the fluid secretion of the lungs, whilst they also possess a certain effect in clearing the bronchial tubes of minute particles which may be inhaled in the air. These microscopic brushes in
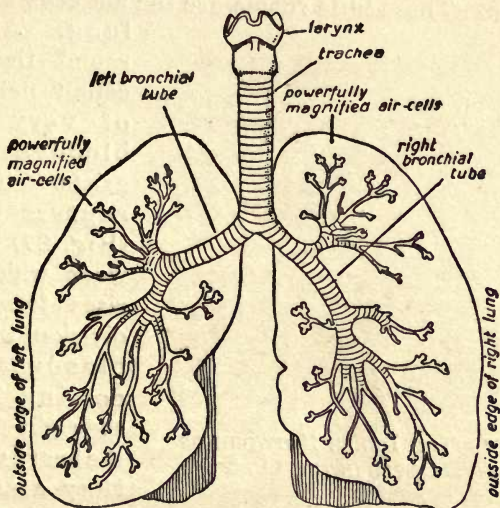

FIG. 26.—STRUCTURE OF LUNGS SHOWING BRON-CHIAL TUBES ENDING IN AIR CELLS.

other words possess the function of keeping the bronchial tubes clear. The action of a cough can only be exercised in bringing up from the lungs matter which has been wafted up to the root of the windpipe, and it is due to the action of these cilia that any extra secretion, as in the case of bronchitis, is brought within reach of the cough through the action of which it is expelled from the body.

THE AIR CELLS.—Tracing one of the divisions of the windpipe to its end, we find that it ultimately expands into a clump of little cells or compartments (Fig. 26) varying in diameter from 1-40th to 1-70th of an inch. The end of the bronchial tube in this way may be compared to a passage from which opens a series of little rooms arranged in a somewhat circular fashion. These little rooms are the **air cells of the**
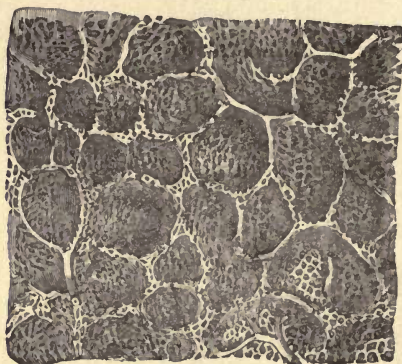

Fig. 27.—THE DENSE NETWORK OF BLOODVESSELS IN THE LUNGS.

lung. All around the air cells a network of very fine bloodvessels exists. These represent the (Fig. 27) network which arises from the division of the bloodvessels coming from the right side of the heart, whilst they also represent the beginnings of the vessels returning pure blood to the heart's left side. Each little clump of air cells is in fact a lung on its own account, so that when air is breathed in and passes down the minute sub-divisions of the windpipe it ultimately arrives at the air cells of the lung, encompassed, as we have seen, on every side, by bloodvessels bringing impure blood from the body. The real work of the lung takes place in the air cells, for according to a physical law, that of "the diffusion of gases," the air breathed in passes through the thin walls of the air cells and

bloodvessels into the blood, while in the reverse direction the carbonic acid gas and other waste matters pass from the blood into the air cells and are thus breathed out. This is the essential feature of the act of breathing, an interchange of gases taking place in the air cells of the lung. The lung might in fact be well compared to a market place or exchange where business is conducted by two merchants represented by the air and blood respectively. The transaction is one of barter, the air proposing to give to the blood its oxygen, whilst the blood exchanges for this necessary item, carbonic acid gas, heat and water, which are given forth in expiration.

How WE BREATHE.—The one movement of breathing, *inspiration*, differs very materially in its nature from its neighbour, that of *expiration*. We may determine this fact if we pay attention to our own breathing movements. Breathing in is essentially a muscular act which chiefly depends on the action of a very large muscle forming a moveable floor to the chest, this muscle being known as the *diaphragm* or *midriff* (Fig. 23). This muscle, when it acts, descends and becomes less convex in shape, with the result, that on account of its attachment to the chest walls it enlarges that cavity, making it broader and longer. At the same time the breast bone is pushed forward and upward chiefly by the action of the little muscles which exist between the ribs, so that the chest in this way is also enlarged in depth. The lungs, which are highly elastic bodies, follow every movement of the chest, hence, pressed as they have been to a certain degree before the act of inspiration begins, they expand in virture of their elasticity, and thus admit the supply of air which is drawn in by the act of inspiration. When this action comes to an end, it is

exchanged for that of breathing out. Here we come face to face with an act which is largely mechanical in its nature, and does not involve muscular action, In breathing out we simply see the recoil of the chest. and the return of the elastic structures to their position of rest from which they were disturbed by the act of breathing in. Inspiration, therefore, is the one act which involves an expenditure of muscular energy, while breathing out as a mechanical act makes no demands upon our working power. Nature in this respect supplies an example which might be paralleled by many other instances, of an economical use of her working powers.

THE SKIN.—The lungs do not stand alone in the category of our bodily belongings. As a matter of fact they represent one of a number of organs performing the same work although the labour is carried out in different fashions. The neighbour organs of the lungs are the skin and kidneys, so that the three form a kind of physiological trio whose action is that of excreting waste matter from the body, the lungs acting in a highly important fashion because they likewise perform the function of absorbing oxygen. The functions of the skin are of a varied character. In addition to serving as a body-covering, the nerves of its under layer supply us with the means of exercising the sense of touch. The glands of the skin constitute it an organ of excretion for the getting rid of waste matter, whilst the large supply of blood contained in these minute bloodvessels renders the skin an organ which regulates to a large degree the temperature of the body. These varied functions being borne in mind teach us that the skin is really an extremely complex structure, and in respect of its functions it may be described legitimately as a kind of lung

spread over the surface of the body. In its structure the skin exhibits a main division into two layers. The outer coating is the *epidermis* or *scarf skin,* which possesses neither nerves nor bloodvessels and consists of cells perpetually renewed from the upper surface of the under skin. The *dermis* or under skin, lying below the outer layer, contains both nerves and bloodvessels, the ends of the nerves being contained within little projections of this under layer known as *papillæ.* Below this under layer of the skin we come upon other tissues including fat.

