A PRIMER OF PHYSIOLOGY

E. H. STARLING, F.R.S.

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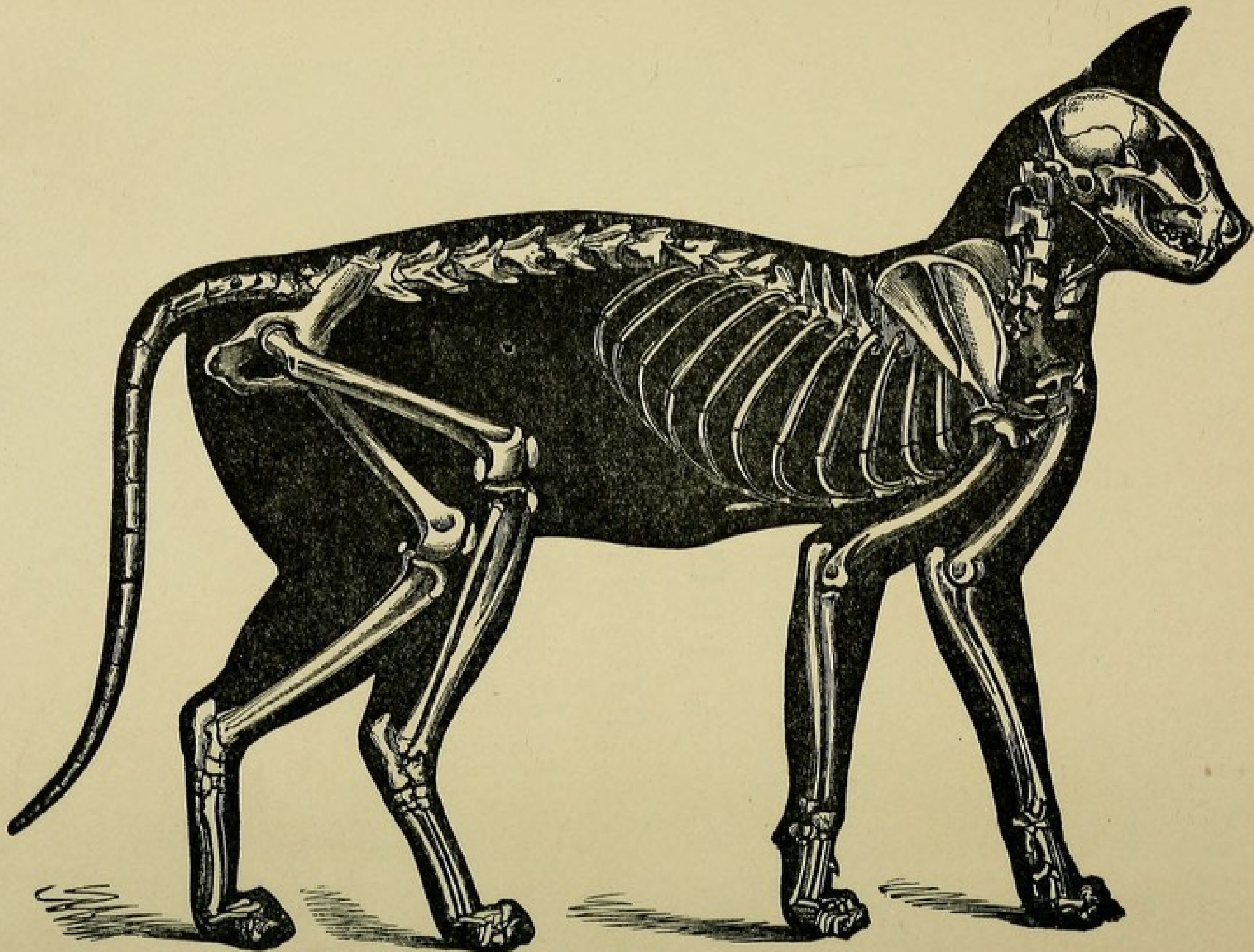

External form of wild cat and figure of the skeleton, showing the relations of the latter to the external form.

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BY

E. H. STARLING, F.R.S.

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PREFACE

In this little book I have endeavoured to present, with as few technical terms as possible, the leading ideas which make up present-day physiology. I have found it impossible to treat the subject without assuming, on the part of my readers, an elementary knowledge of the main facts of chemistry and physics; but in any curriculum the study of these subjects should always precede that of the more difficult one of physiology. Most of the illustrations in the volume are taken from Mivart's work on the Cat, and were placed at my disposal by the publishers. Six illustrations are taken from my "Elements of Human Physiology," with the kind consent of the publishers, Messrs. J. & A. Churchill. I trust that this primer will be of value to young people who are desirous of learning something of the manner in which the normal processes of life are carried on.

ERNEST H. STARLING.

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CHAPTER I

INTRODUCTORY

Physiology is the study of living things. It teaches us how our bodies and the bodies of animals are built up, and how every part of our bodies works. In chemistry you have learnt what things are made of, and have found that all the varied objects with which you are familiar consist of a few simple substances—elements, bound together in different ways. In physics you have studied what matter does, and have learnt to recognise and compare the different forms of energy under the names of heat, light, electrical energy, etc. In both these sciences you have had first to study certain facts, and then to put these facts together and find certain laws which we call laws of nature. These laws, which are derived from series of observations, enable us to predict the results of any action, and so we are able to alter and control both the states of matter and the energy of the natural forces. In fact, the use of science to mankind is to give him control over the forces of nature. Every advance in science has increased man's power of living comfortably or luxuriously, by showing him how

to harness the winds and the streams, or use the energy of the coal shut up in the earth's crust to do his work for him.

The final object of physiology is the same as that of the other sciences—viz., the improvement of man's condition. By teaching him the laws which govern all the activities of his body, it shows him how to live healthily; and, in time, the exact understanding of the human machine will enable him to put this machine right when it is out of order. This is the object of the science of medicine.

Like chemistry and physics, physiology is founded on experiment. Many experiments we can carry out on ourselves; others we can perform on parts of the body taken from animals just killed. All parts of the body do not die at the same time; and a limb-muscle or the heart, taken from a recently killed frog, will, under suitable conditions, continue to live for many hours. Other experiments may be made on the higher animals, any pain being prevented by the use of chloroform or some such anæsthetic. Although there is a very great gap between the intelligence of the lower animals and that of man, depending on the greater development of the brain in the latter, most of the other functions of the body are closely alike throughout the whole of the vertebrate kingdom. Thus the processes of digestion in the frog differ only in degree from those in man; and although the heart of the frog presents considerable divergence in structure from that of man, the general laws governing its action are practically identical in the two cases.

How do we recognise that anything is alive? What are the properties of living things which we have to analyse and study? If we take for example a tame mouse, we see that it is always in movement. When it is not changing its position, it is washing its face with its fore-paws, or eating; and even when these movements are absent, we can see the quick movements of breathing and, if we pick it up, can feel the beat of the heart through the chest-wall. At the same time we notice that it is warmer than the surrounding air; and if by means of a thermometer we take its temperature, we find that this does not change with variations in the surrounding temperature, but remains at a constant level of about 100° F.

The production of movement and of warmth means expenditure of energy. In the case of the larger animals we use this energy for the performance of useful work, such as the drawing of carts, etc. If we employ a traction-engine for the same purpose, the energy is furnished by the combustion of coal or petroleum—*i.e.*, the union of the carbon and hydrogen of these substances with the oxygen of the atmosphere to produce carbon dioxide (CO_2) and water, the process being accompanied by the **evolution of heat**, part of which in the engine is converted into mechanical work.

Has the energy in the living animal a similar source? There is no difficulty in answering this question. We know that every animal must be fed if it is to be kept alive. If the mouse be starved, its power of doing work becomes less and less, its temperature falls, and finally it ceases to live. To keep an animal in health and enable it

to work, it must receive a certain amount of food every day. Thus each day the mouse takes in a certain amount of oats and water and gives out in its fæces and urine, its solid and liquid droppings, a much smaller amount of material. We know that matter is never destroyed. What has happened to the rest of the food?

When a candle burns, the whole of it disappears, although the material of the candle is not lost. If the candle be enclosed in a bottle, it very soon goes out, unless a constant stream of air is kept up through the bottle by an arrangement similar to that in the diagram. If the air entering and leaving the bottle be analysed, it will be found that, whereas the air entering consists roughly of four parts of nitrogen, one part of oxygen, and the merest trace of **carbon dioxide** or **carbonic acid gas**, the air which has passed over the candle has lost a considerable proportion of oxygen, its place being taken by carbon dioxide and by water vapour. These two substances can be collected by passing the air which leaves the bottle first over sulphuric acid to absorb the water, and secondly over soda-lime to absorb the carbon dioxide. If the candle be weighed at the beginning and at the end of the experiment, it will be found that its loss of weight is smaller than the gain of weight of the two vessels 3 and 4, since the carbon dioxide and water represent not only the candle which has been burnt but also the oxygen of the atmosphere which has been used up in the burning of the candle. In a careful experiment it will be found that these quantities exactly balance each other,

and that in the whole operation there has been neither gain nor loss of matter.

It is quite easy to perform an exactly similar experiment on a mouse without inconveniencing it in the slightest degree. The mouse is placed in a bottle, through which dry air free from CO_2 is led. The air, after leaving the bottle, is passed, as in the previous experiment, over sulphuric acid and soda-lime. The mouse is weighed, its temperature taken, and it is then placed in the bottle. At the end of half an hour it is again taken out.

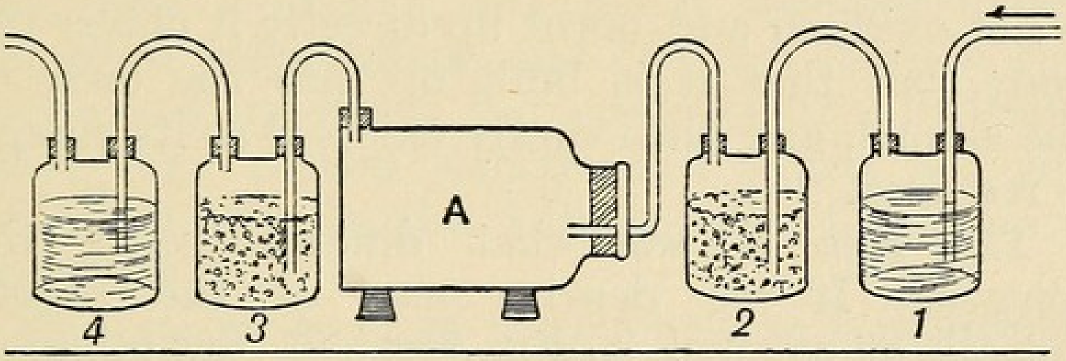


Fig. 1.—The bottles 1 and 4 contain soda lime, to absorb CO_2. Bottles 2 and 3 contain bits of pumice moistened with sulphuric acid, to absorb the water vapour.

It will be found that it has lost weight, but this loss of weight is more than balanced by the gain in weight of the sulphuric acid and soda-lime. If the air issuing from the whole apparatus be analysed, it will be found to have lost a certain amount of oxygen, and this loss of oxygen *plus* the loss in weight of the mouse is exactly equal to the weight of carbon dioxide and watery vapour which have been produced.

So we see that here also no matter is lost or destroyed. The mouse is constantly taking in oxygen in addition to its food. This oxygen

unites in the body with carbon and hydrogen derived from the food, and produces thereby carbon dioxide and water.

The maintenance of the life of the animal depends on these two factors—the taking in of food and of oxygen. If the animal be deprived of food it dies, but not immediately; and if we examine an animal which has been starved for one or two days and contains no food in its alimentary canal, we still find that it is capable of movement, that it is warm, and is giving off carbon dioxide and water: showing that the food is not oxidised and burnt up directly it enters the body, but that it is built up into the body of the animal, and then slowly oxidised as its energy is required.

The case is somewhat different with the oxygen. If we deprive any of the higher animals of oxygen, it dies within a few minutes. This deprivation can be carried out by constricting the neck, or by putting the animal in an atmosphere which contains no oxygen or which prevents the taking in of oxygen—as, *e.g.*, coal-gas. In either case the animal is suffocated, and dies within a few minutes.

Thus the food taken in by the mouth is, to the greater extent, built up to form part of the body, and this is gradually oxidised by the oxygen taken in with the air breathed, giving rise immediately to carbon dioxide, water, and other waste products. One of the main subdivisions of our work must therefore be the examination of the constituents of the food, the tracing out of the changes undergone by the food after it has been eaten, the way

in which it is built up into the body, and finally, the manner and locality in which the different constituents of the food meet the oxygen of the air and undergo combustion.

This includes a number of what are called **Functions.** The taking in of oxygen and the giving out of carbon dioxide in breathing is the function of **respiration**, the taking in of food and the changes it undergoes immediately after being taken in is the function of **digestion.** The changes which the food, or its constituents, undergo in the tissues of the body, including their final oxidation, are classed together under the term **metabolism,** and the last stage is the mechanism by which the products of oxidation, other than carbon dioxide and water, are got rid of, chiefly by the kidneys—the function of **excretion.**

The use, however, of these functions is to furnish energy for the body—energy which may be applied in the forms of work or movement, or in keeping the temperature of the body constant in the midst of cooler surroundings. The first question which we must decide is whether the great doctrine of "Conservation of Energy," which holds in the external world, is also applicable to our bodies. To this end we must measure the total energy of the food taken in by the body, (or rather the energy which this food can liberate if burnt in the presence of oxygen,) and compare this amount with the total energy given out from the body in the form of work or heat. The energy taken in by the body is easily estimated. All that we have to do is to collect the food given to an

animal during one day, burn this in oxygen, and measure the total amount of heat which is evolved. From this heat we must subtract the heat which can be obtained by burning the solid matters of the urine and fæces, since these contain substances, derived from the food, which are not fully oxidised. The result is the total energy available for the body. To measure the total energy given out by the body, the best method is to allow the animal to do no external work, and therefore to measure the whole amount as heat. In both cases the measurement is carried out in an instrument called a calorimeter—which, however, must be more complicated when we wish to measure the heat given out by an animal than when the heat produced by the combustion of the food-stuffs is to be determined.

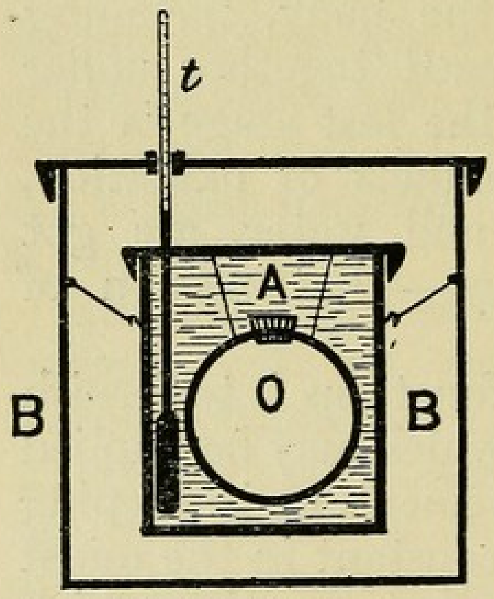


Fig. 2.—Calorimeter.

A calorimeter for the determination of the heat produced by the combustion of food or any other substance is shown diagrammatically in Fig. 2. The food is placed in a steel shell (O) which contains compressed oxygen. The whole shell is immersed in water (A), and around the water are concentric polished chambers (B), to prevent any gain or loss of heat of the apparatus from the external air. When the temperature of the whole apparatus is constant, the food is fired by electrical means. It is totally burnt up by

the oxygen, and produces a certain amount of heat, which warms the surrounding water. The temperature of the water is taken accurately before and after the combustion. The amount of water is also measured, and the amount of heat can thus be directly determined.

Accurate measurements have been made of the heat produced by burning the chief food-stuffs. Thus, one gram of sugar when burned produces 4·1 calories—that is to say, enough heat to warm 4·1 kilograms of water 1° C. One gram of fat would produce more than double—namely, 9·5 calories; and one gram of the chief nitrogenous food-stuffs, so-called **proteids,** such as white of egg or lean meat, would produce 4·5 calories. Thus, knowing the amount of food taken in during the day, we know how much energy the animal has at its disposal. In a more complicated calorimeter the total heat output of the animal can be measured, and it is found that the latter quantity is exactly equal to the former.

The result of our experiments is therefore to show that energy is neither created nor destroyed in the body. All the energy which is given out by the body comes from without—namely, from the food, by its union with the oxygen of the atmosphere. An important part of our work, therefore, will be the consideration of the manner in which the energy of the food is utilised for the various functions of the body, such as the production of movement and work, as well as of heat, electrical changes, movements of fluid, etc., in the body.

So far we have dealt with the living animal as

if it were a mere machine or locomotive; but there are important peculiarities of the living animal which we must now consider, and which have no analogies in the dead machine. If we study a mouse in its cage, we see that it is moving spontaneously, and that these movements all seem to have some motive: they are directed movements. If we bring our hand to the side of the cage, the mouse moves away; if food is placed in the cage, it moves towards the food and begins to eat it. If it be placed in a very warm room, the animal becomes quiet, the movements diminish, and we find that the output of carbon dioxide by the animal is also diminished. This diminution shows that there is less heat produced than before. If the cage be placed in a cold room, the animal becomes much more lively, and the output of carbon dioxide is increased, showing an increase of the processes of combustion, and therefore of the amount of heat evolved. It is a common experience that we ourselves are disinclined to take active exercise in extreme heat, whereas on a cold day we are impelled to move rapidly, in order, as we say, to keep ourselves warm; and this increased activity can be shown to be attended by increased output of carbon dioxide.

All these alterations of the activity of the animal are for its good; they are evoked by changes outside the animal, and are what we call **adaptive reactions**—*i.e.*, movements elicited by change without, and directed to the preservation of the animal in a healthy and normal condition. We come to the same conclusion by studying ourselves or our fellow-creatures. The whole of education is

merely the application of the right stimuli—that is to say, changes which act on the body to evoke reactions which may be useful to the man in his future life. As we study the various functions of the body, we shall see that they are all alike in this one respect—namely, that they are governed by the needs of the rest of the organism and aroused by changes in the surroundings of the animal. These complicated reactions make up the whole of life; and the most interesting part of physiology is their study and their analysis, beginning with the simplest and ending with the most complex of our daily activities. In some animals we can contrive to shut out all impressions from the exterior, and we find that the result is not merely to destroy the movements in response to stimulation, but also to abolish all spontaneous movements. In these animals at any rate the whole of life is a response to changes in the animal's environment, and the energy for this response is, as we have just seen, furnished by the combustion of the food.

These adaptive reactions are not, however, confined to movements. We find, for example, that a certain change in the kind of food given to the animal may injure its health, but after a short time the animal gets used to its new diet: it has reacted to the change in its condition, and its organs have undergone such an alteration as to fit them for the proper digestion of the new food.

A very important factor in our growth or bodily education is our adaptation to poisons—poisons of the food or living poisons which, in the form of bacteria and other microbes, can invade

the body and produce sickness or death. Thus, in vaccination, an enfeebled dose of an organised poison (smallpox) is introduced into the body. The patient is slightly ill and then recovers; after his recovery it is found that he is adapted to this poison, and a big dose may now be introduced into him without producing any evil effects. In the same way, if diphtheria poison be introduced into a horse, the animal is ill and then recovers; larger and larger doses can now be injected, and, after some time, it is found that the reaction of the horse to the poison has resulted in the production of a body called **antitoxin,** which circulates in his blood and has the power of destroying diphtheria poison. We can obtain this antitoxin by bleeding the horse, and use it for the destruction of the poison in cases of diphtheria in man.

Thus the whole of life is a series of adapted reactions. Physiology consists in the study of these reactions, in their localisation, and in the research into the mechanism by which each of them is carried out.

CHAPTER II

STRUCTURE

In physiology we have therefore to consider the changes of matter which occur in the body—namely, physiological chemistry; the changes of energy involved in movement and heat production; and the mechanism by which these are co-ordinated with one another and with the changes in the environment of the animal. Before, however, entering on this strictly physiological part of our subject, we must have some idea of the machinery at the disposal of the animal.

The characteristic features of living beings which we have studied in the mouse are the same throughout the animal and vegetable kingdoms; all living beings are in fact built up on the same fundamental principle. If we examine a drop of stagnant water under the microscope, we find, amongst other micro-organisms, little microscopic lumps of moving jelly, which are known as **amœbæ.** These can be seen to move about spontaneously, to eat up little food particles, to excrete or turn out of their bodies the indigestible portions of the food, and finally, to grow and at a certain stage in their history to divide

and produce a new generation of amœbæ. In the centre of the lump of jelly is a rounded body which is known as a nucleus, and the whole animal is spoken of as a cell.

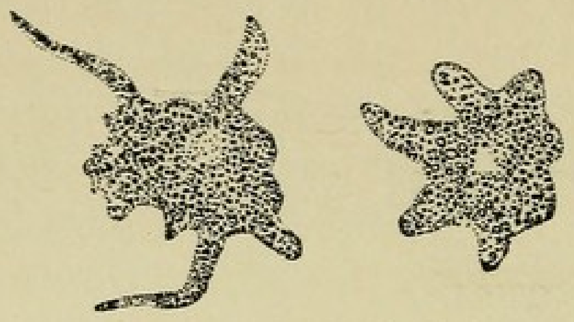


Fig. 3.—Amœbæ : unicellular animals.

A **cell** is thus a little mass of living material which is called **protoplasm**, containing in its centre a specialised portion known as the **nucleus**. There are many varieties of such unicellular animals. Thus, in some (as, *e.g.*, the vorticella) we find that there is a differentiation of parts even within this microscopic structure. At one end is a mouth fringed with small processes known as **cilia**, which leads into a digestive cavity or stomach. In the main mass of protoplasm surrounding the stomach we find the nucleus, and also little cavities containing fluid (contractile vacuoles), which diminish in size at intervals so as to squeeze the fluid they contain through the rest of the body of the animal. The whole animal is attached to a piece of stick or rock by a long stalk, and this stalk is endowed with contractile powers. The slightest movement in the vicinity of the animal causes the stalk to shorten, curling up in a corkscrew form, so that the vorticella is withdrawn close to its base out of danger. We have, therefore, in this tiny animal the processes of digestion, metabolism, excretion, and reaction to stimuli, every reaction being adapted to the preservation of the animal from injury. A

little higher in the scale of animal life we come to such organisms as sponges, which are aggregations of amœba-like cells; and in the hydra the body cavity is surrounded by a wall composed of two layers of cells, of which the outermost layer carries out the reactive movements of the animal, while the innermost layer surrounding the body cavity serves for the digestion of the food.

As we go higher in the scale, this separation of particular sets of cells for certain objects becomes more and more marked; and in ourselves and the higher animals the whole body consists of cells packed together in various arrangements, and having different appearances according to their functions. Every cell of the body has some particular function, and the welfare of the whole body depends on the welfare and the proper action of each of its parts. Thus, in ourselves, the outer layer of the body consists of cells which are especially adapted for protection, and also for feeling, or for receiving the impressions produced by changes in our surroundings. Our innermost layer of cells, lining the alimentary canal, are specially fitted for the digestion and absorption of the food. Between these two layers we find the skeleton, which gives firmness to the body, and all the apparatus for reaction and movement and for furthering the food from the alimentary canal to all parts of the body.

We can arrive at a sufficient idea of the way in which our own bodies are built up by making a rough study of one of the higher animals, such as the rabbit, or a cat or kitten; and it would be

advisable for any person beginning the study of physiology to procure a recently killed cat or kitten and by actual dissection and handling of its organs learn the relations and arrangement of the various parts of the animal body. The body of the cat, as of man, consists of head, neck, trunk, and four limbs, the whole being covered with skin. On cutting through the skin of a limb and tearing it off, a process which can be effected without much difficulty, we find underneath a layer of flesh or meat. Here and there this may be covered with a thin layer of fat. With a knife and forceps it is easy to separate the flesh into a number of bands, which are called **muscles.** At each end these fleshy bundles are continued into white glistening cords known as tendons, and these cords can be traced to their insertion or attachment into the bones forming the framework of the limb. If in the fore-limb we take the muscle which corresponds to our biceps, its tendons will be found to be attached above to the shoulder-blade or scapula, and below to one of the bones of the lower leg corresponding to our fore-arm. If the upper end be fixed and the muscle be pulled, the effect will be to bend the lower leg on the upper; and in ourselves it is a common experience that, when the arm is bent at the elbow, the biceps muscle swells up. If the animal that we are dissecting has been killed only recently, so that it is still quite warm, the fleshy muscles may be excited to contract by stimulating them with electric shocks. If electric shocks be passed through the biceps muscle, it will be seen to shorten, thicken, and draw its two attachments

nearer together. These muscles are the means by which all the movements of the body are carried out.

As we are dissecting out the muscles we come across small white glistening cords, which are the **nerves.** As these are traced up they tend to run

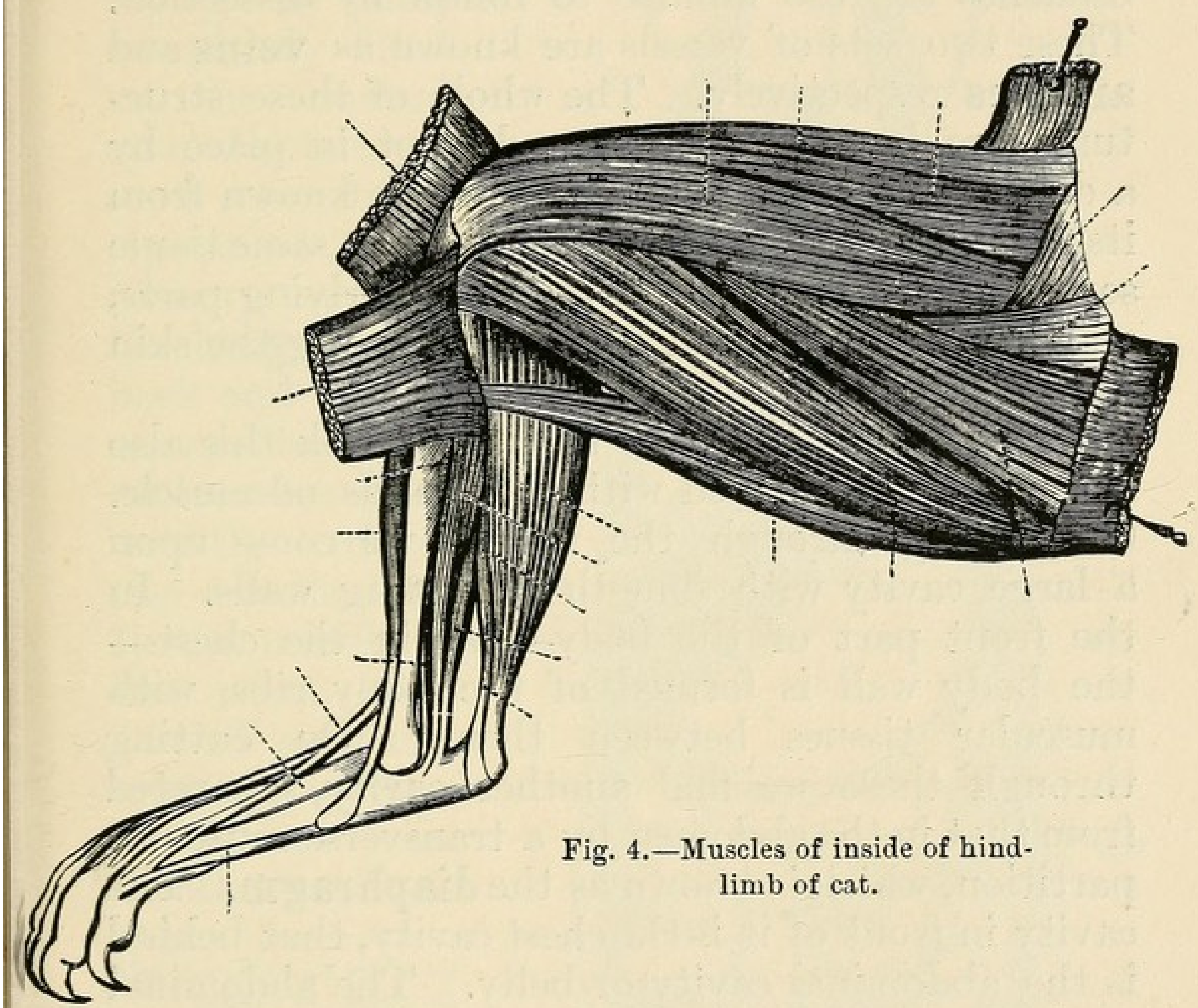


Fig. 4.—Muscles of inside of hind-limb of cat.

together so as to form one or more large trunks at the level of the shoulder. Traced down towards the paw they divide again and again, and finally disappear as microscopic branches in the muscles or skin.

Besides these we shall see tubes of two kinds:

one kind is dark in colour, and on pricking is found to contain blood; the other kind, generally running alongside of the first, is almost empty, and has much thicker walls. Both kinds, when traced upwards, join together to form larger trunks, and traced downwards subdivide until their branches are too minute to follow by dissection. These two sets of vessels are known as **veins** and **arteries** respectively. The whole of these structures are bound together and kept in place by a delicate felt-work of fibres, which is known from its function as **connective tissue.** The same tissue serves to connect the skin to the underlying parts, and has to be torn through in removing the skin from the limb.

On removing the skin from the trunk this also is found to be covered with flat bands of muscle. On cutting through the muscle we come upon a large cavity with smooth glistening walls. In the front part of the body—*i.e.*, in the chest—the body wall is formed of the bony ribs, with muscular tissues between them. On cutting through these we find another cavity, separated from that in the abdomen by a transverse muscular partition, which is known as the **diaphragm.** The cavity in front of it is the chest cavity, that behind is the abdominal cavity or belly. The abdominal cavity is quite filled with the entrails or **viscera.** At the front part, just behind the diaphragm, we can see on the right side a large brown organ known as the **liver.** To the left of this is a large sac forming the **stomach,** and the rest of the cavity is filled up with a coiled tube, which is the **intestine.** By moving the intestine to either side

it is easy to see the two **kidneys** lying at the back of the abdominal cavity.

The chest cavity is also completely filled in the normal animal; but, as soon as it is opened, air rushes in, and the **lungs** shrink back and can be seen as two light pink masses lying on either side of the middle line. In the middle of the chest is a conical muscular or fleshy organ, which contains blood, and is

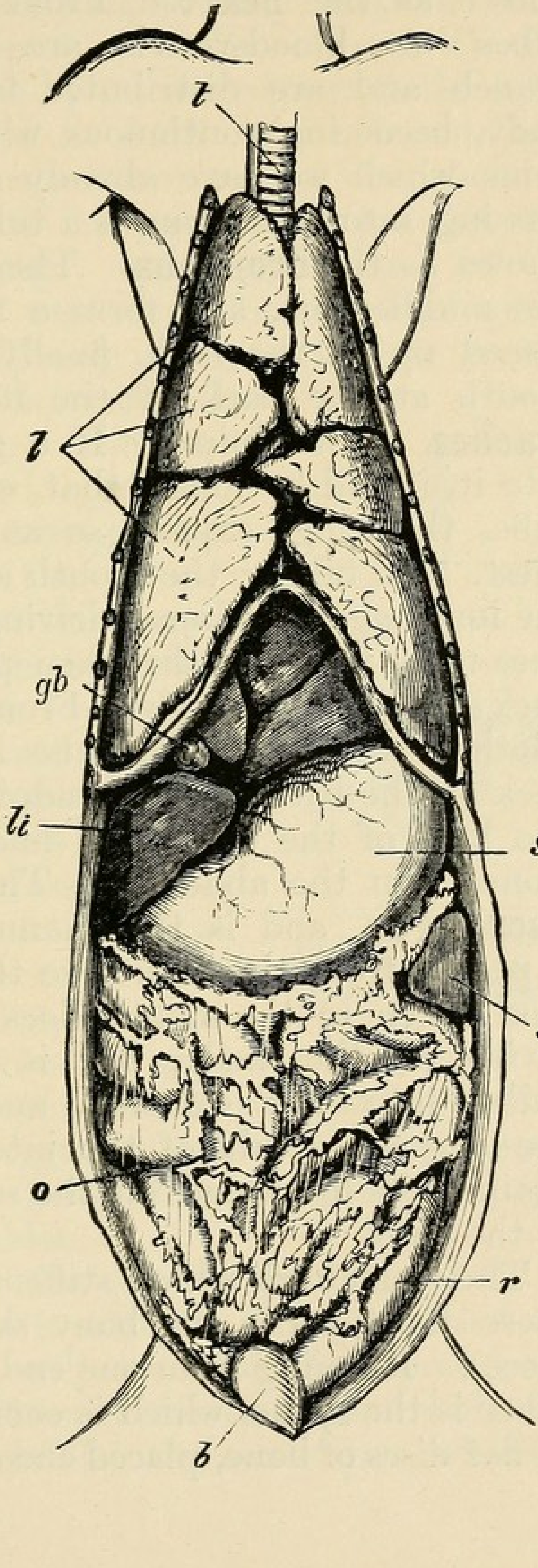
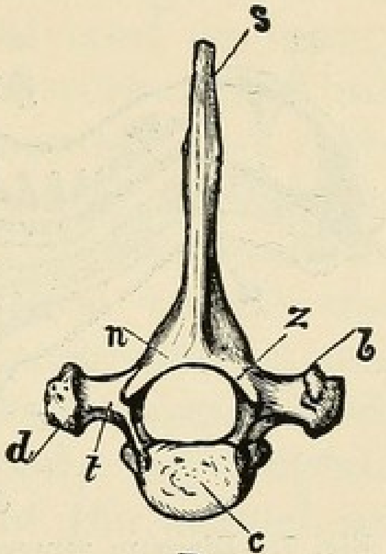


Fig. 5.—View of the cat's viscera in situ, as seen on removing the lower wall of the belly and chest. (*b*) Urinary bladder. (*gb*) Gall bladder. (*l*) Lung. (*li*) Liver. (*o*) Omentum: a thin membranous apron lying on the coils of intestine. (*sp*) Spleen. (*t*) Trachea. (*s*) Stomach.

known as the **heart**. From this organ large tubes or blood-vessels are given off, which branch and are distributed to all parts of the body, becoming continuous with the arteries and veins which we have already seen in the limb. Passing into each lung is a tube with rigid walls, known as the **bronchus**. These join together in the middle line, and form a tube which can be traced up in the neck, finally opening into the mouth at the back of the tongue; this is the **trachea** or windpipe. If a glass tube be tied into it, it will be found that, on blowing into the tube, the lungs expand so as to fill the whole chest. On taking the mouth away from the tube the lungs again collapse, driving out the air, and once more form the shrunken pink masses at the back of the chest cavity. From the mouth itself another large flattened tube leads through the neck at the back of the windpipe, passes through the back of the chest, and finally opens into the stomach in the abdomen. This is the **gullet** or **œsophagus,** and is the channel by which food is passed from the mouth to the stomach. Thus food taken by the mouth does not pass into the cavity of the belly, but is sent through the gullet into the stomach, and thence through the long coiled tube of the intestine, which opens again at its lower end on the surface of the body at the anus.

The framework which stiffens and supports all these structures is the bony skeleton (see frontispiece). Running from one end of the body to the other is the **spine**, which is composed of a number of flat discs of bone, placed end to end, so that the

column is not perfectly rigid, but permits the body to bend in one direction or the other. To the anterior part of the spine are attached the ribs, which are connected in front to the breast-bone and form a bony cage surrounding the whole of the chest, fitted by its rigidity to prevent the lungs from collapsing. Attached to each of the discs of bone, or **vertebræ,** forming the spinal column, is a small ring of bone known as the vertebral arch. The vertebral arches of adjacent vertebræ, being closely applied together, form a canal running the whole length of the spine. In the fresh animal this canal is filled with a thick white glistening band or cylinder, similar in appearance to the nerves we have already seen in the limb. This is the **spinal cord.** Between each pair of vertebral arches is a small hole on either side. On opening the spinal column it will be seen that from the spinal cord arise nerves, known as nerve roots, which pass through these openings and join together to form the great nerve trunks, some of which we have noticed in the region of the shoulder.



B

Fig. 6.—Fifth dorsal vertebra of cat, showing vertebral arch (*n*), and the flat disk or body (*c*).

To understand the structure of the head it should be compared with the dried skull of the same animal. It will be seen that practically the whole of the head consists of the skull, the mouth being formed by the lower jaw, which is

jointed on to the bones of the skull. At the back part of the skull will be seen a round hole, which leads into a large hollow cavity in the skull. This round hole is directly over the spinal canal formed by the apposition of the arches of the vertebræ. Through it the spinal cord enters the skull, and there widens out to form a rounded mass of nervous tissue known as the **brain.** From the brain also nerve trunks are given off, and

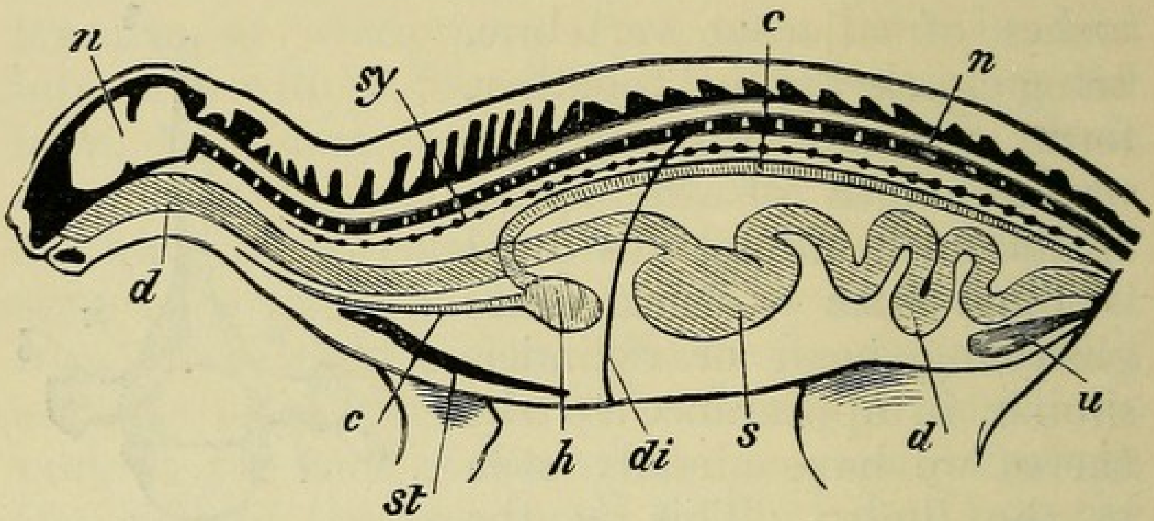


Fig. 7.—Diagram representing a vertical section through the cat's body. (*n*) Brain and spinal cord contained within the skull and backbone, which are deep black. (*st*) Breast bone. (*d d*) Alimentary canal. (*s*) Stomach. (*h*) Heart. (*c c*) Great blood-vessels. (*u*) Urinary bladder. (*sg*) Sympathetic ganglia. (*di*) Diaphragm.

pass through small holes in the base of the skull, to be distributed to the various parts of the head, face, and neck.

The body thus consists of a bony skeleton which encloses behind an almost closed cavity containing the spinal cord and brain. In front it partially encloses, by the ribs, the large body cavity. Through the body cavity passes a tube, the **alimentary canal,** formed by the gullet, the stomach, and the intestines. To the skeleton

is attached by joints the bony framework of the four limbs.

All parts of the body are connected and bound together in two ways. In the first place, we find blood-vessels of two kinds, arteries and veins, which are all of them derived from or connected with the central fleshy organ in the chest cavity—viz., the heart. In the second place, all parts of the body are supplied with nerves which, joining together into larger trunks, are finally connected to the spinal cord or brain. In these two ways, therefore, the workings of all parts of the body can be harmonised and each part made subservient to the needs of the whole. It is through the blood-vessels that the products of digestion of the food are carried to all the organs of the body for their nourishment and growth. It is through the nervous system that the complex movements of the body are adapted to changes in the surroundings of the animal, so that it may pursue its food or escape from its enemy. These adapted movements, evoked by external events, are often classed together as **reflex actions.**

CHAPTER III

THE FOOD

We have already seen that the food is the source of all the energy of life. As we have now to trace the alterations of this food in and through the body, let us take the food of man and see of what it consists. Bread, butter, and meat together would make a nourishing meal; and we shall find that these three substances contain the same approximate principles as all the other varied kinds of food of which we make use.