THE GLANDS OF THE SKIN.—The glands of the skin are two in number. The *sebaceous glands* are small pocket-like organs, the ducts or tubes of which open into the sheaths of the hairs and also frequently pass to the surface of the skin itself. These glands secrete an oily or fatty material, the function of which is to keep the skin pliant and moist, whilst from their relation to the hairs it may be assumed that their secretion may also be held to represent a natural oil or pomade. More important are the *sweat glands* whose action it is to separate from the fine bloodvessels surrounding them certain waste products constituting the sweat. The sweat consists of a large amount of water, minerals (amongst which common salt is prominent), and certain fatty matters derived from the skin's surface. A certain amount of carbonic acid gas is also given forth from the skin, whilst most physiologists agree that the skin has a limited power of absorbing oxygen. The sweat glands consist each of a minute coiled up tube, the end of which passes upwards to the skin and opens in a *pore.* The coiled up part of the tube especially is lined by cells, which are the active agents in taking from the blood the

waste matters which the gland passes upwards to the skin surface. Sweat glands are most numerous in the palm of the hand and sole of the foot, the number in these regions being estimated at about 3,000 per square inch. In the neck and back they are less numerous. It has been estimated that over two millions of these glands exist in the skin surface of a human body. If the coiled up tube was stretched out at full length it would measure about a quarter of an inch, so that according to one estimate, in a square inch of skin from the palm of the hand the length of the sweat tubing would be found to be over seventy-three feet. The total length of sweat tubing in the body has been variously given as amounting to ten miles, some estimates vastly exceeding this calculation.

THE SKIN ACTION.—The skin glands are always acting, and hence perspiration which is poured forth under circumstances of quietude of the body is termed *insensible perspiration*. After exertion, when the sweat may become visible on the surface of the skin, it is then known as *sensible perspiration*. The amount of sweat given off on an average from the body of a man per day is about two pounds, an amount liable to be vastly increased where violent exercise or heavy work is represented.

THE SKIN AND BODILY HEAT.—In order to appreciate the duty of the skin as a regulator of the temperature or heat of the body, we have first of all to remember the vast amount of blood which is perpetually circulating through the skin in its minute bloodvessels or capillaries. These bloodvessels are under the control of the nervous system, and are maintained in a medium state which may be described as that between contraction and expansion. If,

however, from any circumstances the nervous control is lessened, the bloodvessels dilate or expand, with the result that a greater flow of blood passes through them and greater activity of the sweat glands is produced. A warm bath produces this effect. It relaxes the skin and bloodvessels, brings more blood to the skin surface, and this favours perspiration. Cold acts in a reverse fashion and diminishes the supply of blood, lessening at the same time the amount of perspiration given off. Something of this skin regulation of temperature and the resulting alteration produced in its work may be appreciated in the difference between the work of the kidneys and skin in summer and in winter. In summer when the skin acts freely, the work of the kidneys is lessened, whereas in cold weather skin-action is apt to be in some degree checked and the kidneys excrete more fully. It is the evaporation of perspiration from the skin surface that aids largely in the regulation of temperature. The sweat, as a fluid, evaporates and passes off into the air, and thus removes a certain amount of heat from the body with the result of cooling the body at large. On the other hand, when the atmosphere is cold, less sweat being produced, the loss of heat from the body is lessened; and so under the varying circumstances of life and under varying degrees of temperature the bodily heat is regulated and maintained at very much the same degree—98.4 degrees F.

THE CARE OF THE SKIN.—Of the most extreme importance to health is the care of the skin. Recognising the elaborate functions it performs, we are taught our duty to the skin in maintaining its cleanliness and in encouraging its work. Interference with the functions of the skin may be productive of very

serious results, a sudden checking of these functions reacting upon the internal organs of the body and producing congestion which is the first stage of inflammation, thus giving rise to cold and lung troubles at large. Again, any material interference with the free excretion of perspiration may have a fatal result. In a Papal procession at Rome, the body of a child was covered over with gold leaf to represent a figure in the pageant of the Golden Age. The child died in a few hours from a veritable process of suffocation due to the retention within the body of the waste products naturally secreted by the skin. The proper use of baths, and the maintenance of the skin in a state of high cleanliness is therefore one of the duties we owe to ourselves when the care of our health falls to be considered.

THE KIDNEYS.—The interdependence of the lungs, skin and kidneys may be demonstrated in yet another fashion apart from that which teaches that the three organs perform very much the same kind of work. Where the lungs are affected, part of the rational medical treatment of lung troubles is to increase the action of the skin by administering medicines which cause profuse perspiration; and the same is true when the kidneys are affected. One organ is thus capable to a certain extent of relieving the others in their work. The kidneys are two in number, one on each side of the lumbar or loins region of the body. The term "kidney-shaped" is a familiar enough expression, and serves to indicate the form of the kidney which is convex to the outer side and deeply indented on the inner side. A very large artery, the *renal artery*, given off from the aorta, enters each kidney, and a very large vein, the *renal vein*, joining the vena cava, leaves it (Fig 28). The blood leaving

the kidneys is the purest blood in the body, but of course it soon mixes with the general venous stream from the body at large, passing back to the lungs by the vena cava (Fig. 28) for purification. There is thus a perpetual flow of blood through the kidney, and although it is pure blood which enters by the artery, such blood nevertheless contains
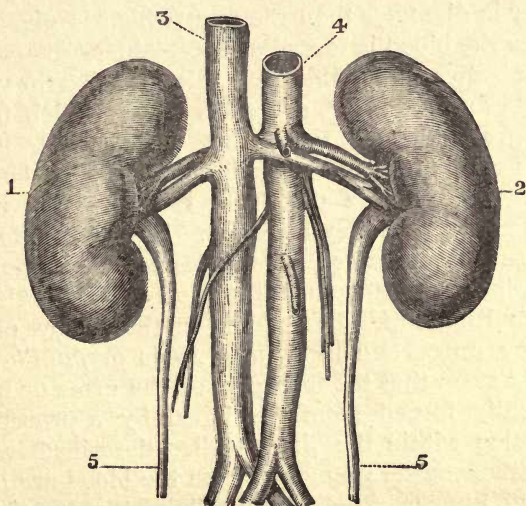

Fig. 28.—THE KIDNEYS IN POSITION.
(1 and 2) kidneys, (3) vena cava, (4) aorta, (5, 5) ureters leading to bladder.

certain of those products which, resulting from the breakdown in the body of the nitrogenous foods, are destined to be removed from the blood by the organs we are considering. The structure of the kidney is somewhat of a complicated nature. The essential feature of the organ consists in the presence of a large number of little bodies, each containing a ball or network of fine capillaries which

represent the end of the renal artery and the beginning of the renal vein. The blood which, so to speak, circulates in and out of the kidney, finds its turning point in the little bodies (Malpighian bodies) just noted. These structures are lined by cells which represent the active agents in the kidney's work. The little artery entering the Malpighian body is wider in diameter than the vein which is given off, hence the blood is forced at a certain pressure into these bodies, and in this mechanical fashion the waste matters are excreted, especially water, which forms the great bulk of the kidney secretion or *urine*. Each of the Malpighian bodies is in fact a kind of filter which filters out from the blood the waste matters of the kidney secretion. From each of these bodies a tube passes out in a varied and somewhat complicated arrangement to the centre of the kidney, the multitude of tubes ending in the hollow of the kidney on certain little projections or *papillæ*. It would seem that the fluid part of the urine or water is really forced from the blood by a process of filtration within the little bodies described, whilst the other matters removed from the blood are in all probability separated by the cells of the Malpighian bodies themselves, and by those which line the tubes leading from the bodies in question and which conduct the urine to the outlet of the kidney. From each kidney a special tube, the *ureter*, leads to the bladder in which the urine is stored preparatory to its expulsion.