Bread is made from flour and water. If we take some of the flour, put it in a muslin bag and wash it under the tap, a large amount of fine white powder is washed away from it, leaving finally a sticky mass in the muslin, which is known as vegetable gluten. If we allow the washings to settle, a fine white powder falls to the bottom of the vessel; and this powder, examined under the microscope, is seen to consist of granules with concentric rings. These granules are starch. A similar substance can be obtained from practically all the cereals and from other vegetable food, especially potatoes. This starch is not soluble in cold water, but if boiled with water enters into

a state of semi-solution, and forms a thick fluid which becomes a solid jelly on cooling. It is tasteless, inodorous, and chemically inert—that is to say, it has no acid or alkaline properties. On heating it gives off water, and chars, leaving a solid mass of carbon. If subjected to accurate analysis, it is found to consist of three elements—carbon, hydrogen, and oxygen—the two latter substances being present in the proportions to form water. Its composition can be represented by the formula $C_6H_{10}O_5$. In consequence of this composition it is spoken of as a **carbohydrate**. If we add a little acid to a solution of starch and boil for half an hour, the solution becomes clear, and at the end of this time contains no starch at all, the whole of this substance having been converted into grape sugar. Under the influence of the acid the starch has taken up water according to the following equation :—

$$\underset{\text{Starch.}}{C_6H_{10}O_5} + \underset{\text{Water}}{H_2O} = \underset{\text{Grape sugar.}}{C_6H_{12}O_6}$$

This grape sugar, which is found in large quantities in fruits and honey, is a type of a class of foods known as the **sugars**, the most familiar member of the group being cane sugar. All these sugars have the formula $C_6H_{12}O_6$, or are derived from two molecules of a sugar of this formula, with the loss of one molecule of water, according to this equation :—

$$\underset{\text{Grape sugar.}}{C_6H_{12}O_6} + \underset{\text{Fruit sugar.}}{C_6H_{12}O_6} - H_2O = \underset{\text{Cane sugar.}}{C_{12}H_{22}O_{11}}$$

The sugars, like starch, easily yield up water

and leave carbon behind. In the case of cane sugar we can effect this change by means of strong sulphuric acid. If a little warm water be poured on cane sugar and then strong sulphuric acid added, the whole mass swells up and chars, the sulphuric acid drags the water from the sugar, and we get a pasty mass of charcoal or carbon left. The sugars belonging to the grape-sugar class are easily oxidised, and in alkaline solutions will deprive substances like copper salts of oxygen. All the carbohydrates are easily combustible; if burnt in the air or oxygen they give rise to carbon dioxide and water. One gram of dextrose, when completely burnt, will give out 4·5 calories—that is to say, enough heat to raise 4·5 kilograms of water 1° C.

The butter in our typical meal consists of fat. **Fats**, like the carbohydrates, are directly combustible, and have indeed been used from time immemorial as the commonest means of light and heat. In their combustion they give out more energy than the carbohydrates, one gram of fat evolving, on complete oxidation, 9·5 calories of heat. Some light is thrown on the composition of fats by the study of the changes which go on when they are used to make soap. In the manufacture of soap, animal fats are boiled with an alkali, soda. After some time we get a gelatinous fluid, and on adding salt to this fluid soap is thrown out of solution. It can be collected and moulded into bars or tablets. If the remaining solution be evaporated down, we finally get a thick clear fluid, which is glycerin. In this process the soda combines with the chief constituents of the

fats—namely, the fatty acids—leaving over the other constituent, glycerin.

The fats, as they occur in the body or in butter, are therefore compounds of fatty acids with glycerin. There are many different kinds of fatty acids, the three chief ones being palmitic, stearic, and oleic. On analysis they are found to contain the same elements as the sugars—namely, carbon, hydrogen, and oxygen ; but the oxygen is much less in proportion than in the case of the carbohydrates. Thus the formula of stearic acid is $C_{18}H_{36}O_2$. The combinations of these acids with glycerin are called palmitin, stearin, and olein. Of these the first two are solid, while the latter is liquid at the ordinary temperature. Most of the fatty acids belong to a great group having the formula $C_nH_{2n}O_2$. A familiar example of the lower members of this group is acetic acid, which is the main constituent of vinegar, $C_2H_4O_2$. Another important member is that containing six carbon atoms—namely, caproic acid, having the formula $C_6H_{12}O_2$.

We have finally to consider the sticky mass left over after washing the flour. This gluten belongs, like the main constituents of meat, to a class of bodies known as **proteids**. When heated, these bodies give off an odour of burnt feathers and a large amount of ammonia (NH_3), showing that they differ from the two classes which we have just considered in containing nitrogen. They also contain sulphur, since, if they are boiled with potash and a lead salt added, a black precipitate is produced, consisting of lead sulphide. Their other constituents are carbon, hydrogen, and oxygen. We can study the characteristics of

this group by taking white of egg, which consists of an almost pure solution of proteid. This is a tasteless substance, neutral, chemically indifferent. If a solution of it be boiled, it undergoes what is known as coagulation—that is to say, it becomes solid—an experiment which is demonstrated whenever an egg is boiled for breakfast. It resembles starch, but differs from the sugars, in that it will not pass through parchment paper or animal membranes—*i.e.*, it is indiffusible. Proteids are found in large quantities in all animal cells and tissues—in fact, protoplasm has sometimes been said to consist of "living proteid"; but as a matter of fact we never find, in living cells, proteid quite free from carbohydrates or fats.

Thus there are three classes of food-stuffs, which together, in varying proportions, make up the whole of our foods. Many of our dishes are artificially compounded of these three substances; flour, which consists of only two—namely, proteids and carbohydrates—is mixed with suet or fat for most culinary purposes. In an omelette consisting of flour, eggs, and fat, all classes of food-stuffs are represented.

It is important to know how much of these foods should be supplied to an animal in order to meet its daily requirements. It is evident that the amount will vary with the size of the animal and with its activity; and it is a familiar experience that hard muscular work increases the appetite—that is to say, the need of the body for food. The exact amount of each food required will depend on the nature of the food and its content in proteid, fat, or carbohydrate. A number of

experiments have shown that a man doing ordinary work requires in 24 hours 100 grams proteid, 240 grams carbohydrate, and 80 grams fat. Considerable variation is possible in this diet. Thus some of the carbohydrate can be omitted and the amount of fat increased ; proteid can be slightly diminished if the fat and carbohydrate are at the same time largely increased. In any diet the main point to consider is its energy-giving value. A man requires in the day about 3000 calories to supply his loss of energy by heat and work ; and in every case we can tell whether a diet is sufficient or not by computing how much heat will be given out by the complete combustion of the day's food. Thus the ordinary ration of the British soldier would be quite inadequate if it were not that he is expected to supply himself with his chief energy-giving food in the shape of groceries.

Every diet, besides the three classes of food-stuffs just mentioned, contains two others—namely, **water** and **mineral salts.** These substances, though absolutely necessary for the maintenance of life, do not serve as sources of energy, but act rather as vehicles or media for the suspension or solution of the other food-stuffs. Every living tissue, whether of man or animals, is in fact found to contain as an essential part a large number of salts—namely, chlorides, sulphates, and phosphates of calcium, magnesium, sodium, potassium, as well as iron in organic combination. An animal fed with food which has been washed free of its salts will die as rapidly as an animal which is totally starved.

CHAPTER IV

DIGESTION

We must now consider how these classes of food are so altered in the body as to be able to be taken up, carried to all parts, and built into the totally different substances which form the constituents of the various tissues of the body. That a considerable amount of change in the food is necessary is at once apparent, when we consider that a man can form the tissues of his brain, muscles, bones, etc., out of the tissues of the wheat-plant, and that he will form the same tissues if, instead of wheaten flour, he employs peas or beans, eggs or meat.

The alteration and preparation of the food is carried out in the **alimentary canal,** which, starting at the mouth, leads by the gullet into the **stomach.** This organ lies at the upper part of the abdominal cavity. From it the food passes through a tube about thirty feet long, which lies in coils in the abdominal cavity. The upper twenty-five feet is narrow, and is known as the **small intestine;** the lower five feet is much wider, and forms the **large intestine,** and this latter tube terminates again on the outside of

the body by the anal orifice. The whole tube from mouth to anus is lined with delicate cells which are specially modified for their functions, the digestion and absorption of food. Round these cells the main wall of the tube is formed of muscle, which has the function of driving the food gradually on from the upper to the lower part of the tube, and at the same time mixing up thoroughly the contents of the canal. Since the whole work of digestion and absorption is done by the lining cells, in all the higher animals special arrangements are developed in order to increase their number without taking up too much space. Thus, from the mouth, stomach and

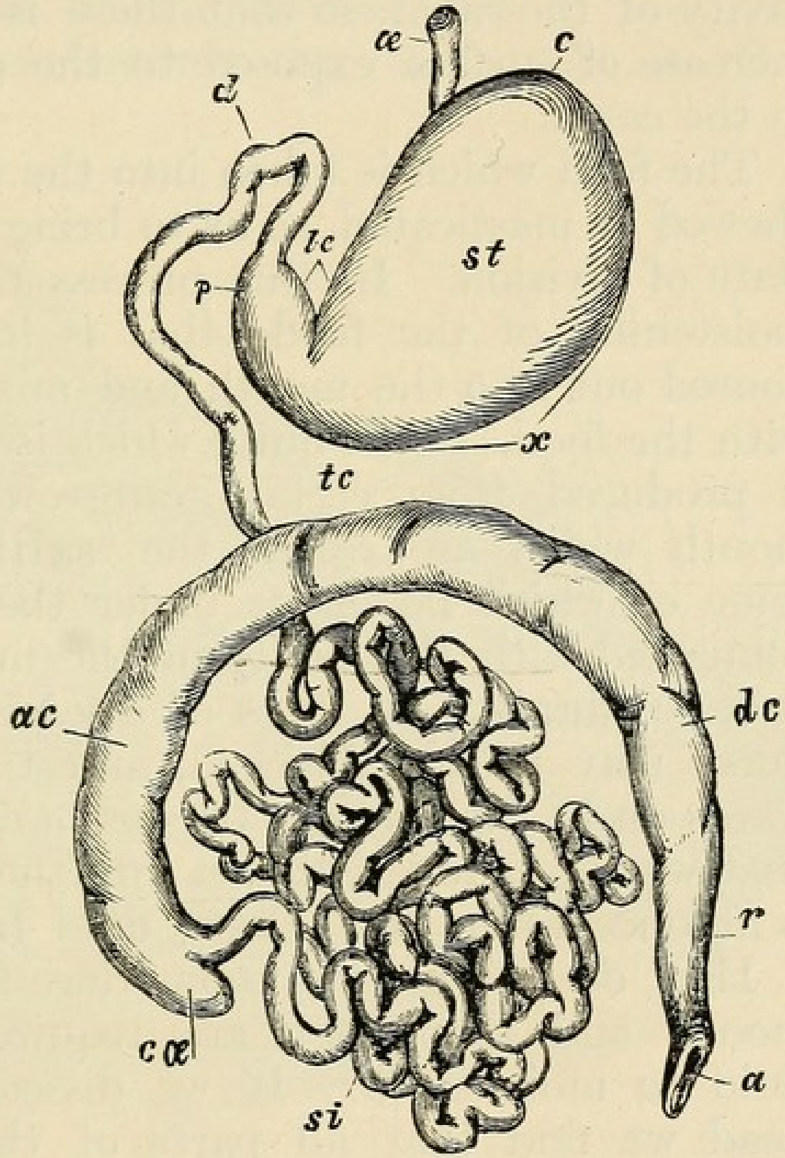


Fig. 8.—View of alimentary canal of cat. (œ) Gullet. (st) Stomach. (si) Small intestine. (ac dc) Large intestine. (a) Anus.

intestines special outgrowths of the cells occur; these outgrowths form compact masses of branching tubes all lined with cells, and are known as **glands**. In the small intestine we find ingrowths of these cells on finger-like processes into the cavity of the canal, so that there is an enormous increase of surface exposed to the digesting food in the canal.

The food which is taken into the mouth is first chewed or masticated, so as to bring it into a fine state of division. In this process there is also a moistening of the food—that is to say, fluid is poured out into the mouth and mixed intimately with the food. This fluid, which is called **saliva,** is produced from certain outgrowths from the mouth which are called the **salivary glands,** some of which lie on or under the jaw, and are connected with the cavity of the mouth by long tubes or **ducts.** In cases of disease one of these ducts may become blocked, and then open outwards on to the cheek. In such a case it is found that whenever food is taken into the mouth there is at once a flow of a glairy fluid from the duct.

How do the glands know that food is in the mouth and that they are required to secrete fluid to moisten it? If we dissect an animal's head we find that all parts of the mouth, including the glands, are supplied with nerves. Whenever food enters the mouth, a message or impulse is sent up from the nerves of the tongue to the brain, and a reflex impulse is sent down along the nerves of the salivary gland and causes this to secrete. We can, in fact, imitate this natural message artificially. If we dissect out in

a living animal under anæsthetics the chief nerve to one of these glands, and then stimulate the nerve with electric shocks, we at once get a flow of saliva from the duct of the gland.

This saliva is not the ordinary fluid of the tissues, but is specially manufactured by the cells of the

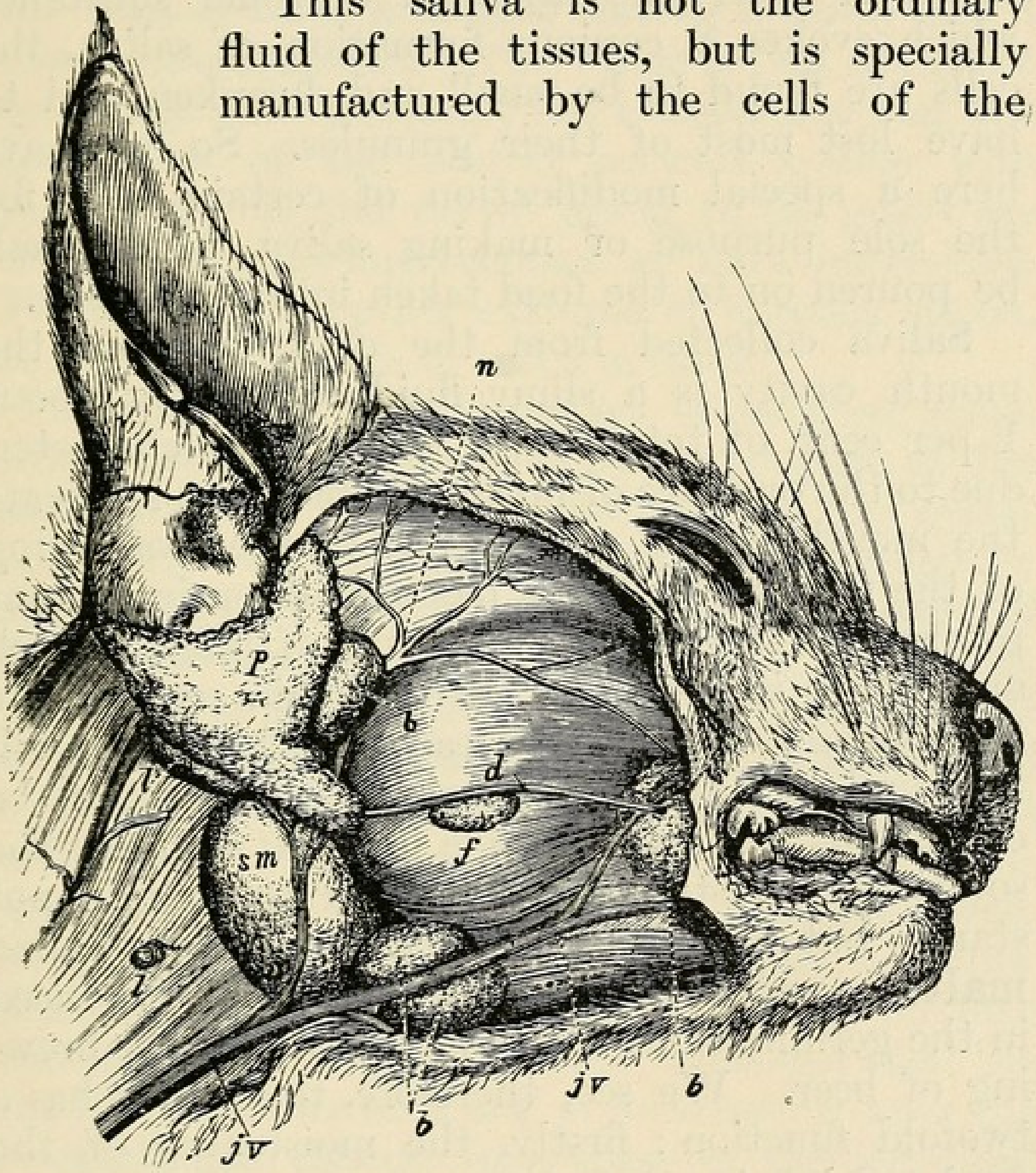


Fig. 9.—View of salivary glands in cat. (*p*) Parotid gland with its duct (*d*). (*sm*) Submaxillary gland.

glands, and we find that the cells undergo alteration when the secretion occurs. Thus, if we examine a gland from an animal which has had

no food for some time, and has therefore secreted no saliva, the cells are found to be swollen and full of fine granules. If, instead of this, we take the glands from an animal after a prolonged meal, or after the injection of some substance which evokes a copious formation of saliva, the cells are found to be small and shrunken, and to have lost most of their granules. So we have here a special modification of certain cells for the sole purpose of making saliva, which shall be poured on to the food taken into the mouth.

Saliva collected from the duct or from the mouth cavity is a slimy fluid containing about 1 per cent. of total solids. This slimy character, due to the presence of mucin, enables it to lubricate the mouth cavity and so aid in the swallowing of the food. But saliva has one other important property. If we take a solution of boiled starch and add to it a drop of saliva, within one minute the solution will become clear and the starch will be found to have disappeared. If the action be continued for another five or ten minutes, the solution on testing will be found to contain not starch but sugar. The sugar formed is called **maltose**, and is exactly similar to that produced in the germination of barley and used for the brewing of beer. We see, therefore, that saliva has a twofold function: firstly, the moistening of the food and lubrication of the upper food-passages; and secondly, the conversion of the starch into a crystalline sugar.

When the food has thus been chewed and thoroughly moistened, it is collected into a mass on the back of the tongue. There is a sudden

swallowing movement, in which the tongue carries the mass rapidly to the back of the throat. Here the mass is grasped by the muscular wall of the gullet, and this wall contracts in a ring behind the mass of food, gradually forcing it down till it reaches the stomach. The whole action after the first stage is involuntary, but is dependent on the connection of the central nervous system with the gullet. If the nerves going to the gullet are divided, swallowing becomes at once impossible. We have here another example of a reflex action, or rather of a series of reflex actions.

The stomach is a large sac of peculiar shape which lies at the upper and left-hand part of the abdominal cavity. Near its middle the gullet opens into it, the opening being surrounded by muscular tissues which can prevent the passage of food backwards from the stomach into the gullet. This ring of muscle is normally kept closed, but opens with each act of swallowing to allow food to pass into the stomach. The other smaller end of the sac is known as the **pylorus**. This too is surrounded by a strong ring of muscular tissue, which opens only when it is necessary to allow food digested by the stomach to pass on into the upper part of the intestine. During a meal the food is driven by each act of swallowing into the stomach, and collects in a mass in the left-hand part of it—the so-called **fundus**. During the time that the food is being chewed in the mouth, a fluid, the **gastric juice**, is being poured into the stomach, and this fluid is formed with still greater rapidity when the food enters the stomach. Like the saliva, this fluid is specially made from

the blood by glands, which are little tubular depressions covering the whole internal surface of the stomach, and not limited, as in the mouth, to certain definite masses. If in an animal the gullet be divided so that the food cannot reach the stomach, the taking of food into the mouth is still attended by the pouring out of gastric juice into the stomach.

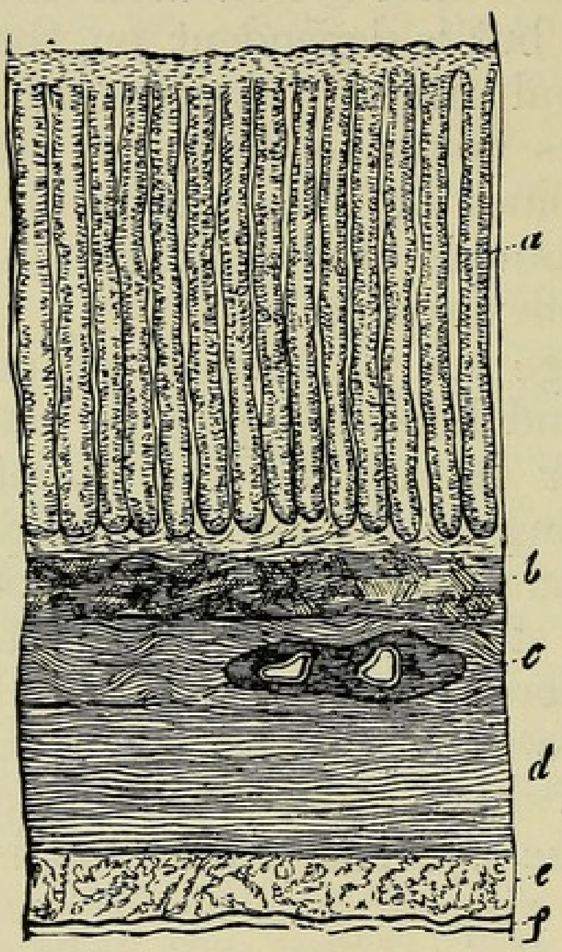


Fig. 10.—Vertical transverse section of the coats of a pig's stomach, magnified 30 diameters. (*a*) Gastric glands. (*d*, *e*) Muscular coats.