THE KIDNEY SECRETION.—A healthy adult will pass from the kidneys in twenty-four hours between fifty and sixty fluid ounces of urine, although the quantity varies materially according to the circumstances of life, and even according to the outer

temperature. The urine consists in 1000 parts, of about 958 parts of water and 42 parts of solids, the latter consisting of urea, uric acid, minerals and other substances, whilst a certain amount of carbonic acid gas has also to be reckoned with as being contained in the urine. The special feature we have to remember in connection with the functions of the kidneys relate to the *urea* and the *uric acid*. Both substances represent what we may term the breakdown of the nitrogenous foods consumed and utilised by the body. The uric acid, in the opinion of many physiologists, represents a stage in advance of that which results in the production of urea. As an excess of uric acid in the body is the cause of gout, that disease may be presumed to arise from some condition or other which prevents the work of the kidney being carried on to its normal end.

A Bodily Balance Sheet.—It is now possible to summarise in the form of a bodily balance sheet the general income and expenditure of the living body, the details of which have hitherto formed the subject of our studies. In this fashion we may gain a summarised idea of the manner in which the business of life is conducted, and we may also be prepared to discover that in respect of economical working, nature presents a highly typical example of the wise and orderly ruling in her conduct of the human household. The total income of a human being is derived from three sources, namely, the solid food he consumes, the water or other fluids he drinks, and the oxygen of the air he inhales. The expenditure of his body is represented by the waste materials which have resulted from the work his body performs. The income of an adult man doing an ordinary amount of work per day may be calculated as nearly as possible

to amount to 8,000 grains of solid food, 37,650 grains of water, and 13,000 grains of oxygen, making up a total of about 8⅓ pounds of material by weight. His expenditure from the lungs of the waste matter given forth will amount to 20,000 grains, the skin giving off 11,750 grains, the kidneys 24,100 grains, the intestines 2,800 grains of waste digestive matter. The expenditure, amounting to about 8⅓ pounds, would be found to balance the income. It is impossible for us of course to obtain mathematical exactitude when dealing with living beings, but the figures just given offer as near an approach as is possible to the real facts of the case.

OUR BODILY PROFIT.—Here arises an extremely interesting question, namely, that regarding the profit which is derived from this apparant exact balancing of the income and expenditure. Unless the business of life is conducted on lines widely different from those on which the commercial transactions of men are founded, it is clear the business of living must in one sense be regarded as highly unprofitable, and as showing nothing which may be reckoned in the light of gain. This conception, however, is extremely erroneous, for the profit derived out of the business transactions of life really represents an enormous gain. The profit we obtain, summed up in a single word, is "the power of doing work." Whatever work man performs in the world, his ability to exercise bone, muscle, and brain, is derived from the transaction just chronicled. The case of the engine we may again recall to mind by the statement of the bodily balance sheet. The profit represented by the work of the engine is found in the power which it develops out of the fuel supplied to it. Now in respect of man's inventions this profit is by no

means large. Even the best constructed machine will only give a very limited percentage of power when compared with the amount of fuel it consumes. The case is extremely different with the human engine, for on a comparatively small amount of fuel it gives an amount of energy which is positively startling when we come to sum up the various items whereof it is composed. If we calculated the power developed by the body as a living engine out of the food it consumes, we find that according to one calculation, the internal work, that of maintaining the body itself, may be reckoned as equal to 2,800 foot tons per day—that is to say, if applied in the shape of mechanical work, this amount of energy would be capable of raising 2,800 tons one foot from the ground. The same estimate maintains that an ordinary day's work, about 300 foot tons. will really be increased five times, namely, 1,500 foot tons, in addition to the quantity required for the body's own maintenance. Thus we get 1,500 foot tons *plus* 2,800, or 4,300 foot tons in all, developed from the fuel supplied to us in the shape of our food. This tremendous amount of working power represents the profit we obtain from the transactions we carry out every day, in the way of obtaining our food, and of assimilating it and digesting it. If the amount of power expended in the work we perform daily, apart from the internal work of the body, be calculated, a man at light work develops from 150 to 200 foot tons per day. The average work is estimated at from 300 to 350 foot tons in the case of a hard worker. In the case of a hard worker he may develop between 450 and 500 foot tons, and in laborious work between 500 and 600 foot tons. Another mode of calculation teaches us that out of his daily food a man requires

to renew daily his store of energy equal to a mechanical work which would lift nearly 1 ton a height of 1,094 yards. Differ as the estimates may regarding man's working profit derived from his food consumption, we are at least standing on sure ground when we assert that the profit he exhibits as a working engine, in the shape of energy, far exceeds that ever likely to be developed by any of his own inventions.

CHAPTER VI

THE STORY OF THE BRAIN AND NERVE

The Two Nervous Systems.—The control of a living body, like the government of a country, is found to be determined by a specially appointed organisation to which we apply the general name of the nervous system. This system, whilst exhibiting a distinct unity, is nevertheless composed of elements or parts of diverse importance, some being of vastly greater importance than others, judged by the special share of the work of government they perform. Two nervous systems exist in the bodies of all back-boned animals, a fact already alluded to when we dealt with the general constitution of the body. The more important of these two systems consists of the *brain* and *spinal cord* (Fig. 29 and 30), which last may be described as the main line of the nervous system, lying protected within the spine, and the nerves issuing from both brain and cord supplying the body with the means of communication between itself and the outer world. The second system, known as the *sympathetic system*, exists in the form of a double chain of *ganglia* or *masses of nerve cells* lying in front of the spine. This latter system has an individuality of its own, though it is connected at certain points with the brain system of nerves. The term *cerebrospinal system* is scientifically applied to the latter in contra-distinction to the term *sympathetic*, denoting the other main portion of the nervous apparatus. In

the presence of these two nervous systems, we come face to face with what may be termed the principle of the division of labour as represented in the government of the body. The brain system exercises all those functions which are especially associated with voluntary movements and the exercise of the will. The power, in other words, of doing as we like, depends upon our possession of this nervous system whereby the commands which the brain sends forth are capable of being executed by the body at large, whilst in the same way, information conveyed by the senses from the outer world to the brain can be appreciated, and, if necessary, acted upon by the body. The sympathetic system, on the other hand, may be described as the "involuntary" nervous system. It cannot be directly brought into play by the exercise of the will, but can only be stimulated indirectly, as, for example, when we take food into the stomach, the movements of the organ, regulated by the nervous system, being thus stimulated. Actions, of which a very considerable number are performed by the body, such as are more or less of automatic or machine-like character, are regulated and supervised by the sympathetic system. For