This fluid can be collected and its action on different foods studied. It is strongly acid in character, containing 0·4 per cent. hydrochloric acid; but this is not its sole constituent. If we allow it to act on meat or boiled white of egg, we find that these solid substances are gradually dissolved, and the solution which is obtained, although it contains proteid, yet differs from the ordinary solution of egg-white, since it is not coagulated by boiling. If some raw white of egg be hung up in a tube of parchment paper or of animal membrane (sausage skin) and be surrounded by distilled water, it is, as we have said, indiffusible. If, however, the solution obtained by the

action of gastric juice on meat or solid white of egg be placed in a similar vessel, after some hours it will be found that proteid has escaped into the surrounding water. Thus the action of the digestive juice of the stomach is to dissolve insoluble proteid and to turn it into another kind of proteid, which is both soluble and diffusible, and which, therefore, can pass easily through the walls of the stomach—*i.e.*, be absorbed. The same process occurs in the stomach when a meal is taken.

Shortly after food has entered the stomach, the muscular walls of this organ enter into activity: rings of constriction pass along the organ from left to right, causing a thorough mixing of the food with the gastric juice. As the proteid is gradually dissolved, and the food thus broken up, the semi-digested fluid is forced from the pyloric end into the small intestine, and this transference goes on with the gradual solution of the food until the whole of the food, in a semi-digested state, has been transferred to the small intestine, and the stomach is empty and contracted and ready for a fresh meal. Thus in the mouth the starchy constituents of the food are digested, in the stomach the proteid constituents. Moreover, in the latter organ, the proteid and connective-tissue envelopes of the fatty tissue are dissolved, so that the melted fat floats freely in the fluid.

One other action of the gastric juice must be mentioned. It is, as we have already seen, strongly acid, and all solutions of mineral acids are very fatal to bacteria; hence any of the micro-organisms of disease, such as typhoid or

cholera bacilli, which are swallowed with the food, are infallibly destroyed if they come in contact with the gastric juice. It is only when the action of the acid is prevented by taking at the same time too large quantities of fluid that these bacteria can pass on into the intestine, and there produce their deleterious effects.

Some time after a meal, a strongly acid fluid, containing semi-digested proteid and starch and undigested fat, is forced in small quantities, at frequent intervals, into the beginning of the small intestine. Here there are two large glands which pour fluid into the gut—viz., the **pancreas** (or stomach sweetbread) and the **liver**; the secretion of the latter is known as the **bile.** Within two minutes of the entry of the acid fluid into the intestine, there is a flow both of bile and of pancreatic juice. Both these fluids aid in the completion of the digestive process.

The **pancreatic juice** contains an active principle or ferment which has a strong digestive action on starch, converting it into the sugar, maltose. It also contains a substance which, though inactive while in the gland, is converted on entering the intestine into an extremely active ferment for proteids. Under its action the proteids or the peptones, which have entered from the stomach, are dissolved and broken down into their proximate principles. The great edifice of the proteid molecule is taken to bits, so that out of these bits the body may build up other proteids or constituents of its cells, varying according to the nature of the cells.

The **bile** has the power of dissolving fatty acids.

The pancreatic juice splits the fats into their two constituents—fatty acid and glycerin. The fatty acids are dissolved by the bile; and this solution, as well as the glycerin, can pass easily through the walls of the intestine and thus be absorbed. All three classes of food are therefore digested—*i.e.*, converted into a soluble diffusible form—in the intestine, and this process is continued throughout the whole length of the small intestine.

An interesting question arises as to the mechanism of the two secretions we have just studied. How do the pancreas and liver know that food has entered the intestine and requires the presence of their secretions for its digestion? In the case of the salivary glands and the stomach this information, this calling forth of the activity of the gland, was carried by the nervous system—*i.e.*, was an ordinary reflex action. In the case of the pancreas, however, the information is sent in a different way. When the acid of the gastric juice enters the small intestine, it acts on something in the cells lining the intestine and produces a new body, which is called **secretin**. This body is absorbed into the blood and carried to the gland, and on arrival there acts as a direct stimulus to the cells of the gland, causing them to secrete. We have, as it were, a message sent by special messenger instead of by the telegraphic communications of the central nervous system.

The digestion of the food is not, however, the only process which goes on in the small intestine. As the constituents of the food—proteids, fats, and carbohydrates—are made soluble and diffusible, they are taken up by the walls

of the intestine; and we find special arrangements to increase the surface of the intestine exposed to the food, and so favour absorption. Thus the whole of the lining membrane of the small intestine is thrown into transverse folds; and these folds, on examination, are seen to have a velvety appearance, due to the fact that they are closely set with little projections called **villi.** These villi, which are represented in the figure, are coated internally by a layer of cells. Immediately under these cells is a thick layer of blood-vessels, and in the middle of each villus is a space—the **central lymphatic.** These two sets of vessels represent the channels by which the absorbed food is carried to the rest of the body, the proteids and carbohydrates being carried chiefly by the blood, while the fats are carried by the central lymphatic and the vessels connected therewith. The further course of these vessels, and the manner in which the constant

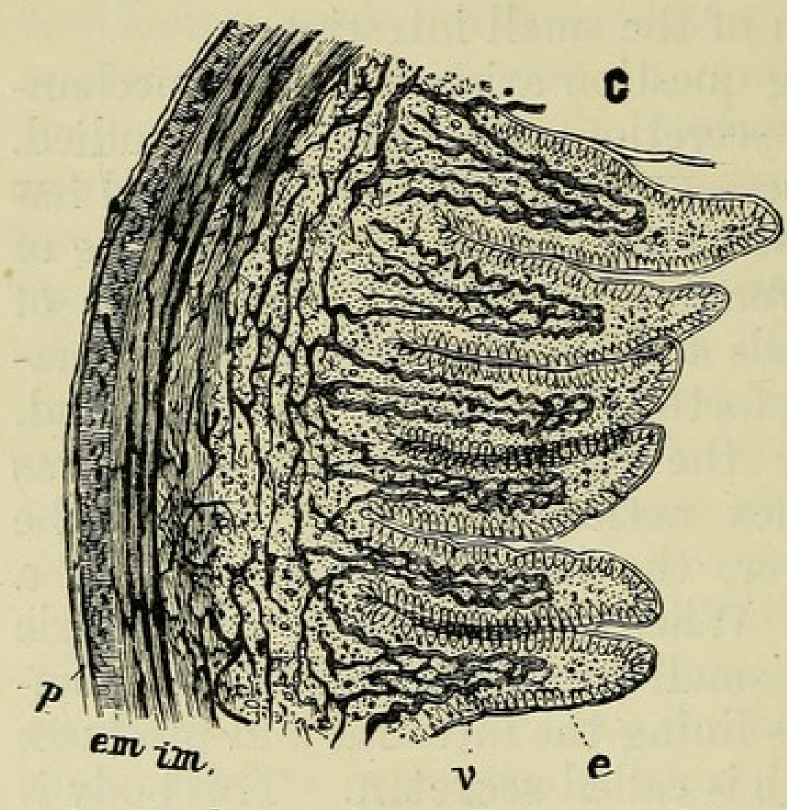


Fig. 11.—Section of the wall of the small intestine. (*e*) Epithelium. (*em*, *im*) Muscular coats. (*v*) Blood-vessels within a villus.

renewal of the fluid in them is maintained, we shall have to consider in the next chapter.

The food at the lower end of the small intestine is propelled along the intestine by ring-like contractions of the muscular coat of the intestine. On arrival, although it has lost a great part of its nutrient material, the food still contains a large amount of water, and is quite fluid. It passes into the large intestine, where there are no villi, but only a number of glands whose chief office is the secretion of mucus. Here the excess of fluid and any remaining portions of nutrient material are absorbed. Finally only the indigestible portions of the food, together with colouring matters derived from the bile and cast-off dead cells from the inner lining of the intestine, are left; and it is this mass which is periodically expelled from the body as the stools or **fæces.**

CHAPTER V

THE CIRCULATION OF THE BLOOD

The food which is thus absorbed from the alimentary canal has to be carried all over the body in order to nourish the skin, bones, muscles, brain, and every other tissue. The only way in which this can be done is by means of a common fluid which can pass round all parts of the body and bathe every cell. This common fluid is the **blood.** If a blood-vessel in an animal be opened and the blood allowed to flow, it will be seen to be perfectly fluid, of a red colour differing in brightness according to the vessel from which it has been collected. Thus blood from a vein is purplish in colour, while that from an artery is bright scarlet. It is quite opaque, even in thin layers ; and if it be examined under a microscope, it will be seen that this opacity is due to the fact that the blood consists of a number of little red discs—the **blood corpuscles**—suspended in a yellow transparent fluid—the **blood plasma.**

If the blood be allowed to stand for three or four minutes, it becomes thicker, and finally sets into a solid clot. After a few hours the clot begins to shrink like the curds of milk, and we finally get a

shrunken clot containing all the blood corpuscles entangled in it, floating in a colourless fluid which is called **blood serum**. On analysis, the blood serum is found to consist chiefly of proteids. If boiled, it sets solid like the white of egg. Besides the proteids, of which it contains about 8 per cent., it contains traces of other substances—some nitrogenous, others non-nitrogenous, such as sugar. It also contains about 1 per cent. salts.

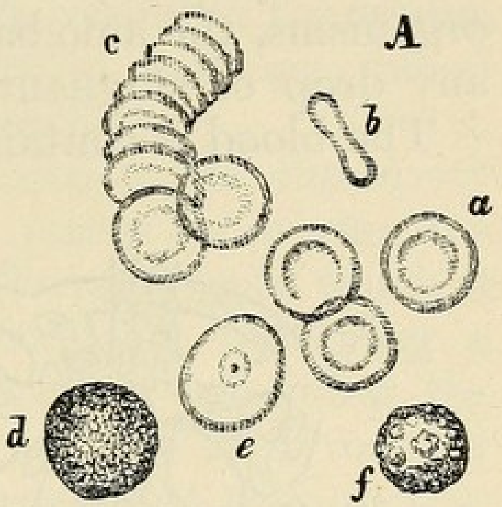


Fig. 12.—Blood corpuscles, highly magnified. (*a*, *b*, *c*) Red corpuscles. (*d*, *e*, *f*) White corpuscles, or leucocytes.

The clot consists of a spongy meshwork of an insoluble proteid called **fibrin.** When blood is shed this fibrin is produced in the blood plasma by an alteration of one of its constituents, which is called **fibrinogen.** There are many analogies between the clotting of blood and the clotting which occurs when rennet is added to milk. In both cases a soluble becomes converted into an insoluble proteid, which entangles in its meshes all the particles of the fluid blood corpuscles in the case of the blood, fat globules in the case of the milk. The red corpuscles also consist chiefly of proteid, but this proteid differs from all others in its colour and in the fact that it has attached to it a body containing iron. The red iron-containing proteid is called **hæmoglobin,** and, as we shall see later, is chiefly concerned in carrying oxygen from the lungs to the tissues of the body. Besides these

red corpuscles we may see, under the microscope, a certain small number (1 to 500 of the red) of colourless corpuscles or **leucocytes,** which are little nucleated masses of protoplasm, possessing the power of taking in food-particles and moving about from place to place just like the unicellular organisms, the amœbæ, which may be observed in any drop of stagnant water.

The blood is contained within a system of tubes

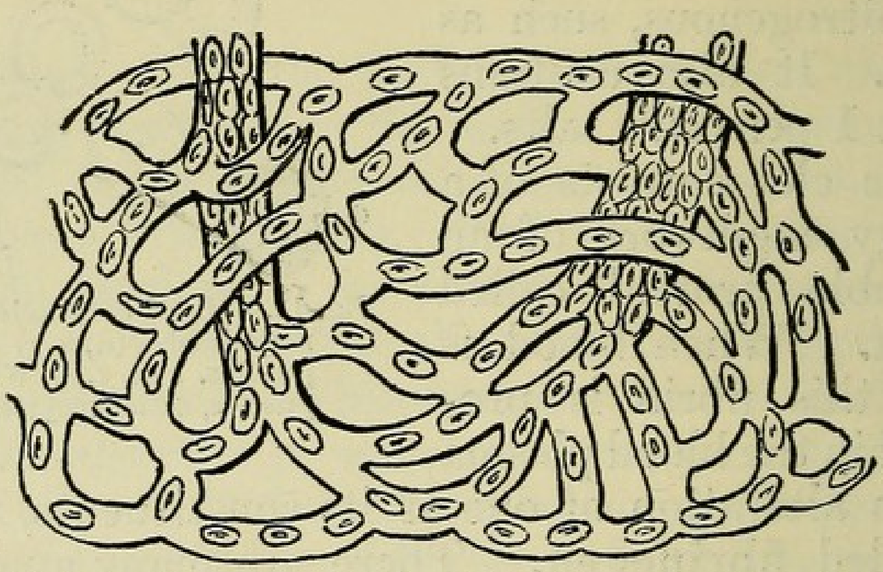


Fig. 13.—Diagram of blood capillaries in web of frog's foot.

—the **blood-vessels.** All parts of the body are closely beset with a meshwork of very fine tubes (much finer than a hair), which are known as **capillaries.** The wall of these tubes is formed only of a single thin layer of cells, so that it is easy for substances carried by the blood within them to escape through the walls and get into the tissues. In the same way any waste products, such as urea or carbon dioxide, produced by the tissue-cells, can diffuse through these thin walls into the blood. Thus we have in these

capillaries the finest possible arrangement for the rapid exchange of material between blood and tissues, without actual escape of blood into the tissues. Two sets of larger tubes lead to and from each part of the body. These are, first, the **arteries,** which carry blood from the heart in the chest to the capillaries; and secondly, the **veins,** which are larger, thinner-walled, and carry blood from the capillaries to the heart.

The **heart** itself, which is situated in the cavity of the chest, represents the pump for driving the blood round this system. The manner in which it works can be best understood by obtaining a sheep's heart from a butcher, and examining the way in which it is built up. It is a roughly conical mass of flesh, which presents at the junction of its middle and upper thirds a transverse groove running round the organ. Besides this groove there is a vertical groove running obliquely downwards and to the right on the anterior surface, and a similar groove on the posterior surface. These grooves correspond to septa or divisions in the interior of the heart, which is in this way divided into four cavities. The two cavities above the transverse groove have thin walls, and are known as the **auricles.** The two cavities forming the main mass of the heart are the **ventricles.**

From the upper end of each ventricle a thick-walled tube is seen coming off. That from the left ventricle is known as the **aorta**, and is the starting point for the arteries which go to all parts of the body, except to the lungs. That from the right ventricle is the pulmonary artery, and soon divides into two large branches to supply the

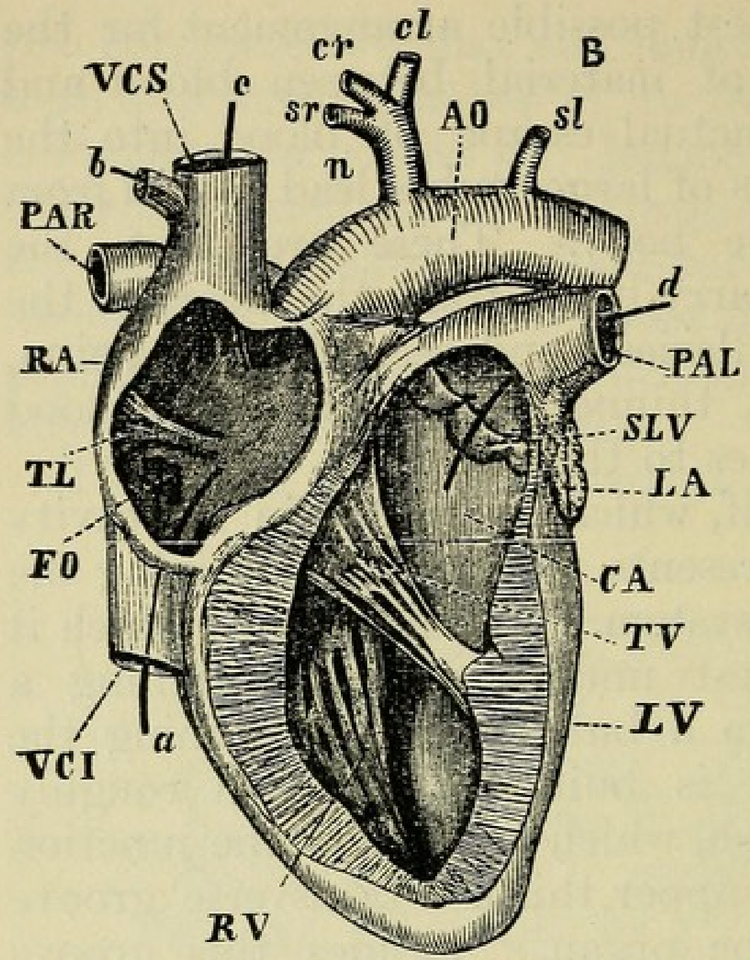


Fig. 14.—The right side of the cat's heart, laid open. (*RV*, *LV*) Right and left ventricles. (*PAL*) Pulmonary artery. (*RA*) Right auricle. (*VCS*, *VCI*) Superior and inferior venæ cavæ. (*AO*) Aorta. (*SLV*) Semilunar valves. (*TV*) Tricuspid valve between right auricle and right ventricle.

two lungs. Large thin-walled vessels also pass into the auricles. The right auricle receives a large vein which collects the blood from all the veins of the upper part of the body, known as the **superior vena cava,** and also another vein, the **inferior vena cava,** which carries the blood from all the lower parts of the body. The left auricle receives four veins, two from each lung. The right auricle communicates by an opening with the right ventricle, and the left auricle with the left ventricle; but there is no connection between the right and left sides of the heart, except by the long *détour* of the pulmonary or body capillaries.

If the aorta or pulmonary artery be cut off close to the heart and water poured in, it will be found that the water will not pass into the heart; and on looking into the vessel it is seen that the

water is stopped by the presence of three little folds of membrane, the semi-lunar valves, which meet accurately in the middle of the vessel and effectively prevent any water running to the heart. These membranous valves can, on the other hand, be opened without any difficulty from the side of the heart. It is evident, therefore, that they allow the passage of fluid in one direction only—namely, from heart to arteries. A similar group of valves is found at the beginning of the pulmonary artery.

If the heart be laid open by cutting with a pair of scissors from auricle into ventricle, it will be seen that the orifices between left auricle and left ventricle, or right auricle and right ventricle, are also provided with valves, the auriculo-ventricular valves. If, instead of the previous cut, the auricle is simply cut off short, and water be poured into either ventricle, the valves are seen to float up and close the auricles. These valves, of which there are two on the left side of the heart and three on the right side, are formed somewhat differently from those in the aorta and pulmonary artery. They have ragged margins, and to the margins are attached tendinous threads which pass down into the cavity of the ventricles to little elevations of the ventricular wall. These tendinous cords have the function of supporting the edges of the valves and preventing their being forced into the auricles and made inefficient, when there is a big rise of pressure on their ventricular side.

The walls of the heart have the appearance of ordinary flesh or muscle, and their function can be studied if an animal be killed rapidly by a

blow on the head and the chest opened. The heart will then be seen to be beating. The muscles, which compose its wall, contract, become shorter, and so diminish the heart cavities. Each beat begins by a contraction of the auricles, which empty themselves into the ventricles. Immediately afterwards the ventricles also get hard and contract; but they cannot empty themselves into the auricles, as any passage of blood backwards is prevented by the auriculo-ventricular valves. The semilunar valves, on the other hand, present no obstacle to the passage of blood *from* the heart; and so the ventricles continue to contract until they force these valves open and empty themselves into the pulmonary artery and aorta. The heart can be even cut out of the body without causing it to stop beating at once. It can be held in the hand, and the sequence of the beats, auricle to ventricle, observed quite easily.

The branching system of vessels which lead from heart to capillaries presents considerable resistance to the flow of blood along them, and this resistance becomes greater when the arteries become smaller. In order to overcome this resistance, we must have a considerable pressure of blood in the aorta, and we find, therefore, that the aorta is always in a more or less stretched condition. When the heart beats, it forces blood into the already full aorta. When the heart ceases to beat and no more blood flows into the aorta, the flow of blood into the capillaries does not cease, since the elastic wall of the aorta contracts on the blood and continues to send it on. After it has passed through the capillaries we therefore

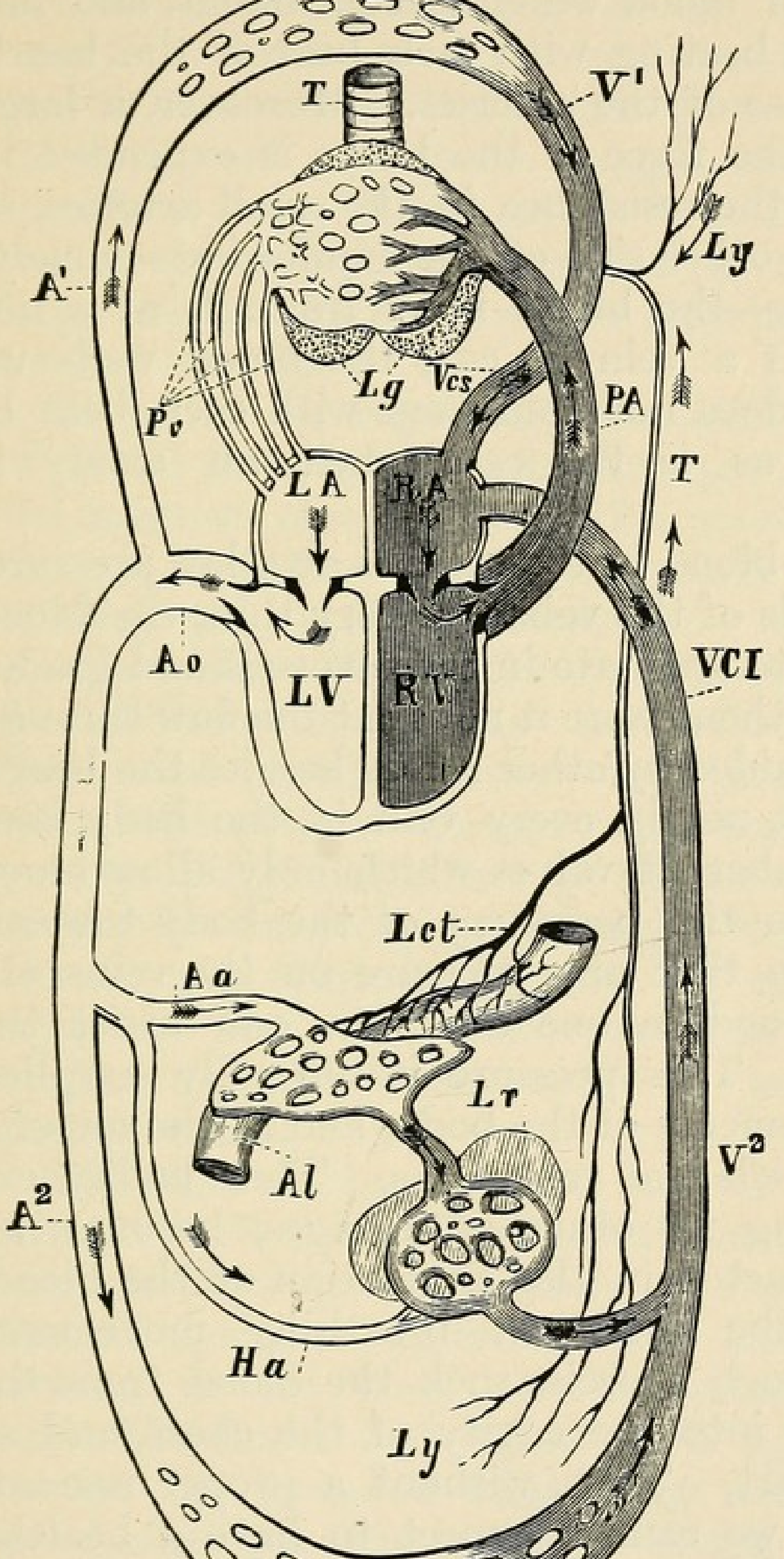


Fig. 15.—Diagram of the Course of the Circulation. (*LA*) Left auricle. (*LV*) Left ventricle. (*Ao*) Aorta. (A_1) Arteries to head and fore limbs. (A_2) Arteries to hinder parts of body. (*Aa*) Arteries to alimentary canal. (*Ha*) Artery to liver. (*Al*) Alimentary canal. (L_2) Liver. (V_2, *VCI*) Inferior vena cava. (V_1, *Vcs*) Superior vena cava. (*RA*) Right auricle. (*RV*) Right ventricle. (*PA*) Pulmonary artery. (*Lg*) Lungs. (*PV*) Pulmonary veins leading from lungs to left auricle. (*Lct*) Lacteals or lymphatics from intestine. (*T*) Thoracic duct carrying lymph from alimentary canal and all parts of body back into superior vena cava.

get a flow of blood which is continuous, and not pulsatile or beating with each beat of the heart, as in the case of the arteries. Moreover, a large amount of the force of the heart is expended in overcoming the resistance in the small arteries, so that on the other side of the capillaries—namely, in the veins—the blood flows through at a low pressure. If a vein be cut, the blood wells up slowly and does not spurt out with each beat of the heart, as is the case when an artery is divided.

Since the blood in the veins is at a low pressure, and the walls of the veins are very thin, the blood would tend to stagnate in these vessels and gradually distend them, were it not that the flow through the veins is aided by other forces besides the heart-beat. Thus, nearly every vein in the body contains a number of valves which only allow blood to flow from the periphery of the body towards the heart, so that any pressure on the veins will send the blood in one direction and assist the circulation. This pressure is normally supplied by the movements of the body, and of the muscles through which the veins pass. Thus bodily exercise, among its other advantages, becomes an important factor in the circulation of the blood. Moreover, the increased breathing movements caused by such exercise suck the blood from the larger veins into the cavity of the chest, and so into the heart. Thus, without a proper amount of exercise we cannot expect to have a healthy supply of blood to all parts of the body.

So far we have spoken of the blood-vessels as if they were merely elastic tubes containing blood ;

but the needs of any part of the body, whether muscle or brain or alimentary canal, will depend on the state of activity of this part. When it is active it will need more oxygen, more food, and therefore more blood; when it is inactive there is no object in supplying it with a large amount of blood which may be wanted elsewhere.

In order to regulate the amount of blood flowing through each part, the arteries are supplied with muscles: in fact, the walls of the smaller arteries are entirely composed of muscle cells. When these contract, the arteries shrink up and allow little or no blood to pass; when they relax, the arteries become wide and present little resistance to the flow of blood. In every active organ the vessels are dilated, whereas in an organ at rest the vessels are contracted, and the blood supply to the part is small.

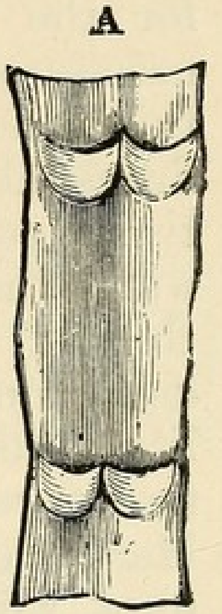


Fig. 16.—Part of a vein laid open to show two pairs of valves. On account of the vessel being thus opened out, each pair of valves appear as if placed side by side, instead of one opposite the other.

The state of these muscles is determined partly by local conditions, but chiefly by the action of the central nervous system. All the arteries in the body are connected with the brain and spinal cord by nerves, the so-called **vasomotor** nerves; and by these channels the nervous system is able to regulate the blood supply to any part according to the needs of that part and the needs of the rest of the organism.

The Lymphatic System

The walls of the capillaries, being composed of cells, allow a certain amount of leakage of the fluid constituents of the blood. This fluid escapes into the spaces in the tissues, and there serves for the nourishment of the cells. But it is necessary to provide for the ultimate removal of this fluid, otherwise the tissues would become dropsical or water-logged. To this end all the tissues contain a second system of capillary vessels, wider than the blood capillaries, but with a still thinner wall. From these vessels arise larger ones, known as **lymphatics,** which pass through little bodies known as lymphatic glands, and finally reach the back of the abdominal cavity. Here they join in a large vessel, the **thoracic duct,** which runs upwards in the chest, and finally pours its contents into the big veins at the root of the neck, so that the drainage fluid of the tissues is once more returned into the circulating blood. In the abdominal cavity these vessels are joined by others, the **lacteals**, which come from the intestines. They have the office of carrying the greater part of the fat which has been absorbed by the central lymphatics of the intestinal villi. Like the veins, the lymphatics are thickly set with valves. The main factor in maintaining the movement of lymph along them is the muscular movements, especially those of breathing. Every contracting muscle presses on the vessels, and thus drives the lymph along in the only direction allowed by the valves—namely, towards the heart.

CHAPTER VI

BREATHING

We have already seen that, to keep an animal alive, it must be continually taking in oxygen and giving out carbon dioxide. This gaseous exchange of the animal is effected in the lungs by means of the movements of breathing or **respiration.**

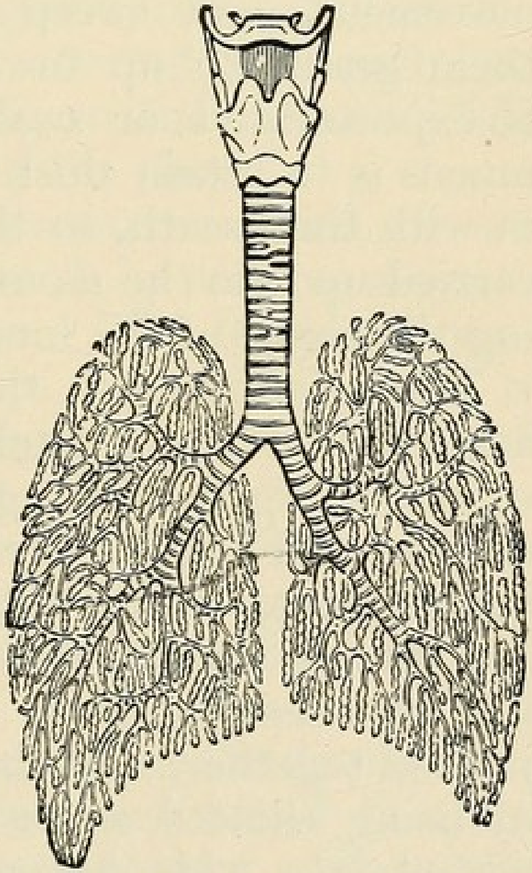


Fig. 17.—Diagrammatic representation of the structure of the lungs.

Two tubes open into the back of the mouth. One of them, the **gullet,** which is muscular, is in a collapsed condition at all times except when food is being swallowed. The other tube, the **windpipe,** which opens at the root of the tongue just behind a lidlike gristly process which is called the **epiglottis,** is always open, being kept from collapse by rings of cartilage or gristle in its walls.

At the upper part of the windpipe is a cartilaginous box, the **larynx,** which can be felt from the outside of the neck as "Adam's apple." This box contains the apparatus for producing sounds. Below the larynx we can feel the hard rings of the windpipe and trace them down into the chest. This tube, which in man is about four and a half inches long, on section presents cartilaginous rings in front forming about two-thirds of a circle. The space between the ends of the rings behind is filled in with membrane containing muscular fibres. The whole tube is lined internally by cells which have small processes or **cilia.** Opening on to the surface are the ducts of small glands which secrete a mucous or slimy material. The cilia are in constant movement, and sweep the mucus which covers them gradually up towards the mouth, where it is expectorated or swallowed. The use of this mucus is to retain dust particles which are taken in with the breath, so that these particles can be carried up into the mouth and kept from obstructing the tissue of the lungs.

The windpipe, in the chest, divides into two large tubes, the **bronchi,** and these divide and subdivide again and again like the branches of a tree. Finally, the smallest divisions, the **bronchioles,** widen out into the air-cells, which are placed round the endings of the bronchioles like bunches of grapes. These air-cells are closely packed together. In them the lining cells, instead of being ciliated as in the bronchi, become converted into wide flattened plates extremely thin in proportion to their area. Between adjacent

air-cells we find a close meshwork of blood capillaries. These capillaries are separated from the air in the air-cells only by the thinnest possible layer of protoplasm. The effect of the continual subdivision and branching of the bronchi is to expose the largest possible surface of blood in the capillaries to the influence of the air in the air-cells. It has been calculated that two thousand square feet of blood surface is exposed to the air within the lungs.

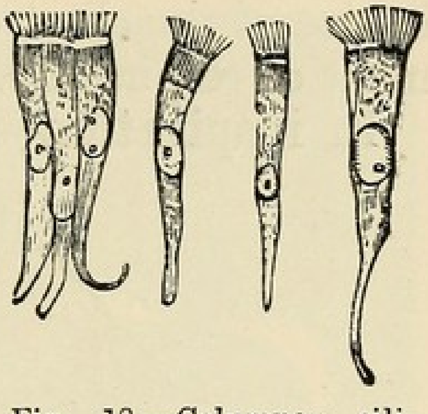


Fig. 18.—Columnar ciliated cells, magnified 300 diameters.

The subdivisions of each bronchus form one **lung.** The framework of the lungs is composed of elastic tissue, and each lung is covered externally by a smooth moist membrane, so that it can glide easily over the inner wall of the chest.

The ventilation, the constant renewal of air within the air-cells, is effected by the movements of breathing or respiration. The lungs are suspended within a bony cage, the chest, which is bounded behind by the spinal column, in front by the chest bone, and at the sides by the ribs. Above, the narrow opening in the bony cage is closed in by the soft tissues of the neck. Below, where the cage is wider, there is a dome-shaped floor separating the cavity of the chest from the abdomen. This dome is formed by the diaphragm, and is composed of muscle fibres round the circumference and a membranous centre. Since the lungs are slung in this bony cage they must follow

its movements. If the cage increases in size, the lungs will also increase in size, and air will be sucked in through the trachea into the lungs. On the other hand, if the cage diminishes in size, air will be blown out of the lungs. This change in size of the chest cavity occurs with every movement of respiration.

In **inspiration**—that is to say, breathing in—the ribs are raised by the contraction of the small muscles, the intercostal muscles, which pass from one rib to the other. This movement is aided by the contraction of other muscles, which pass from the vertebræ of the neck to the upper ribs and from the spinal column behind to the upper and lower ribs. This movement of the ribs is accompanied by a contraction of the diaphragm. When the muscle fibres of the diaphragm contract, they pull down the central membrane, making the whole dome flatter, pressing down the contents of the abdomen, and increasing the vertical diameter of the chest cavity. Inspiration, therefore, is associated with the active contraction of muscles.

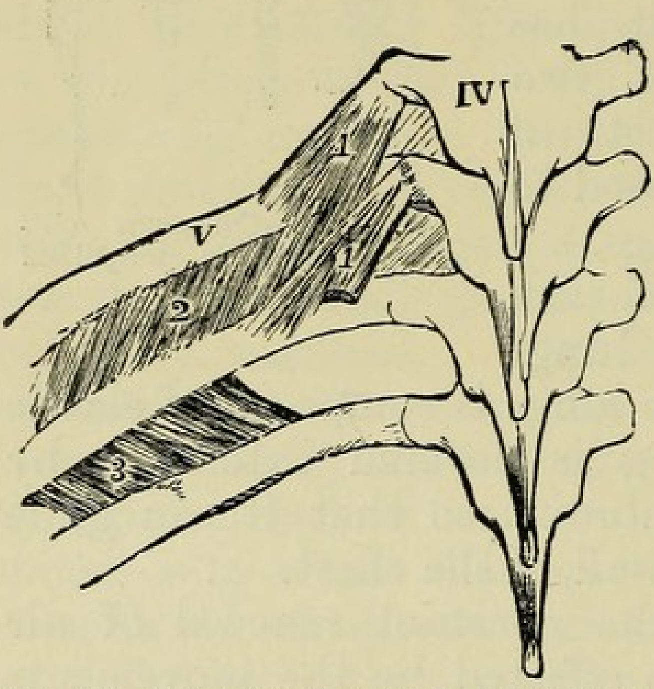


Fig. 19.—Four vertebræ and their ribs, to show attachments of respiratory muscles. 1, Elevators of ribs. 2, 3, Intercostal muscles.

Under normal circumstances, when a man is breathing quietly, **expiration** or breathing out does not require any muscular effort. The ribs tend to drop by their own weight; their attachments in front to the chest-bone, being stretched in inspiration, tend to return to their previous condition directly the stretching force, the contraction of muscles, is removed. In inspiration the abdominal wall also is stretched by the contraction of the diaphragm. When the diaphragm relaxes, the stretched abdominal wall returns to its previous position, compresses the contents of the abdomen, and therefore drives the central membrane of the diaphragm once more into the chest.

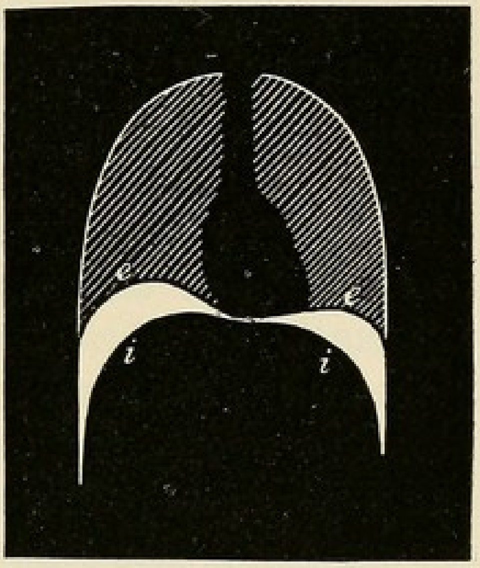


Fig. 20. — Diagram showing movements of diaphragm in respiration. (*i i*) Inspiratory position. (*e e*) Expiratory position.

These alternate movements of inspiration and expiration are repeated in the adult man about seventeen times per minute. Although they can be altered by the will, they are involuntary; no man can stop breathing for more than a certain time. The movements continue during sleep and in many conditions of complete unconsciousness. They are, however, dependent on the central nervous system, since they always cease if a certain part of the lower brain in the **medulla oblongata** is destroyed. Like all other processes carried out by the brain, they are adapted to the requirements

of the animal. When the chemical changes in the animal are increased, as during muscular exercise, more oxygen is consumed and more carbon dioxide is produced. The ventilation draught, therefore, must be also increased, and it is a familiar experience that the movements of respiration are much increased by any form of exercise. As a matter of fact, we find that the part of the brain whose office it is to look after the respiratory movements is extremely sensitive to changes in the amount of gases in the blood, especially of the carbon dioxide. The slightest increase in the amount of carbon dioxide in the blood causes increased depth and frequency of the respiratory movements. This is another example of an adaptation of one function to other functions of the body, which is carried out by chemical means, the chemical messenger being the carbon dioxide. If the increased movements thus produced are not sufficient to aerate the blood, the respiratory centre becomes more and more active, until finally it sends the whole body into convulsions. When an animal is suffocated these convulsions always come on before death, but at a period when the animal has already lost consciousness.

A man with each breath takes in from 400 to 500 cubic centimetres of air (about $\frac{3}{4}$-pint). If we compare the composition of the air which is taken in with the air which is breathed out, we find that during its short sojourn in the lungs it has undergone marked changes. Whereas inspired air contains in every 100 volumes about 21 parts of oxygen, 79 parts of nitrogen, and about 4

parts in 10,000 of carbon dioxide, expired air contains 16 volumes per cent. of oxygen and 4 volumes of carbon dioxide, the rest being made up of nitrogen. In fact, in respiration about 5 volumes per cent. of oxygen disappear and are replaced by 4 volumes of carbon dioxide. In addition to these changes, the expired air contains a large amount of watery vapour, and is practically saturated with moisture. It is also, of course, warmer than the air which is taken in. We know already that the reason for these changes is that oxygen is consumed in the body in burning up the food-stuffs or the constituents of the tissues. If these constituents were merely carbohydrates, the amount of carbon dioxide given out would be exactly equal to the oxygen taken in :—

$$\underset{\text{Sugar.}}{C_6H_{12}O_6} + 6O_2 = 6CO_2 + 6H_2O.$$

All animals, however, take in proteids and fats along with carbohydrates, and their tissues also contain representatives of the three classes. In the oxidation of proteids and fats, some of the oxygen is taken up in burning the hydrogen to form water, so that only a certain proportion of the oxygen will be returned in the expired air as carbon dioxide.