Fig. 29.
THE BRAIN AND SPINAL CORD—
THE CEREBRO-SPINAL SYSTEM.

example, the heart and bloodvessels are controlled by this system, and the movements of the intestine in digestion, depend for their control upon the sympathetic nerves. The division of labour principle is, therefore, seen to be illustrated in the work of the two nervous systems, seeing that a vast number of important actions upon the due performance of which existence itself may be said to depend, are regulated not by us, but for us. The work of the sympathetic centre consists in supervising what may be called the ordinary actions of the body connected with digestion, circulation, and the like, while the brain system remains free for the supervision of the more important questions and actions of the day and the hour.

WHAT THE NERVOUS SYSTEM DOES.— If a broad but
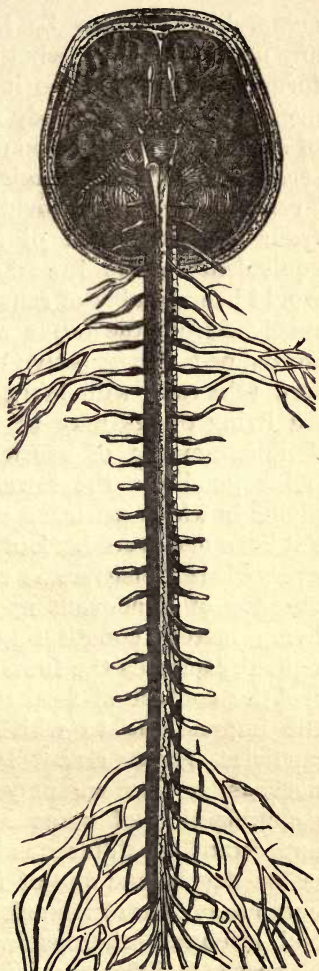
Fig. 30.—VIEW OF SPINAL CORD, SHOWING ITS CONNECTION WITH THE BRAIN, AND THE SPINAL NERVES ISSUING FROM THE CORD.

comprehensive view be taken of the functions of any nervous system, whether in lower or in higher forms, we might define it as a particular series of organs in an animal body set apart for the purpose of exercising the function of *Relation.* By this latter term is implied the bringing of the living being into " relation " with the world in which it lives. Apart from the possession of a nervous system or its equivalent in the lowest forms, the living being would be incapable of reacting upon the impressions received from the outer world. It would, in other words, be a non-sensitive thing, and it might, therefore, take rank with inorganic or non-living objects. All living things may be regarded as possessing a definite amount of sensitiveness, and this opinion holds good for the lowest animals, and also for plants in which no trace of nervous system has as yet been discovered. But as living matter itself is everywhere sensitive, we can understand that in the absence of a nervous apparatus, a small speck of living matter constituting the body of a lower animal, exercises the function of sensation, is able to feel the contact of food particles, and to act upon the impressions to which the contact with these particles gives rise. From this view of the nervous system we may advance to yet another generalisation of some service in enabling us to understand the difference between a nervous system of low degree and one of high degree. The higher nervous system of animals possesses a more perfect and intimate relationship developed between its possessor and the world in which it lives. Take, for example, the acts of a highly organised brain and nervous system which a dog posesses. It is capable of exercising a high degree of intelligence, yet it falls

marvellously short of human acquirements, even in respect of those traits which mark a simple mental or nervous operation on the part of man. The dog, in other words, cannot relate itself in such a clear and perfect manner to the world in which it lives as does the man, and the human superiority arises undoubtedly from that higher evolution and development of his nervous apparatus which marks the human estate.

The Essentials of a Nervous System.—If we compare the nervous system to that of a telegraph, we may find the comparison to be thoroughly justified. In the construction of the ordinary telegraph system two chief elements have to be provided. We have first to supply batteries or means for developing electrical energy, and wires require to be furnished for the purpose of carrying or conducting the electrical force. Even if wireless telegraphy be included in such a comparison, the electrical waves will require conduction. The nervous system, following out this comparison, complicated as it may be, is built up of two elements which roughly correspond to those of the telegraph apparatus. These two elements are first, *nerve cells*, and second, *nerve fibres*. It is important to distinguish between the functions of these two elements. Their uses are as clearly defined and distinct as are the batteries and wires of the telegraph. Nerve cells are the originators and receivers of the messages or impressions through which the nervous system is stimulated to its work. A nerve fibre on the other hand, is a mere conductor or conveyer of such messages. A nerve has no power of initiating any message on its own account. In order that a nerve fibre may be stimulated to carry a message, either from brain to body or

from body to brain, it requires the co-operation and, if it may be so termed, the supervision of nerve cells. This definition must be kept fairly in mind, because in common language the term "nerve" is used as if the bodily telegraph wires represented the most essential feature of the nervous apparatus.

NERVE FORCE.—The particular form of energy which nerve cells generate, and which represents the electricity of our bodily telegraph system, is termed *nerve force*. It is this force which flows along nerve fibres, and represents the messages which stimulate the body to action on the one hand, and arouse the brain and nerve centres on the other. The rate at which nerve force passes along nerve fibres has been estimated in warm-blooded animals at about 200 feet per second. This is a slow rate as compared with that of electricity or with the speed of light waves, which pass through space at a rate of 186,000 miles per second. The phrase "as quick as thought" is therefore to be accepted in a relative sense only, though the rate at which our nerve force speeds along nerve fibres is quite sufficient for the perfect carrying out of the work of the nervous system.