It was formerly imagined that the burning up of the food-stuffs took place in the lungs, but it is easy to see that this is not the case by examining the blood which flows to and from the lungs. If we open the chest in an animal and maintain respiratory movements by means of bellows, we shall see that the blood in the pulmonary artery

is dark in colour and exactly similar to the blood in the big veins; whereas the pulmonary veins, which carry the blood from the lungs to the left auricle, are bright red in colour and contain arterial blood. If, by means of a mercurial air-pump, we pump the gases out of the blood, 100 volumes of blood from the pulmonary artery are found to give about 60 volumes of gas, composed as follows :—

Oxygen . . .	12 volumes.
Carbon dioxide . .	46 volumes.
Nitrogen . . .	2 volumes.

The same amount of blood from the pulmonary veins will contain :—

Oxygen . . .	20 volumes.
Carbon dioxide . .	38 volumes.
Nitrogen . . .	2 volumes.

Thus the blood comes to the lungs poor in oxygen and rich in carbon dioxide; it leaves the lungs having gained oxygen and lost carbon dioxide. In this condition it travels through the left heart and returns to the tissues. The reverse changes, namely the giving up of oxygen and taking up of carbon dioxide, take place in the capillaries of the tissues.

How is this large volume of gas carried? Water at the body temperature would only take up about 1 volume per cent. of oxygen from the air. The change in colour of the blood as it passes from arterial to venous would indicate that

the red colouring-matter of the corpuscles, the hæmoglobin, has something to do with the gases of the blood; and this is the case. It is possible to extract the hæmoglobin from the red blood corpuscles in a crystalline form. A solution of this substance, when shaken up with air, is of a bright scarlet colour. If such a solution be placed in an air-pump and exposed to a vacuum, it will be found to bubble and give off oxygen, changing its hue to a dull purple colour. On taking this dull purple solution and shaking it up with air, it once more absorbs oxygen and becomes bright scarlet. We may therefore look upon the hæmoglobin of the red corpuscles as the carrier of oxygen from the lungs to the tissues. In the lungs it becomes saturated with oxygen, forming a chemical compound, **oxyhæmoglobin.** This compound is extremely unstable, and is decomposed on mere exposure to a vacuum. When carried in the blood to the tissues, it reaches a place where there is no pressure of oxygen, since the tissue cells have a great affinity for oxygen, eating up every particle of this substance in their vicinity. The oxyhæmoglobin is therefore practically exposed to a vacuum in the capillaries of the tissues. It gives up its oxygen and becomes reduced, in part at least, to another substance, purplish in colour, which is reduced hæmoglobin. The reduced hæmoglobin travels back along the veins to the lungs, and is there, on meeting the air in the air-cells, once more converted into oxyhæmoglobin.

The carbon dioxide of the blood is also carried in combination, but chiefly in the fluid part of

the blood, the blood plasma. Here it exists in combination with sodium as sodium carbonate or bicarbonate. In the tissues, where carbon dioxide is being continually produced by the cells, this gas passes in solution through the vessel wall into the plasma, there converting the carbonate into bicarbonate. In the lungs the air in the air-cells contains only a small proportion of carbon dioxide. Here the reverse change takes place, the sodium bicarbonate giving off carbonic acid to the air and being converted into sodium carbonate. In fact, the proteids and other acid substances of the blood plasma and of the corpuscles can take up nearly the whole of the sodium of the blood, so that if the blood be exposed to an atmosphere containing no carbon dioxide at all, it will give up the last trace of its carbon dioxide. The whole blood, therefore, acts as a carrier of the oxygen from the lungs to the tissues, and as a carrier of the carbon dioxide, the waste product of the tissues, from them to the lungs.

The lungs represent an organ both for absorption and excretion; interference with either of these functions will rapidly bring about the death of the animal. If the blood be made acid, sodium carbonate can no longer exist as such, and it can therefore not act as a carrier for carbon dioxide. If the hæmoglobin be prevented from dissociating or from combining with oxygen, the animal will die of lack of oxygen. Thus, the fumes of a charcoal fire or coal gas contain a large amount of the gas known as **carbon monoxide** (CO). This gas has a strong affinity for hæmo-

globin, forming a stable compound—**carboxy-hæmoglobin.** If a small percentage of carbon monoxide be present in the air breathed, the carbon monoxide is absorbed and forms a firm combination with oxyhæmoglobin. The carboxy-hæmoglobin cannot be dissociated by the tissues, and in the lungs it can only be decomposed by oxygen with extreme difficulty. The hæmoglobin is therefore removed from its normal function of carrying oxygen, and the man exposed to these gases dies of asphyxia or suffocation. In such cases the blood in arteries and veins alike is found to be bright red in colour, the carb-oxyhæmoglobin having this tint and not being reduced in contact with the tissues. Death therefore may be brought about either by deficiency of oxygen in the air breathed (as in choke-damp), by excess of carbon dioxide, or by the presence of poisonous gases which unite with the hæmoglobin and prevent its acting any further as an oxygen carrier.

CHAPTER VII

EXCRETION—THE FUNCTIONS OF THE KIDNEYS

When a unicellular organism such as an amœba takes in food granules, it can be seen to digest these granules to a certain extent, the indigestible remainder being excreted from the surface of the body. Such a process is, of course, analogous to the rejection of the indigestible portions of the food in the alimentary canal. Of the food which is burnt up in the body a certain proportion—namely, the carbonaceous part—unites with oxygen to form carbon dioxide, and this gas is, as we have seen, poured out from all the cells into the blood, whence it is turned out into the air of the lungs. The water produced by the oxidation of the hydrogen in the fats and carbohydrates may also be got rid of in the same way; but the third constituent of the foods—namely, proteid—in addition to carbon, hydrogen, and oxygen, contains also nitrogen and sulphur.

When proteids are allowed to decompose, the nitrogen is given off as ammonia and the sulphur forms sulphides or sulphates. The former body is too poisonous to be allowed to circulate in any appreciable quantity through the various tissues

of the body. We find therefore that, in the oxidation of proteids in the body, ammonia is first formed, and then undergoes a slight change. It combines with carbonic acid to form ammonium carbonate, and the resulting compound loses two molecules of water to form **urea,** which is a white crystalline substance almost inert in chemical characters and easily soluble. The change which occurs may be represented by the following equation :—

$$CO\begin{matrix}/ONH_4\\ \backslash ONH_4\end{matrix} - 2H_2O = CO\begin{matrix}/NH\\ \backslash NH_2\end{matrix}$$

Ammonium carbonate. Water. Urea.

The sulphur in the proteid also undergoes oxidation to sulphates. Moreover, all our food contains a certain percentage of salts, such as chlorides, sulphates, phosphates, of sodium, potassium, etc. These salts cannot be destroyed or burnt up in the body, and would therefore tend to accumulate if there were not some means by which they can be got rid of in solution. All these substances—viz., the urea, the sulphates, and the salts of the food which are not required in the building up of the tissues—are turned out from the body in the **urine.**

The breaking down of proteids occurs in the tissue cells with the production of urea and sulphates. Both these sets of compounds are diffusible, and therefore rapidly pass out into the lymph and blood bathing the cells. In order to clear them out of the blood a special organ is necessary, with cells lining a cavity which is in connection with the surface of the body. This special organ is the **kidney.**

The general aspect of the kidney can be studied in the butcher's shop. It is an organ of firm consistency and characteristic shape, which has opening into its inner border three vessels: a large artery which supplies it with arterial blood, a large vein carrying the blood away from it, and a tube, the ureter, which joins the kidney by a funnel-shaped enlargement, and serves to carry the fluid turned out by the kidney from this

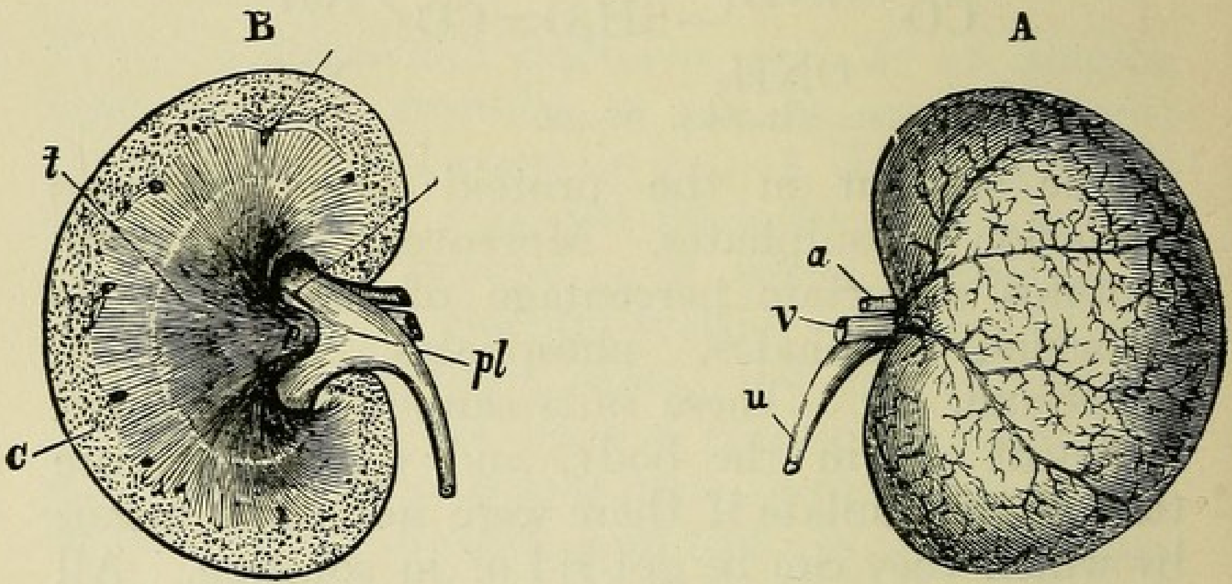


Fig. 21.—The cat's kidney entire, and in section. A. The outer surface of the kidney. (*a*) Renal artery. (*V*) Renal vein. (*u*) Ureter. B. Vertical section through the kidney. (*c*) Cortex. (*t*) Pyramids. (*pl*) Dilated end of ureter.

organ to the bladder. If the ureter be opened in a living animal (and a similar observation has been made on man when the ureter has been opened accidentally by a stab), it will be found that there is a constant dribbling flow of fluid along this tube from the kidney.

This fluid, the **urine,** is of a yellow colour. It contains about 3 to 4 per cent. of solids. Of these solids about 2 per cent. is urea; the rest

consists chiefly of salts. In man about 3 pints or 1,500 cc. are produced every day. This amount will therefore contain 30 grams of urea; each gram of urea contains half its weight of nitrogen, so that a normal man excretes every day about 15 grams of nitrogen, which corresponds exactly to the 100 grams of proteid which he takes in his food. As might be expected, the solid constituents of the urine depend entirely on the nature and amount of the food. On a vegetarian diet poor in proteid the total output of urea will also be low. On a large meat diet the amount of urea excreted will be increased.

The total quantity of urine will depend on the amount of water turned out by the kidneys, and this will vary with the amount of water taken in with the food, and the extent to which this water is got rid of by other channels—namely, by the lungs and by the skin. Thus, in severe sweating the urine may be small in quantity and very concentrated, even though large amounts of fluid may have been drunk. In cold weather, when the skin is not active, the amount of urine may be relatively largely increased. It must be remembered that the amount passed is no clue to the amount of urea which is excreted.

One other nitrogenous constituent of the urine may be mentioned, since, although it is small in quantity, it may, if present in too large amount, give rise to various disorders: this substance is **uric acid.** It is allied to urea, though it has a much more complex composition. A normal individual forms only about ½ gram (8 grains) of uric acid in a day, though the amount varies

greatly with the nature of the food. Not all nitrogenous diets will give rise to the formation of uric acid. Thus a diet of white of egg would give a large output of urea and only a small amount of uric acid. A corresponding quantity of meat, or still better of sweetbreads or liver, would cause a similar excretion of urea but a relatively large excretion of uric acid. This substance is very insoluble, and if present in the urine in too large a proportion may be deposited either in the urinary passages as stone, or in the urine as a brick-red deposit. If the urine be made alkaline by giving large quantities of alkalies or by a diet of fruit, the uric acid is kept in solution.

Whereas most of the salts of the urine vary with the amount of salts taken in with the food, the sulphates are derived chiefly, not from sulphates in the food, but from the oxidation of the sulphur of the proteid. The excretion of sulphates will therefore rise or fall with the excretion of urea.

In order to determine the nature of the mechanism in the kidney, we must have recourse to the microscope. On cutting a kidney longitudinally, it will be seen to consist of pyramidal masses, the smaller ends of which open into little dilatations of the ureter. With a hand lens small holes, the openings of tubes, can be seen on the conical ends of these pyramids. The outer portion of the kidney, the **cortex,** is finely mottled, whereas the pyramidal portions are streaked longitudinally. By boiling small pieces of kidney in strong acid, the connective tissue holding its elements together can be softened or

dissolved, and it is then possible to unravel the complex structure of this organ. It will be seen that each pyramid is a bunch of branching microscopic tubes. These tubes are much coiled in some parts, especially in the cortex. They begin in the cortex by a blind extremity, into which projects a little bunch of capillary blood-vessels known as the **glomeruli**. This bunch of capillaries, as well as the blind extremity of the tube, is covered by a thin layer of flattened cells. Leading from this we find a coiled tube lined by peculiar striated cells, and these again lead into a straight narrow tube which passes down towards the apex of the pyramids. This turns up again to the cortex, becomes once more convoluted, and finally joins a large tube, the collecting tubule, which, after receiving many others, passes straight down in the pyramid, and opens on its apex into the dilated end of the ureter.

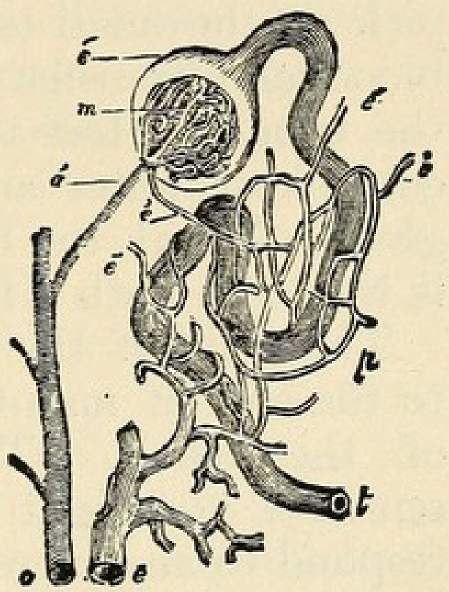


Fig. 22.—Diagram showing the relation of the glomeruli to the uriniferous tubules and blood-vessels. (*a a*) Arteries. (*c*) Capsule surrounding glomerulus. (*t*) Uriniferous tubules. (*p*) Plexus of blood capillaries ending in small veins (*e*).

It is evident from the structure of this tubule that at least two processes must go on within it. The little bunch of capillary vessels, which are connected directly to a large artery, are traversed by blood at a high pressure. Here we have probably an arrangement for filtering off from

the blood any excess of water with dissolved salts which the blood may contain.

The convoluted tubules with their rodded epithelium are able, on the other hand, to act like secreting glands. They differ from the salivary gland only in the fact that, whereas the latter secretes a substance formed in the cells of the gland itself, the cells of the convoluted tubules pick up the small traces of urea circulating in the blood and transfer these to the other side into the tubule. Here the urea is washed away by the current of water and salts proceeding from the glomerulus at the beginning of the tube. Urine is therefore both a filtrate and an excretion.

The cells of the kidney are constituted solely to the end of maintaining a normal constitution of the blood. They are therefore extremely sensitive to slight changes of this fluid, and respond to any increase in the waste products or abnormal increase in the normal constituents of the blood by an increased excretion. As might be expected from the structure of the kidney, the blood supply to the glomeruli has a potent influence on the **amount** of urine secreted. Increased blood supply will produce increased filtration and therefore raise the amount of urine formed. For instance, cold applied to the skin causes a constriction of the blood-vessels in the skin, a rise of blood pressure, and therefore increased flow of blood to the kidneys. This increased flow may, within a few minutes, double or treble the amount of urine which is being formed by the kidney. On the other hand, if the blood pressure is low, as after bleeding, very little

blood flows to the glomeruli, and the amount of urine is largely diminished.

The two factors, therefore, in determining the secretion of urine are: (1) the blood supply to the kidney, (2) the composition of the blood flowing through the kidney. These two factors suffice to account for the marvellous adaptation of the kidney activity to the different conditions under which the animal may be placed, and the extreme accuracy with which this organ maintains a constant composition of the circulating blood.

CHAPTER VIII

THE SKIN AND ITS USES

The whole external surface of the body is formed by the skin, which consists of a thick felt-work of fibres covered externally by a layer of cells, the **epidermis.** The most superficial of these cells undergo a horny change and die. They form the **cuticle,** of which flakes are being continually cast off, the waste being replaced by the growth of the deepest layer of cells.

The skin has various important functions to perform. In the first place it supplies a strong elastic coat to the whole body, serving to confine in their places the underlying tissues and protecting them from evaporation or injury. In the second place it is a great sense organ : it is richly furnished with nerves which carry to the central nervous system information as to the size, shape, consistence, and temperature of any objects in contact with the skin.

In animals with a moist skin, such as the frog, a large amount of gaseous exchange can go on between the blood-vessels underlying the skin and the surrounding atmosphere, so that the skin acts as a respiratory organ. In such animals we

find a considerable absorption of oxygen and corresponding evolution of CO_2 going on at the surface of the body. In frogs the lungs may be extirpated without interfering to any marked degree with the total gaseous exchange of the animal. Although similar changes (namely, taking in of oxygen and evolution of CO_2) go on through the skin of man, the skin is too thick and dense for these changes to be of any importance in maintaining the proper composition of the blood flowing through the skin.

One of the most important of the functions of the skin in warm-blooded animals is the regulation of the bodily temperature. The body, being normally warmer than the surrounding atmosphere, will continually lose heat from its surface. This loss of heat will be greater the warmer the surface is maintained, and the warmth of the surface will depend on the richness of its blood supply and the amount of the blood flowing through it. At any given time, when the surrounding air is warm, or the amount of heat produced in the body is largely increased by muscular exercise, we find that the skin is hot and the blood-vessels are dilated. Under these circumstances there is an increased loss of heat from the surface of the body. On the other hand, when the surrounding air is cold, the arteries of the skin contract and very little blood flows through the surface. The skin is therefore cold, and can lose very little heat to the surrounding medium. In this way the temperature of the body is maintained nearly constant—namely, about 98·4° F. (37° C.). It is very little affected by changes in

external temperature. Even after severe muscular exercise, the temperature only rises one or two degrees, to fall again to the normal within a short time after exercise has ceased.

If the bodily exercise be severe, or the external temperature very nearly that of the body, as in the tropics, no amount of dilatation of the vessels of the skin will bring about a sufficient loss of heat to keep the temperature of the body down to the normal. In this case another regulative mechanism comes into play—namely, the **secretion of sweat**. The skin, throughout all parts of the body, is beset with little tubes which dip down from the surface and become coiled up in the fibrous layer of the true skin; these are the sweat glands. They are supplied with nerves, and, when the temperature of the body rises above a certain height, they are excited through their nerves to secrete. Sweat, which is little more than water and salts, is poured out on to the surface of the body. Here it evaporates and cools the body considerably, just as a vessel may be cooled by surrounding it with wet cloths and exposing it to a draught to provoke evaporation of the water. It is by the evaporation of sweat that the temperature of the body is kept approximately normal, even in a Turkish bath where the temperature is 150° F., or in the Tropics at a temperature of 110° F. If, under such circumstances, the secretion of sweat stops, the temperature of the body runs rapidly up, and the man dies of heat-stroke when his temperature has reached 110° or 112° F.

CHAPTER IX

THE HISTORY OF THE FOOD IN THE BOLY

THE proteids, fats, and carbohydrates taken in with the food become, after absorption, built up into the living tissues of the body. In the living cells they undergo oxidation, and we have traced their final products, carbon dioxide, urea, water, as they leave the body. The history of these substances from the time of their absorption to the time of their excretion includes the whole of the vital processes, and we are but very imperfectly acquainted with the various steps in this history. Once these food-stuffs have become part of the living protoplasm of the cells themselves, they elude all attempts at their investigation; but we are able to follow them on their passage from the alimentary canal to the tissues, or from one tissue to another, in the 'give and take' of the different organs which make up the balance-sheet of the living body.