NERVE CELLS AND FIBRES.—Nerve cells form, in one sense, the central figure of the nervous system. Like all other cells a nerve cell is a mass of living protoplasm, and, having regard to the duties it discharges, we may safely conclude that the protoplasm of the nervous system is of higher order than that represented in the other cells of the body. This much, indeed, we are legitimately entitled to assume from the character of the work it performs. Like all other cells, nerve cells are microscopic in size, some of them extremely minute. They vary in

diameter from the 1-500th or the 1-600th part of an inch to the 1-5000th part of an inch, many of the cells in the brain exhibiting even more minute dimensions. The characteristic feature of a typical nerve cell is that it gives off branching threads or processes of its substance called *dendrons*. Certain of these connect the cell with neighbour cells, for as a rule we find in the brain and spinal cord cells are gathered together into groups to which the general name of *nerve centres* has been applied. Amongst the processes or dendrons which a nerve cell possesses, one stands out more prominently than the rest. This process is termed the *axis cylinder*, and differs from other branches or dendrons in that it can be traced passing from the cell outwards to the body. When so traced, this axis cylinder is found to become one of the fibres of a nerve. In other words, just as the wires of the telegraph system are directly connected with the batteries, so the nerve cells give off their axis cylinders, which pass forth and become veritable wires of the body. It is unnecessary to detail the different forms and shapes which nerve cells assume, save to record that in the spinal cord and elsewhere, the cells give off many dendrons or branches, and are called *multi-polar* cells, whereas those which are characteristically typical of the brain are triangular in shape, giving off a branch at each angle, and one from the centre and base, this last representing the process which ultimately will pass to become a fibre in one of the nerves of the brain. The nature of the second element in the nervous system, the nerve fibre, has already been sufficiently indicated. Even the finest nerves of the body are made up of bundles of fibres which originate from nerve cells. If these fibres be

traced outwards into the body, we discover that their endings are of diverse character. Thus in the skin we find nerve endings devoted to the exercise of the sense of touch. In the nose, the ends of the olfactory nerves, or those of smell, terminate in special cells called *olfactory cells*, which may be presumed to be the organs whereby the smell sense is excited through contact with odoriferous particles which come in contact with them. More complex are the endings of the nerves of sight and hearing, these being connected with a complex apparatus in the shape of eye and ear respectively. An important point to be noted is that each ordinary nerve of the body, apart from the nerves of sensory organs (eye, ear, etc.), will be found to include two kind of fibres indistinguishable from each other, but performing different duties. Thus, as will afterwards be shown, each nerve is like a double telegraph wire, in the sense that one set of its fibres conveys messages from brain to body, the other set carrying messages in the opposite direction, from body to brain.

ABOUT THOUGHT.—In the case of the lowest animals no question arises regarding the possession of will, intellect or mind. They may be considered to be in the position of living machines, which respond automatically to the impressions made by the outer world on their sensitive parts. As, however, we advance in the animal scale, we begin to find, with the rise and development of the nervous system, new phases of nervous work. These fresh aspects are associated with a higher development of the nervous apparatus, this development mostly taking the form of the massing together, especially in the head region, of nerve centres, which we have seen to represent collections of nerve cells. The

higher animals thus become raised from the automatic or machine-like life of their lower kith and kin, and develop accordingly degrees of intelligence and independent action, which vary with their rank; this advance attaining naturally its highest development in man and his neighbour animals. In the human domain we meet a still further development of the work of the nervous system. In addition to the regulated play of instinct, a higher intelligence appears as well, to which we apply the terms reason and consciousness. It may be said that the highest level of nervous work is found in the case of man, because he is conscious not merely of his own existence, but is also enabled to reason out and to understand generally the conditions under which that existence is passed, whilst he is also enabled to adapt his life much more readily than his animal neighbours to the varying conditions of life. Having regard to the fact that nerve cells, or, in the case under discussion, brain cells, represent the highest items in man's bodily structure, the question naturally arises whether science can lead us to a perfect understanding of the manner in which these cells govern and control existence. This much is certain, at least, that the living matter of the brain cells is the seat of those particular changes and actions arising from the play of nerve force, which can be converted into force or energy of other kinds. Thus a thought arising in, or produced by, certain brain cells can be converted at once into movements either simple or complex. The act of writing or of speaking, for example, involves a whole series of brain actions, the main feature of which is the conversion of thought—which need not necessarily manifest itself externally at all—into a

variety of actions, having for their object a definite purpose. We thus arrive at the conclusion that the brain cell is the seat of those actions or processes which are generally spoken of under the name of "thought" and "consciousness," and which are made manifest through the bodily actions. One proof of this fact is found in the phenomena of disease, for, when certain cells undergo degeneration, the power of naturally exercising the brain becomes very much altered, and the responsibility of the individual may, as in cases of insanity, be practically abolished. Here, it would seem, we stand on fairly firm ground in assuming that the brain cell is a generator of that subtle and particular kind of energy to which, in one of its manifestations at least, we apply the name of "thought." Beyond this stage of reasoning it is impossible to proceed with exactitude. What thought is in its essence we do not know. We can merely indicate the apparatus by which this phase of mental action is manifested, namely, by the highest protoplasm or living matter of which brain cells are composed. As we cannot understand the nature of life itself, so we remain ignorant to-day of the precise conditions under which the living matter of the brain cells gives rise to the higher expressions of consciousness.

How THE NERVOUS SYSTEM ACTS.—One general principle is found to underlie the working of this complicated system. To this principle the name of *reflex action* is given. A simple illustration of the working of the nervous system is afforded in the case of a person withdrawing the head from a blow aimed at him. Here the action he performs begins at the eye, which, like every other organ of sense, is a mere "gateway of knowledge" devoted to the

purpose of affording information to the brain through a particular channel. The impression of imminent danger is conveyed along the optic nerve, or that of sight, arousing in other parts of the brain consciousness of the attack about to be made. The message thus received by certain brain centres is instantly "reflected" to other centres, namely, those governing the muscles of the neck, the result being that these muscles, stimulated to action, withdraw the head from the threatened blow. In this case, the incoming, or *afferent* message is "reflected," and converted into an outgoing or *efferent* message. It may be, however, that the simple reflex action may become more complicated and more extended in its range. For if the threatened individual seeks safety in flight, the reflex action will extend to the stimulation of the muscles of the legs and body, carrying him out of the reach of danger. A man crossing the street hears the sound of a rapidly driven vehicle coming up behind him. In this case the primary message is received by his ear, and the same process is gone through as in the case of the eyes. The message is "reflected" from the brain and sent to the muscles by centres governing these organs so as to hasten the man's footsteps, and thus enable him to seek safety on the pavement. When the mouth waters at the sight of something good to eat, the message conveyed from the brain is "reflected," in this case, to the salivary glands of the mouth, producing a copious flow of saliva. Many more illustrations of reflex action might be given, but suffice it to say that the principle animating all our acts, whether of simple or complex nature, is the same. Occasionally a reflex action starts from the outside of the body, as, for example, when the finger comes in contact

with a hot surface it is instantly withdrawn. Here the incoming or *afferent* message starts the action which involves the conveyance of the sensation of heat to the centres governing the muscles of the arms, which operate to withdraw the limb. For the performance of a reflex action, we therefore find that what is required, apart from more intricate details, are essentially an incoming nerve fibre, an outgoing nerve fibre, and a nerve cell or centre which deals with and reflects the message it receives. A reflex action may, of course, be performed unconsciously and without involving the arousing of attention. An act, such as that of closing the eyelids in face of danger, for example, takes place automatically, and is all the more quickly performed on that account.