The **fats** were traced from the intestines by the lymphatics and thoracic duct into the blood (p. 40). After a fatty meal the blood contains such large quantities of fat that, if some blood be drawn and allowed to clot, the blood-serum may be

quite milky in appearance and may even become covered by a creamy layer of fat-globules which have risen to the surface. Within four or five hours, however, all this fat has disappeared: some of it is doubtless carried direct to the tissues and burnt up at once for the production of energy as heat or work, or built up into the living framework of a growing tissue. If the food supplied

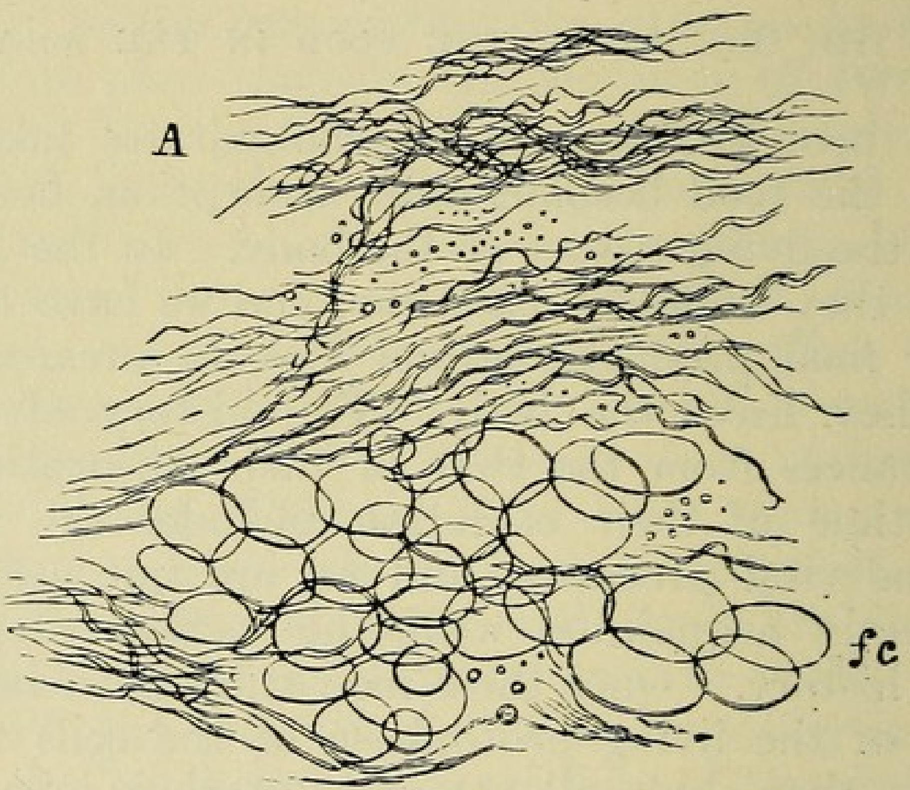


Fig. 23.—Loose connective tissue with fat cells (*fc*) (highly magnified).

be plentiful, the fat is taken up from the blood into connective-tissue cells which lie along the blood-vessels. These cells deposit the fat unchanged in their interior, and this process goes on until each cell is simply a protoplasmic bladder surrounding a large drop of fat. The cells are closely packed together, and form masses of fatty tissue, which lie underneath the skin, and are also

found surrounding the internal organs, especially the kidneys. In this situation the fat is not involved in the living processes of the body; it represents simply a store which the body can draw upon in times of need. If an animal be starved, the first tissue to diminish and finally disappear is the fatty tissue distributed over various parts of the body.

The **carbohydrates**—viz. the starches and sugars, are converted in the alimentary canal into dextrose (grape sugar), or an allied sugar. This dextrose is taken up by the blood circulating through the intestinal villi, so that, during a meal rich in starchy food, the percentage amount of sugar in the blood of the portal vein is increased. If, however, we analyse the blood from an artery, we find that it contains a certain amount of sugar (about 15 parts in 10,000), and this proportion remains the same whatever the condition of the animal, whether well-fed or starving. There must thus be some means between the portal vein and the rest of the circulation to prevent the excess of sugar, taken in after a meal, from getting into the general circulation. If sugar be injected into the general circulation, it appears in the urine; the kidney-cells turn out sugar as soon as the proportion of this substance in the blood exceeds 20 parts in 10,000. If, however, the sugar be injected slowly into the portal vein, none of it appears in the urine. Since the portal vein breaks up into capillaries in the liver, it is in this organ that we should look for the sugar which has disappeared. As a matter of fact the liver does not contain any more sugar than the blood

or the other organs of the body. If, however, it be thrown into boiling water and then pounded up with sand, boiled and filtered, the fluid which runs through is opalescent, somewhat like a solution of starch, although it does not set on cooling. The opalescent appearance is due to a substance called glycogen, which can be precipitated as a white powder by adding alcohol. This white powder, on analysis, is found to have the composition $C_6H_{10}O_5$; it is, in fact, an animal starch, and, like vegetable starch, is converted, on boiling with acids, into dextrose,

$$\underset{\text{Starch.}}{C_6H_{10}O_5} + H_2O = \underset{\text{Grape sugar.}}{C_6H_{12}O_6}$$

If the liver be allowed to remain some time after death before the glycogen is extracted, this substance diminishes in amount, its place being taken by sugar. There is, in fact, in the liver a substance capable of converting glycogen into sugar. We must conclude, therefore, that the liver has, as one of its functions, the regulation of the amount of sugar in the blood. When an excess of sugar is absorbed from the intestine, the liver converts the sugar into animal starch, which it stores up in the meshes of its cells. During starvation, when no sugar is arriving from the intestine, the liver reconverts the glycogen into sugar, and turns it out into the blood in proportion as the sugar is wanted. This power of the liver to form sugar is not, however, restricted to glycogen. We may starve an animal or feed it on a pure proteid diet without diminishing in the slightest degree the percentage

of sugar in its blood. Under these conditions the liver contains no glycogen, but obtains the sugar by the conversion of the proteids of the food or of the tissues.

The sugar thus turned out into the blood is one of the most important foods of the different cells of the body. Its value has been chiefly demonstrated in the case of muscular tissue. A heart may be made to beat for some time by passing through its blood-vessels a salt solution saturated with oxygen. After a time the beat comes to an end, the heart-muscle having apparently no further food-material at its disposal to serve as a source of energy. Under these conditions a little grape sugar added to the circulating fluid will cause the heart to start beating again. In certain diseases the tissues seem to lose their power of using up sugar, and a condition is produced known as diabetes, in which all the sugar taken in with the food is turned out in the urine. The patient under these circumstances has to supply all the needs of his body at the expense of the proteids and fats of the food. His nutrition therefore suffers, and he finally dies either from wasting or from the production of abnormal substances in his blood as the result of the restricted food-supply to the cells of his body.

The liver can lay down only a certain amount of sugar as glycogen, and this amount may be largely exceeded in a diet rich in carbohydrates. If the total food is more than sufficient to meet the energy demands of the body, the excess of carbohydrate is taken up by the cells of the body,

deoxidised to a certain extent and converted into fat, three molecules of grape sugar forming one molecule of fatty acid, according to the following equation :—

$$\underset{\text{Dextrose.}}{3C_6H_{12}O_6} - \underset{\text{Oxygen.}}{8O_2} = \underset{\text{Stearic acid.}}{C_{18}H_{36}O_2}$$

Thus both fat and carbohydrates in excess may serve as a source of fat in the body.

The **proteids** undergo far more extensive changes than either of the other two classes of food-stuffs. As they are the chief constituents of the living protoplasm, we must assume that the proteid in the brain cell differs from that in the kidney cell, and this again from that in the liver cell, and finally that the proteids from the cells of one animal will be somewhat differently constituted to those of another animal or of a plant. Since we can satisfy the proteid needs of our bodies with proteids from peas or beans or oysters or oxen, it is evident that a considerable amount of readjustment of the different constituents of the proteid molecule must take place. In the intestine the proteid molecule is, in fact, taken to pieces and converted into a number of simpler bodies, all containing nitrogen, but otherwise of the most diverse constitution. These simpler bodies are absorbed by the epithelial cells lining the intestine, and are then built up in these cells, or in the blood, or in the tissues, to form the various proteids characteristic of the different cells of the body. Apparently proteid is never stored in the body, as are fats or carbohydrates. If we increase the amount of proteid in the food, we simply

increase the proteid consumption of the cells. The cells satisfy their needs at the expense of the proteid, leaving the fats or carbohydrates to be stored up. Thus an increase in the amount of proteid taken in with the food leads at once to a corresponding increase in the amount of urea turned out into the urine. On the other hand, if the proteid be diminished, the cells begin to live more economically, satisfying, so far as they can, their needs with carbohydrate or fat. If all food be withheld, the output of urea sinks within a few days to half its previous amount, so that a few days' starvation will cause a large diminution in the fat of the body, a total disappearance of glycogen from the liver, but only a small loss of the proteid tissues of the body.

Whatever the constitution of the food, provided it contains representatives of these three classes, any excess tends to cause accumulation of fat. Obesity is therefore always due to an excess of income over expenditure, and can only be cured by diminishing the amount of food or by increasing the using up of food by muscular work. The cure which consists in allowing the patient to eat as much meat as he likes but nothing else, is really only a form of starvation, for it must be remembered that the value of a food is measured by the heat evolved in its oxidation. Even three pounds of meat a day would be only equivalent to 400 grams of proteid, and this would, in its complete oxidation, only produce 1,600 calories as against the 3,000 which is the normal amount of energy evolved by a man in the day.

The oxidation of the proteids of the tissues

gives rise probably in the first place to ammonia or ammonium carbonate, the conversion of this substance into urea being carried out by the liver. If a solution of blood containing ammonium carbonate be led through the vessels of the liver, the ammonium salt disappears, and its place is taken by urea. Thus destruction or disease of the liver may cause the urea in the urine to be diminished, its place being taken by ammonia and by other decomposition products of proteids, such as the nitrogenous derivatives of fatty acids known as amido-acids.

CHAPTER X

THE CHEMICAL FACTORIES OF THE BODY

Every cell of the body receives oxygen and food-stuffs from the blood and lymph which bathe it, and returns to these fluids in exchange certain products of its own activity. We have hitherto alluded to these products only as waste products. Some of them, such as carbon dioxide, ammonia, or urea, certainly belong to this class; but in many cases the cells produce other substances which are destined, not for immediate excretion, but to aid in the activities of other cells of the body. These cells, that is to say, act as the butcher or baker for the other units of the organism, and supply to them food or other substances which are essential for the proper carrying out of their vital functions. This power of modifying the composition of the blood flowing through them for the advantage of other parts of the body is found especially in certain glands of the body, such as the liver, pancreas, and the so-called **ductless glands**.

Sitting as it does at the entrance of the blood from the alimentary canal to the circulation, the **liver** is in the best possible position for controlling

the composition of the blood which passes through it. We have already seen that the liver plays an important part in the regulation of the sugar supply to the rest of the body. In addition to this 'glycogenic' function, it takes an important part in the destruction of proteids; and the last stage in the production of urea, namely the conversion of ammonium carbonate into urea, is almost exclusively carried out by the liver. Moreover, in conditions when the storage of glycogen in the liver is prevented, we find that this organ loads itself with fat. In these three cases the liver controls the composition of the blood by taking from it or by adding to it.

The bile-producing functions of the liver are relatively insignificant in comparison to these other functions. The **bile** may be regarded partly as a secretion destined to aid in digestion, partly as an excretion, as a vehicle for getting rid of waste products. It is a fluid of slimy consistence, and varies in colour from dark green to golden brown. Its chief constituents are bile salts and bile pigments.

The **bile salts** as solvents for fats and fatty acids play, as we have seen, an important part in digestion and absorption of fat. They are for the most part reabsorbed from the lower part of the small intestine in order to be used over and over again in the upper part of the gut for the digestion of fat.

The **bile pigments**, on the other hand, are purely excretory products; they are derived entirely from the death and breaking down of the red blood-corpuscles. The red colouring-matter,

the hæmoglobin, of these corpuscles, is taken up by the liver cells. Its iron is split off and the coloured remainder is converted into the bile pigments, which are excreted with the fæces. Part of these are changed in the intestine, absorbed into the circulation, and turned out in the urine as the colouring-matter of this fluid. If the passage of bile into the gut be prevented by the stoppage of the bile duct, two effects are produced. In the first place there is deficient absorption of fat, which passes from the intestine unchanged in consequence of the absence of bile salts from the intestine. In the second place the bile pigments, which are being continually produced by the breaking down of the red corpuscles, cannot be got rid of from the body, and so are absorbed back through the lymphatics of the liver into the blood stream, and circulating all over the body are deposited in the skin and other tissues, giving rise to the deep orange appearance characteristic of jaundice. We can thus speak of the liver as having an internal secretion or secretions—that is, turning substances out into the blood which are important to the rest of the organism, and also an external secretion which it pours into the intestine.

Certain of the other digestive glands have apparently a similar double function. We have learned to know the pancreas as an organ for turning out a juice which has the power of digesting or dissolving all three classes of food-stuffs, and is therefore the most important digestive juice in the body. If its duct be ligatured, disturbances of digestion are naturally set up, but

nothing else occurs. If, however, the whole gland be cut out of the body or waste through disease, not only is the utilisation of the food interfered with, but the animal or man becomes the subject of diabetes. He turns out enormous quantities of grape sugar in his urine, and the grape sugar is derived partly from the carbohydrates of the food, partly from the breaking down of the proteids of the food and tissues. Without the presence of some internal secretion of the pancreas the tissues of the animal, especially the muscles, seem to be unable to utilise the sugar presented to them in the food or by the chemical activity of the liver.

In the so-called ductless glands, the production of an internal secretion—*i.e.* one turned into the blood—seems to be the only function. Thus, just above the kidneys are two small bodies, known as the **suprarenal** bodies. If these undergo wasting in a man he becomes the subject of Addison's disease, which is distinguished by bronzing of the skin, vomiting, and extreme weakness, and always ends fatally. The weakness, at any rate, seems to be due to the absence from the circulation of a substance which is normally produced in this gland, and which can be extracted from the glands as a white powder known as *adrenalin*. Very minute doses of this substance injected into the circulation cause powerful contraction of the muscle fibres of the arterioles, and therefore a great rise of blood pressure. It also improves the tone of the muscles generally, and acts as an excellent though transitory cardiac and muscular tonic.

Another ductless gland, known as the **thyroid gland**, is found over the upper part of the wind-pipe just below the larynx. This body sometimes undergoes enlargement, and forms the swelling known as **goitre**. In many cases it may undergo wasting, and under such conditions the patient gradually becomes the subject of a disease known as myxœdema. His face and hands become puffy, the hair falls out, and all processes of the body seem to be slowed. The chemical exchanges are diminished, speech and thought are much delayed. All these symptoms can be removed by giving to the patient fresh thyroid glands from sheep or oxen. We must therefore conclude that this little gland makes some substance which is poured in infinitesimal quantities into the blood stream, but which is absolutely essential to the normal functioning of the other parts of the body, including the tissues of the skin, the central nervous system, etc.

It is probable that many other cells in the body produce substances which influence the activity of distant organs, but the foregoing will serve as examples to illustrate the close connection which exists between the functions of all the several parts of the body. No one part can live a selfish existence, except to the detriment of all other parts. Every cell must, besides its own life, do something for the common weal of the cell republic which makes up the living organism.

CHAPTER XI

THE DEFENCE OF THE BODY AGAINST MICRO-ORGANISMS

THE sole factor which has determined the survival of any organ, in the myriad changes undergone by the race in its evolution from the unicellular organism to man, has been its value in the struggle for existence—*i.e.* the struggle against other forms of life which seek to nourish themselves either on the food, or on the body itself, of the animal. From the lowest unicellular organism up to ourselves, we find that one of the main dangers of existence is the attack of minute forms of animal or vegetable life, the bacteria and the protozoa. The continued existence of any type on the earth's surface must therefore depend on the type having evolved some means of coping with the attacks of these micro-organisms, of preventing their entry into the body, or of destroying them in cases where they have entered by any accidental wound of the surface. We saw that the unicellular organisms such as the amœbæ were distinguished by their powers of locomotion and of ingesting and dissolving small particles which were in their vicinity. If a particle which

may serve as food be placed in a vessel containing these organisms, it will be found that they move towards the food, attracted by its smell or taste. As animals develop from the unicellular to the multicellular condition and acquire differentiated organs, a certain number of their cells remain in the primitive amœboid condition. Whatever animal we study, we find that its body fluids, lymph or blood, contain such wandering cells, which, like the amœba, have the power of eating up small food particles, including bacteria. Thus, if we introduce into the tissues of an invertebrate animal a small drop of fluid containing bacteria, within some hours we find that a number of amœboid cells have wandered towards the spot of the puncture, have collected round the micro-organisms, and are in active process of eating and destroying these invaders.

In the higher animals, including man, this gathering of amœboid cells (**phagocytes**) is aided by the possession of blood-vessels. If a small wound in the finger be infected, the part becomes swollen and hot and painful. If a section be made of the part and examined microscopically, it will be seen that the blood-vessels are dilated, that the part receives a much increased blood supply, and that the walls of the capillaries have undergone alteration. Every leucocyte which is brought by the blood first sticks to the wall of the capillary in the infected part and then squeezes through the wall between the cells of which it is composed, makes its way out into the tissues, and there proceeds to eat up and destroy the micro-organisms with which the wound is infected.

This fight between phagocytes and micro-organisms is a chemical one. The micro-organisms produce poisons in order to destroy the cells of the body; the phagocytes produce substances which may neutralise these bacterial poisons, and also other substances which may kill or digest the bacteria. The final victory rests with the organism which is best prepared by its experience for the conflict. Thus the phagocytes can be taught by small doses of the poison—*e.g.* by vaccination—to resist larger doses; the bacteria can be taught, by cultivation in an animal with a naturally high resistance, to overcome this resistance and therefore still more easily the resistance of less immune animals. Hence it comes that the most mild of diseases may be extremely fatal when introduced into a community for the first time. Under these circumstances measles may become as fatal as an epidemic of plague.

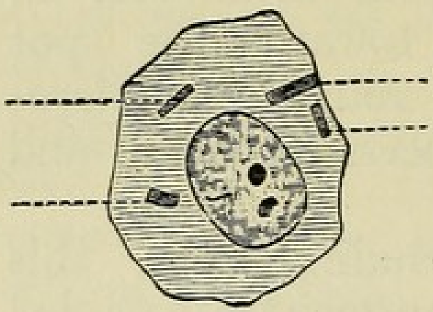


Fig. 24.—Phagocyte containing bacilli undergoing digestion.

In order to guard against infection all parts which are especially exposed to the penetration of micro-organisms are provided richly with phagocytes. This is the function of the so-called lymphoid tissue — depôts for the production of phagocytes—surrounding the mucous membrane of the alimentary canal and of the respiratory passages. Solid particles introduced under the skin travel up slowly from the lymphatics to get into the blood. No lymphatic, however, has a direct course to the blood stream,

but passes first through one or more lymphatic glands, which can be regarded as a close sponge-work of phagocytes. Hence an infection of the finger does not as a rule cause infection of the whole body: the infection may be confined to the injured spot, but if it extends beyond here it generally stops short at the first lymphatic gland; the glands in the bend of the elbow or in the armpit become inflamed, or may even break down into an abscess, but the further progress of the micro-organisms is generally put a stop to.

We find a similar living filter in the blood stream itself. On the left side of the abdominal cavity is a dark red organ known as the **spleen,** which contains nodules of lymphoid tissue and a number of large cells, which are capable of eating up either micro-organisms or degenerated blood-cells. In relapsing fever, which is distinguished by the presence of a small micro-organism, spirillum, in the blood, the cure of the fever and the disappearance of the spirilla from the blood are contemporaneous, and are found to be due to an ingestion of the micro-organisms by the cells of the spleen. In certain other disorders, where bacteria are free in the blood, the spleen becomes enlarged and tender, just as do the lymphatic glands when the infection of micro-organisms is limited to the lymphatics.

This phagocytic reaction is, however, only one means of defence. In certain cases the bacteria act on the body as a whole, not by general infection, but by making a poison which can diffuse through the layer of encircling phagocytes and get into the blood stream, by which it is

carried to distant organs. Instances of this mode of attack are furnished by diphtheria and tetanus or lockjaw. In such cases the organism has to react in a second way—viz., by the production of **antitoxins.** These are substances which will neutralise and destroy the poison produced by the bacteria. It is especially in such cases that we can aid the process of defence by injecting into the infected animal or man antitoxic sera obtained from another animal, in which a large production of this antitoxic substance has been brought about by the repeated injection of small doses of the poison.