THE SPINAL CORD.—Confining our attention to the brain system, we find this portion of the nervous apparatus (Fig. 30) to include (1) the brain itself contained and protected within the skull, (2) the spinal cord issuing from the brain and representing the main line of the nervous system contained within the spine, and (3) the various nerves given off from brain and spinal cord together. The spinal cord, it should be noted, is much more than a great line of nerve fibres. It contains both nerve cells and fibres, and when we make a section of the cord we find its cells to be contained in what is called the *grey matter* in the centre of the cord, the *white matter* outside, representing the nerve fibres which place brain and body in connection. Thirty-one pairs of nerves (Fig. 30) are given off from the spinal cord. One of the most interesting discoveries noted in connection with the nervous system was elicited when the reason for each spinal nerve being

given off by a *double root* from the spinal cord was made plain. One root is named the *anterior root*, because it is given off from the front of the spinal cord, the other, the posterior, proceeding from the hinder portion. Shortly after leaving the cord, the two roots unite to form a single spinal nerve. The hinder root of each spinal nerve may be distinguished by the fact that it possesses a *ganglion* or small collection of nerve cells. The proper understanding of the manner in which the nervous system operates, and especially how reflex action is carried out, was made clear by researches showing the functions of these two roots. If the front root be cut in an animal, whilst the hinder is left intact, the animal loses the power of movement in the parts to which the nerve is distributed, but retains the power of sensation or feeling. If the posterior or hinder root be cut, on the other hand, and the front root left untouched, the opposite result is seen, the animal retaining the power of movement in the parts, but losing the power of feeling. From these facts it is clear that each ordinary nerve in the body comprises two sets of fibres, those derived from the front and hinder roots respectively. The experiment described shows that messages passing from the brain and spinal cord *to the body* pass out by the front roots of the spinal nerves, and are conveyed to the body by the fibres which represent the continuation of these roots. On the other hand, messages coming *from the body* to the brain and spinal cord pass along the fibres of nerves belonging to the posterior or hinder root, and then entering the cord, are subsequently dealt with either by the cord or by the brain, to which the messages, if need be, can be conveyed. The

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name *motor root*, because its nerve fibres are destined to convey messages resulting in movement, is given to the anterior or front root, whilst the posterior is known as the *sensory root*, such a root being the means for conveying impressions made on the ends of nerves, and proceeding onwards to the spinal cord and brain. It follows that the nerves of sense belonging to eyes, ears, nose, etc., are "sensory" nerves, because they only convey messages in one direction, from body to brain and cord.

THE SPINAL CORD AS A CENTRE.—Having regard to the fact that the spinal cord contains an abundant supply of nerve cells, we may again remind ourselves that it is much more than a collection of nerve fibres, since the possession of cells confers upon it the power of acting as a nerve centre, or rather as a series of nerve centres. There is little doubt that a large number of actions, having reference to bodily movements and other functions, can be carried out by the spinal cord independently of the brain, whilst the cord may also be regarded as acting in harmony with the brain in the performance of many of the acts which characterise our voluntary life. Proof that the spinal cord possesses a certain independent action of the brain, is afforded by an experiment in which a decapitated frog has a drop of vinegar or mustard placed on the web of one of its hind feet. It will use the other foot to wipe off the offending substance, and will execute a variety of complex movements to attain this end. Similarly, in the case of a human being who has suffered an accident resulting in the division of his spinal cord, and is therefore unable to move any part below the break, if the foot be tickled the legs will be drawn up. In

frog and man the independence of the spinal cord as a series of nerve centres is thus demonstrated, for in the headless frog the control of its movements can only be effected through the nerve cells of the spinal cord which so far govern its body in the absence of its brain, and in man the impression made upon the feet passing up the cord is dealt with by the nerve cells below the break, which thus "reflect" the message to the muscles, and so produce the movement of the legs. Research has shown that in the upper part of the spinal cord there are nerve centres, or groups of cells, which certainly exercise a command over the heart and other organs, the working of which is governed by the sympathetic nervous system. It has already been shown in dealing with the heart how, for example, the *vagus nerve* has the power of slowing the heart's movements. So also, the regular movements of breathing may be regarded as controlled from the spinal cord, and in its lower portion centres exist exercising a certain amount of governance over the functions of the bowel, bladder, and other organs. The spinal cord is thus seen to be a very effective deputy of the brain itself, and the principle of labour division in the nervous system may find an illustration in the share which the spinal cord assumes in the control of the bodily actions, leaving the brain, so to speak, free for the discharge of more important duties.

THE EVOLUTION OF THE BRAIN.—It is possible to trace from the fish upwards to man, an identity of type or plan in the build of the brain. In fishes, frogs, and reptiles the brain is represented by a series of masses of nerve cells placed, more or less distinctly, in line. For convenience sake, we may enumerate these masses as consisting of the olfactory

or smell parts in front, the forebrain coming next in order, whilst there respectively succeed the middle brain and the hind brain. As we advance towards the reptiles, we discover that the fore brain tends to overshadow by its greater prominence the middle brain, and when we arrive at the bird, we find this
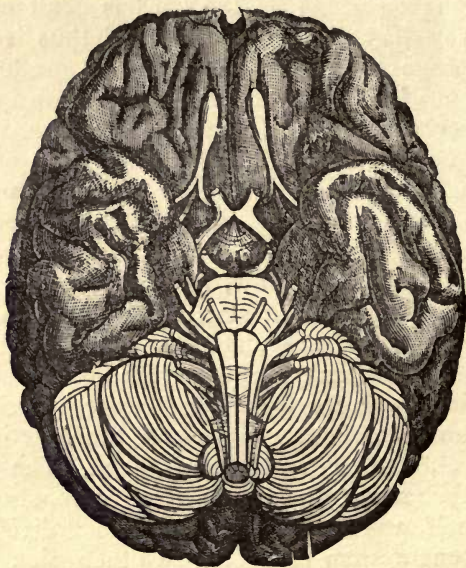
Fig. 31.—The Base of the Brain

Showing the cerebellum behind, and the origin of the spinal cord. The olfactory lobes lie in front, and the optic nerves behind them.

part with its disproportionate size arising from increased growth, and also with the enlargement of the hind brain, completely covers the middle brain. In the lower quadrupeds much the same development is seen. As we advance a tendency is shown for the fore brain to increase in size, and to grow not

merely forwards, but backwards as well, so as to overlap the hind brain. This principle of brain development has its supreme exemplification in man. The fore brain in man attains a size far exceeding its dimensions in any other animal. The smell parts, instead of projecting prominently in front as in fishes, frogs, and reptiles, are found on the under surface of man's brain (Fig. 31), a feature

Fig. 32.—SECTION OF BRAIN
Showing inside of left half of cerebrum, the connecting bridge of the lobes, cerebellum in section, and medulla at top of spinal cord.

also illustrated in many quadrupeds as well. In man, the backward growth of the fore brain is also extreme, and the hind brain is completely covered and hidden when the brain is viewed from above (Fig. 32.) Such is a brief account of the evolution of the brain; and in the development of man's brain we are able to trace with a fair degree of accuracy the various stages which represent the permanent condition of the brain in lower forms of life. The

principle here represented is that of the massing together and extreme growth of certain brain regions; that which distinguishes man being the higher degree of growth and development represented, not merely in the fore brain itself, but throughout the other parts included in the constitution of the organ of mind.

The Build of the Brain.—It is perhaps more legitimate to speak of " brains " than to use the word in the singular, seeing that the brain is not one organ, but a complex array of different centres. Thus, in one part of the brain we may find many different centres to be included, as is the case with the great mass of the brain (or *cerebrum*) in man, which represents the principal and most important part of the organ. The brain regarded in a side view as it lies in the head (Fig. 33) would appear to consist of two large masses only.

Fig. 33—Brain in Position
(cb) Cerebrum.
(cbm) Cerebellum.

Of these, one is much larger than the other, filling the greater part of the cavity of the skull. This is the *cerebrum*, or part to which we have hitherto applied the name fore-brain (Fig. 33). The second prominent portion of the brain lies below and behind the cerebrum, and is known as the *cerebellum*, or *lesser brain* (Figs. 31 and 33). An anatomical examination of the brain reveals other centres lying deeply imbedded in the base of the brain, and to these parts the general name of *central ganglia* has been applied. Regarded externally the

cerebrum is seen to be divided lengthwise into two halves or lobes (Fig. 32), the division extending to a short depth between the lobes, where they are found to be connected together by a bridge of nervous matter known as the *corpus callosum*. The surface of a man's brain is thrown into a series of distinctly marked folds or *convolutions* (Fig. 34). These convolutions are characteristic of many other animals,
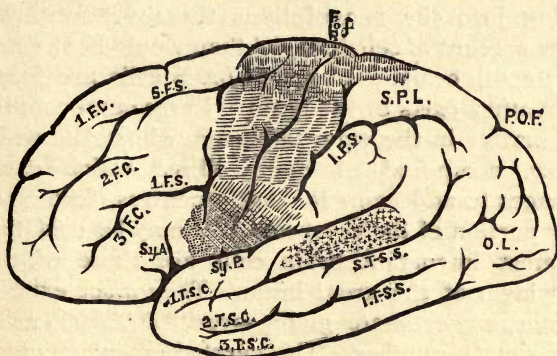
Fig. 34.—Side View of Brain Regions and Convolutions.

The shaded part corresponds to the motor area. The left lobe of the brain is represented here, the front or forehead region lying to the left side.

but are absent in the brains of certain forms, of which the beaver, rabbit, and the like animals are examples. The convolutions do not vary in one individual from those of another—that is to say they form a definite pattern, presenting occasionally variations, but still maintaining a close anatomical similarity and resemblance. For scientific and medical purposes the convolutions are all duly marked and numbered. The surface of the brain has similarly been divided into certain areas or regions corresponding with the

bones of the skull. We thus speak of the *frontal* or forehead region of the brain (Fig 34, *f.c.*), the *parietal* or side region, the *temporal* region at the side of the brow, and the *occipital* region (*o.l.*), or that at the back of the head.

BRAIN CELLS.—A section of the cerebrum shows us that its outer layer consists of *grey matter* composed of brain cells, this grey matter following and dipping into the convolutions thereby affording a larger amount of cell material than would be the case in a smooth brain. Groups of brain cells are found in the other parts of the brain. In the cerebrum the grey matter is the external layer, whilst the white matter, composed of nerve fibres which carry messages to and from the brain centres, forms the inner portion of the cerebrum. It may be said that the most important brain cells are those of this outer layer of the great brain. They must exist in millions, one estimate giving over 800,000,000 as an approximate number. The cerebellum when cut in a section is seen to have its brain cells arranged in different fashion. Externally it presents a layered appearance (Fig. 32), and in section the white matter forms a tree-like pattern to which the fanciful name of *arbor vitæ*, or "tree of life" has been given. The white matter of the brain, consisting as we have seen of fibres, is arranged in definite bands or tracts, and thus, like the telephone system of a great factory, provides for inter-communication between the various groups of brain cells, as well as affording communication between brain and body.

BRAIN FUNCTIONS.—The brain in respect of the functions it discharges might be not inaptly compared to a three-storied warehouse. The lower storey of the warehouse we may suppose is given

over to the carting and packing departments of the business, the men engaged representing the lowest grade of employés. We may suppose that the second storey is given over to the routine business of the firm discharged by clerks and heads of departments. Above this, in turn, would come the offices of the heads of the firm and the partners. Applying this simile to the brain itself, we find that the chief lower centres situated at the base of the brain and upper part of the spinal cord are known as the *medulla oblongata* (Fig. 32). If we include the cerebellum (Fig. 33) along with the medulla we may arrive at some conception of the resemblance of those parts to the lower storey of the warehouse. The medulla is a highly important centre whence arise important nerves, among them the vagus nerve controlling the heart's action, breathing, and other actions. We can therefore understand why an animal that is born with the medulla developed, but the rest of the brain absent, may live for some days because its breathing, the heart's action, and swallowing may be controlled. The cerebellum is the part of the brain exercising what is called the *co-ordination of movements*, by which term is meant the bringing into harmonious action of different muscular movements of the body. The power of bringing the muscles of one side of the body into regulated action with the muscles of the opposite side, as in walking, in swimming, and in flying, is due to the control exercised upon them by the cerebellum. It is to be noted that the cerebellum does not confer the power of bringing these muscles into action. That duty is accomplished by centres in the cerebrum specially devoted to their regulation. The cerebellum in this respect is like the driver of a coach

who does not give the horses the power of doing their work, but controls their movements so as to impart a regular motion to the vehicle. It is natural that in disease of the cerebellum irregularity of muscular movements should be noted as a prominent sympton.

THE CENTRAL GANGLIA.—Buried deeply down below the upper brain in the centre of the organ we find certain masses of nerve cells constituting the *central ganglia.* The function of these parts along with certain other and associated regions in the brain have not been clearly determined. The nearest approach which can be made to an explanation of their use is that of assuming that they act as deputies of the upper brain and stand to the latter structure in the relation which private secretaries occupy to their employer. One of these central ganglia is known as the *corpus striatum,* the other being called the *optic thalamus.* It is believed that the former is a kind of "brain clearing house" through which motor messages are assorted and parcelled out when proceeding from the cerebrum to the body. The neighbour mass, constituting the optic thalamus, may it is supposed act as "a receiving house," wherein messages from the body passing to the cerebrum are received and in some fashion or other fitted for appreciation by the cells of the upper brain itself. It is highly probable that the central ganglia may, under certain conditions, act independently of the cerebrum itself. In persons who are hypnotised or mesmerised, the faculties of the cerebrum may be supposed to be switched off for the time being, leaving the central ganglia largely to carry on the parody of conscious life represented in the mesmeric state.

THE CEREBRUM.—A large amount of investigation and research has resulted in the mapping of the cerebrum into definite regions and centres. The centres of the cerebrum, as revealed by science, are not in any sense to be confused with those which figure in the old phrenological systems of localisation of brain functions. Phrenology is an effete mode of explaining either the brain constitution or the working of the organ. The general distribution of brain centres may easily be remembered if we suppose that each lobe, or half of the cerebrum, is divided into three parts (Fig. 34). Of these, the front third may be regarded as devoted to the higher operations of mind. The cells of the frontal or forehead lobes of the brain are undoubtedly those which may be credited with exercising the highest mental functions -represented by the exercise of our consciousness and will. This section may therefore be termed *the intellectual area* of the brain. The middle third we may term the *motor area*, since the centres represented in the arrangement of brain cells in this region are devoted to the government and control of the muscles of the body. The hinder third of each half of the cerebrum may be termed the *sensory area*. Here we find the centres specially connected with the receiving of impressions from eyes, ears, and other organs of sense, and it is probably in these centres, also, that such messages are fitted for transmission to the intellectual centres, there to have their meaning translated and appreciated by our consciousness.

THE DOUBLE BRAIN.—The two halves of the cerebrum, right and left, govern each the opposite side of the body, although in a limited degree each half also exercises a certain amount of control over its

own side. The nerve fibres of each half of the brain cross in the upper part of the spinal cord to the opposite side of the body, and so give us right-handedness associated with the left lobe of the brain, as the right side of the brain in turn controls the left side of the body. The left side of the brain is thus figured forth as the superior half or lobe, seeing that its functions are more complex and involve the discharge of more important duties (the conduct of the right hand, for example) than those performed by its neighbour, the right half. To what this superiority and selection of the left half of the brain as the controlling lobe is due, is difficult to determine. Whether this superiority arose from the body acting on the brain, or whether right-handedness was developed through the left half of the brain acquiring a dominant power over the right half, it is impossible to say. One important fact, however, teaches us the superiority of the left half of the brain in an unexampled manner. This fact is found in the demonstration that the *speech centre* of the left side of the brain is that by which the ordinary right-handed mortal exercises this special human gift. A similar speech centre exists on the right side, for the centres of the brain are in duplicate; but the right centre seems to remain in abeyance, and it is probably only in the case of left-handed persons, whom the right lobe dominates, that speech is controlled from the brain's right side. In cases of the disease known as *aphasia*, in which the power of speech is lost, while that of the other faculties may remain practically unimpaired, the left speech centre is found to be affected. In cases where this centre has been destroyed and where a certain amount of recovery of speech has taken place, it is believed

that the right speech centre, hitherto dormant, has
come into play.

THE SENSES.—The senses are estimated to be five
in number, including, *sight* (Fig. 35), *hearing* (Fig.
36), *touch*, *taste*, and *smell*.   It is, however, most
probable that we possess a sense of *weight*, and also
that of *temperature* or heat.   Some authorities incline
to believe in the existence of other senses, amongst
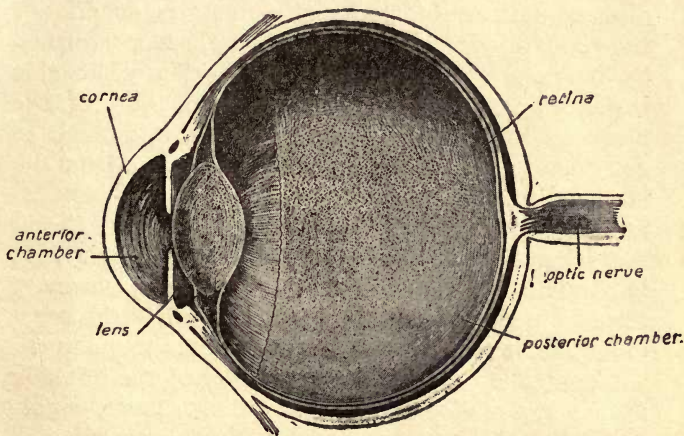
Fig. 35.—SECTION SHOWING STRUCTURE OF THE EYE.

them a sense of *direction* still imperfectly developed
in man.   The senses are mere "gateways of know-
ledge"—in other words, they simply receive inform-
ation from the outer world, modify it, and transmit
to the corresponding centres in the brain,
which in turn pass forward the information to be
submitted for judgment by the intellectual centres.
Thus we do not really see with the eye or hear with
the ear.   Seeing and hearing represent intellectual
acts to which the work of the eye and ear is only a

necessary preliminary. The work of the senses is too complicated for treatment in the present instance. It is a topic, however, of vast interest, and will well repay investigation by the aid of manuals specially devoted to the exposition of the subject.
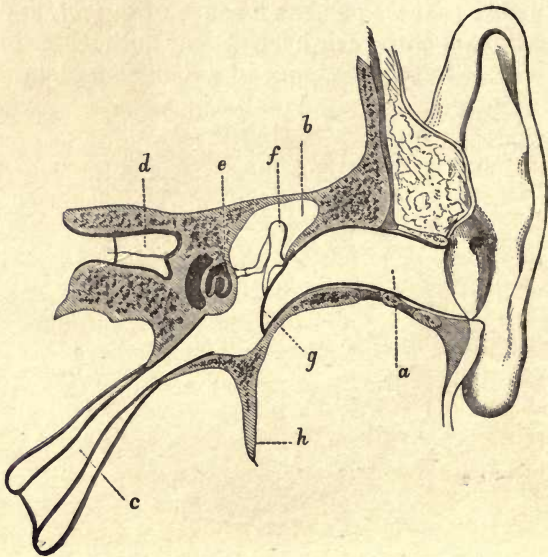
Fig. 36.—Section through the External Meatus, Middle Bar, and Eustachian Tube.

(a) External auditory passage; (b) attic of tympanum; (c) Eustachian tube; (d) internal auditory meatus; (e) cochlea; (f) ossicles; (g) membrana tympani, or "drum"; (h) styloid process.

THE END.

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