CHAPTER XII

THE PHYSIOLOGY OF MOVEMENT—THE MUSCLES

If the skin be stripped off the leg of a rabbit or frog, it will be seen that the flesh is arranged in bands, which pass from one bone to another. Very often the flesh becomes sinewy or tendinous at its attachment to the bones. If these bands be pulled upon, the bones are moved relatively one to another. Thus the muscles running upon the front of the thigh, when pulled upon, will straighten the leg, whilst the muscles at the back of the thigh will bend the leg at the knee. In the recently killed frog, instead of pulling upon the muscles, we can produce the same effects by exciting them by means of electric currents. When electric currents from an induction coil are passed through any one of the bands forming a muscle, it will be seen to shorten and become thicker, and in shortening to produce movements of the bones to which it is attached.

In living conditions the muscles are never excited directly. They are connected with the central nervous system by means of nerves, and the movement which makes up an adaptive reaction or 'reflex action' is evoked by the passage of an

impulse from skin up to nerve centre, and from nerve centre down the nerves to the muscles. If, instead of stimulating the muscle itself, we stimulate the nerve going to the muscle, the same effect is produced—namely, contraction or shortening accompanied by thickening of the muscle. This contraction is very rapidly produced: if a single electric shock be applied to the nerve or muscle, the latter gives a short sharp twitch, which commences within less than one-hundredth of a second after the shock has been sent in, and lasts only about one-tenth of a second. In order to keep the muscle in a contracted condition, as is the case when a weight is held up by the arm, it is necessary to repeat the electric shocks at frequent intervals—namely, about twenty or thirty times per second. If a muscle be cut out of the body, it will still contract on application of electric stimulus. It will not, however, lengthen again unless some weight be hung on to it. Under normal conditions, therefore, the shortening of the muscle is active, the lengthening of the muscle is passive and brought about by the pull of antagonistic muscles.

Many changes occur in the muscle during contraction. One of the most important of these is the evolution of heat. It is a familiar experience that muscular exercise—running, for instance—makes us hot; and we can, by delicate thermometers or other means, show that every single twitch of a muscle is accompanied by the evolution of heat. So in a muscular contraction energy is evolved in two ways—namely, as heat and as mechanical work. This energy must come

from chemical changes in the muscle. Of these the most important is the taking in of oxygen and the evolution of carbon dioxide. If a muscle be richly supplied with oxygen, as is of course the case in the body during contraction, every contraction causes an increase in the amount of oxygen taken in and an increase in the output of carbon dioxide. We may therefore conclude that during contraction there is an increased oxidation going on in the muscle, and that this oxidation chiefly affects the carbonaceous constituents of the muscle. In fact, our experiments with an isolated muscle, well supplied with oxygen, agree with those obtained on the whole animal during muscular work, in which the output of CO_2 may be increased ten- or twelve-fold under these conditions. If the muscle is badly supplied with oxygen, it does not at once become incapable of contraction; it still continues to contract on stimulation with the evolution of heat, but in this case there is no considerable formation of carbon dioxide. The energy in the absence of oxygen seems to be derived from a process of chemical disintegration which results in the formation of acid substances, especially lactic acid, in the muscle. This acid is similar to that formed by the spontaneous souring of milk, and is apparently derived from a splitting of the grape-sugar molecules which are bound up in the muscle. It is doubtful, however, whether any of this substance is formed during the normal activity of a muscle which is richly supplied with oxygen.

In the muscle, as in the steam engine, we have, therefore, a process of oxidation giving rise to the

evolution of heat and the performance of work. A simple consideration will serve to show that the mechanism in the two cases must be absolutely different. In the best of our steam engines the proportion of work done to the total energy of the chemical change (the 'efficiency') never exceeds $\frac{1}{10}$, and to procure this we must use superheated steam and have a very large difference of temperature between the boiler and the condenser. In muscle there can never be a difference of more than two or three degrees at the most between the acting particles of the muscle and the surrounding tissues; and yet we find that the 'efficiency' of the muscle is very much greater than that of a steam engine—in fact, 50 to 60 per cent. of the total energy of the muscle may appear as mechanical energy. It has been found by experimenting on men in bicycle races, that fully this proportion of the energy taken in by them in the food is expended in muscular work. We must therefore conclude that the muscle is a *chemical machine*, and that in it, in some way or other, the energy of the chemical change is directly converted into work, without, as in the steam engine, being first converted into heat. The exact mechanism by which this change of energy is effected still remains to be discovered.

A muscle, like every other part of the living organism, has a considerable power of adapting itself to its conditions of life. Thus, if very little strain is thrown upon it, it tends to waste and become smaller. If it be constantly exercised its efficiency is increased, and increased according to the call that is made upon it. The absolute force

of a muscle—*i.e.* the weight it is just able to lift—depends upon its cross section—that is, the number of fibres which act together in raising any weight. If, therefore, the strain on a muscle is constantly increased, the muscle tends to grow and increase its cross-section. Thus, if it is desired to increase the size of muscles we must ensure that these muscles are constantly exercised against a force which is greater than that which they have normally to overcome. On the other hand, ordinary exercise does not necessarily increase the size of muscles; and we find that many races of men who are able to keep up prolonged exercise have only small muscles. In fact, we may say that exercise improves the efficiency of a muscle and its power of resisting fatigue, while increased strain causes increased size of the muscle. Exercise, however, influences not only the muscular tissue directly involved. As we have seen earlier, every muscular contraction adds to the lymph flow and to the blood flow by pressing on the lymphatics and veins. The increased circulation thus procured improves the nutrition of all parts of the body—a body which has been evolved by the very fact of its being fit to undertake fatigue in the struggle for food and existence in the presence of numberless enemies.

So far we have only spoken of the muscles which are attached to the bony skeleton and are under the direct control of the will. In addition to these, all the hollow viscera, the intestines, bladder, blood-vessels, etc., are surrounded with another kind of muscular tissue, known as **involuntary muscle**. These sheets of muscular tissue are not

under the direct control of the will; their function is, as a rule, to regulate the size of the cavity which they enclose, to empty it in the case of the bladder, to move on the food in the case of the intestines, or to regulate the flow of blood through the small arteries. It is less highly differentiated than the skeletal muscles. If stimulated it gives a long, slow contraction, which may last from two seconds to half a minute. Even when separated from the nervous system it does not become flaccid, like the skeletal muscle, but retains a certain amount of spontaneous contraction, which is spoken of as 'tone.' The tone of the muscle can be altered by the central nervous system in two directions. It can be relaxed so that the organ increases in size, or it can be increased so that the cavity of the organ is diminished or obliterated.

In the **heart** we find a muscular tissue which is intermediate between the two kinds just mentioned. In appearance it has striking similarities to voluntary muscle. Although under the control of the central nervous system, it can, when separated altogether from this system, carry out the spontaneous rhythmic contractions which make up the heart-beat. If a strip of heart muscle, which has ceased contracting spontaneously, be stimulated with an electric shock, it will give one contraction which is slower than that of a limb muscle, but much more rapid and forcible than that of an involuntary muscle. The ordinary contraction of the muscle of the ventricle in a man's heart lasts about three-tenths of a second, and in cold-blooded animals,

such as the tortoise, the contraction may last as much as two seconds. So far as we know, the differences between these various kinds of muscle are chiefly of degree, in every case contraction being associated with chemical change, and probably with evolution of heat.

CHAPTER XIII

THE PHYSIOLOGY OF MOVEMENT—THE CENTRAL NERVOUS SYSTEM

THE movements of the body make up the most important and striking feature of the daily life of the animal, being employed for the purposes of offence and defence, and especially to aid in alimentation by the procuring of food. The daily life of most men may, in fact, be looked upon as a complex reaction conditioned by hunger, or as having for its object the prevention of hunger. The essential organ for these motor adaptations of the body, as well as for the fitting together of the various organ activities which we have studied in previous chapters, is the **central nervous system**, including the spinal cord and brain. The bones (vertebræ) forming the spinal column are pierced by a continuous canal, which contains the spinal marrow or spinal cord. At the upper part of the neck the spinal canal communicates through an opening, the **foramen magnum,** with the cavity of the skull, which is entirely filled with the brain.

The **spinal cord** has the shape of a long flattened cylinder tapering at its lower end. On

cutting it across, it is seen to consist of a white glistening substance externally surrounding a central core of reddish grey material known as the grey matter, which in transverse section has the shape of a letter H. Attached to the spinal cord on each side are a number of processes—the nerve roots. In man there are on each side thirty-one nerve roots; these pass

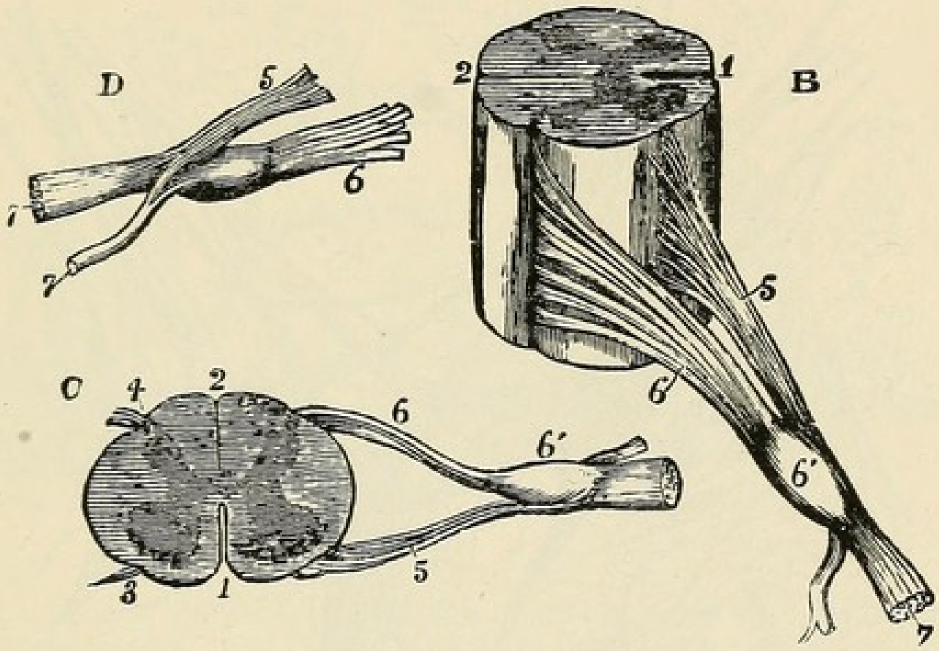


Fig. 25.—Different views of a portion of the spinal cord (human), with the nerve roots. In *B* a view of the right side is given; in *C* the cross section is shown, and in *D* the nerve roots and ganglion on the posterior root are alone given.

outwards into the body, dividing as they go, and are distributed through all the muscles, skin, and other tissues of the body. Each nerve arises from the spinal cord by two roots, anterior and posterior. If we examine the spinal cord by means of the microscope, we see that the white matter consists of fine tubular processes or nerve fibres, almost exactly similar to the fibres constituting the peripheral nerves,

and running for the most part longitudinally in the cord. The grey matter, on the other hand, is formed by a mesh-work of very fine fibres enclosing in their meshes large cells. These cells when isolated are found to have many processes, most of which run out and branch in the adjacent nervous tissue. One, however, which is

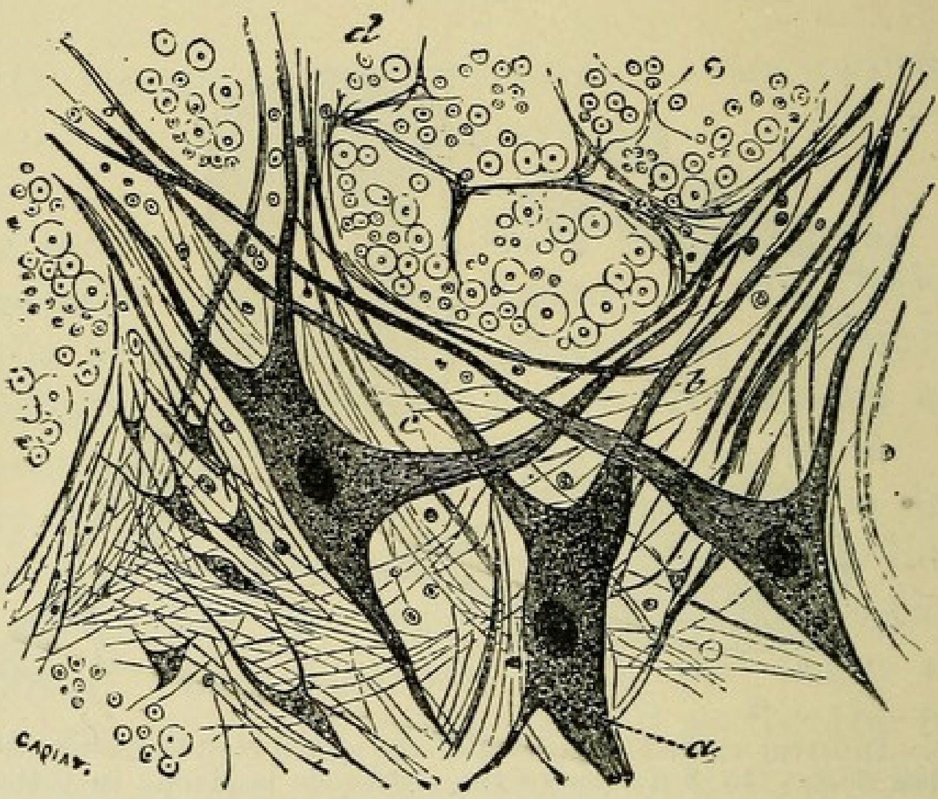


Fig. 26.—View of grey matter of spinal cord, highly magnified. (*a*) Large nerve cells. (*d*) Nerve fibres of adjoining white matter, cut across.

known as the axis cylinder process, passes away from the cell, branches very little, and may either pass out by an anterior nerve root and run down in a nerve to some muscle, or may pass up in the spinal cord to end in some part or other of the brain. Thus each of these cells has a number of short processes by which it may be acted upon by changes in its environment, and one long

process which stretches out to the uttermost parts of the body, and is able to carry to this part any changes set up in the central cell. We can, in fact, look upon the cells of the spinal cord and of the central nervous system generally as derived from cells originally on the surface of the body, where they had the function of feeling changes in the environment of the animal. These cells have been withdrawn from the surface, but are

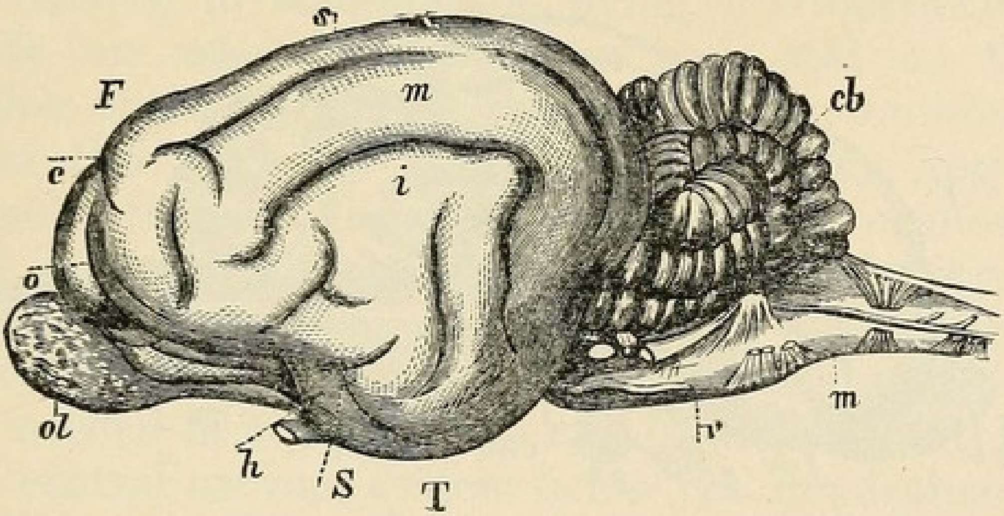


Fig. 27.—View of cat's brain from the left side. (*m*) Medulla oblongata. (*v*) Pons varolii. (*cb*) Cerebellum. (*F*, *S*, *T*) Different parts of cerebral hemisphere. (*ol*) Olfactory lobe. (*h*) Cut end of optic nerve.

still influenced by impulses which act upon cells at the surface, and travel thence along nerve processes to the spinal cord.

The **brain** is much more complex in structure than the spinal cord. It can be regarded as a central axis prolonged forward from the spinal cord, out of which a series of excrescences have grown. As the spinal cord enters the foramen magnum it widens out to form the **medulla.** Just in front there is an outgrowth from the

posterior surface of the medulla, which forms the **little brain** or **cerebellum.** The axis is then prolonged forwards as the mid- and fore-brain. From the front of the fore-brain we find two grey outgrowths, which, in man, exceed in size and overshadow all the rest of the brain. These are known as **cerebral hemispheres.** Whereas in the axial part of the cerebral nervous system the grey matter containing nerve cells is situated

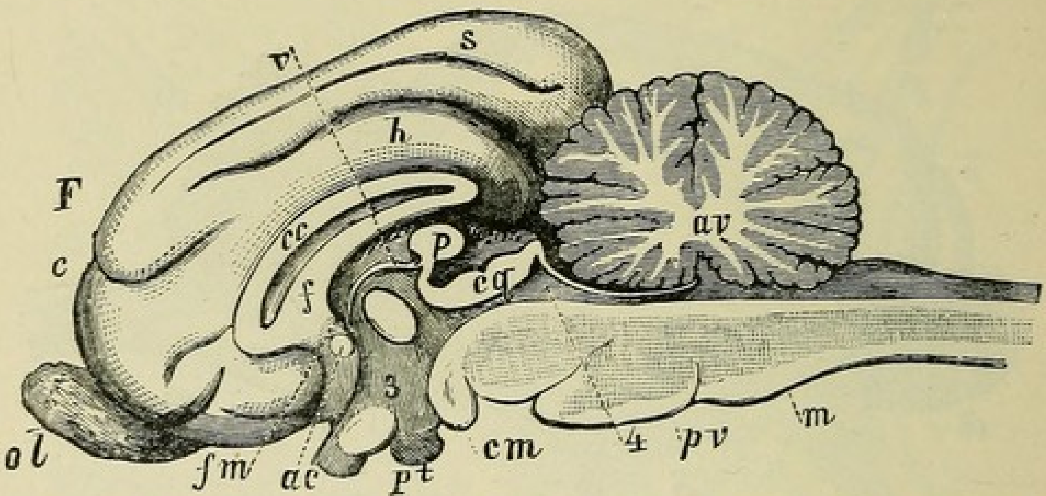


Fig. 28.—Cat's brain, as seen when a vertical longitudinal section has been made through its middle. (*ac*) Represents the anterior limit of the forebrain ; (*p*) of the mid-brain ; and (4) of the hind-brain. (*av*) Cerebellum. (*m*) Medulla. (*F*) Cerebral hemisphere. (*ol*) Olfactory lobe.

in the centre, in the outgrowths forming the cerebral hemispheres and cerebellum the grey matter lies on the surface surrounding a core of white fibres, and is called the cerebral or cerebellar cortex.

The function of these various parts can be studied by observing the effects of their destruction. If the cerebral hemispheres be removed in a frog or a pigeon, the animal becomes a machine whose actions are directed immediately by

changes occurring in its environment, without any interference or check which may be ascribed to memory or intelligence. A pigeon under such circumstances remains perfectly still, and, if left to itself, will starve to death ; if thrown into the air it will fly, but on coming to rest will once more remain perfectly still. If its beak be plunged into corn it will eat. When made to move, all its actions are carried out as in a normal pigeon ; it avoids obstacles, and is able to preserve its balance in standing or flying. Observations made on cases of disease in man and on the higher animals confirm the conclusions obtained from the study of the pigeon and the frog—namely, that intelligence, consciousness, memory, and experience are bound up with the integrity of the cerebral hemispheres. These observations teach us also that all the complex movements which are needed in our daily life can be carried out by the central nervous system below the hemispheres. If in the frog the whole head be cut off, so as to remove all parts of the brain above the medulla, the animal is no longer able to walk, to sit, or to swim. The movements of breathing are still carried out, and the animal will react to stimuli, such as pinching the skin of its body, with movements of escape—movements which are in most cases ineffective, but which are similar to the movements made by an intact animal.

To the cerebral axis, the fore-, mid-, and hind-brain, are connected a number of nerves which supply the special senses of smell, sight, and hearing. These sensations must play a very large part in the guidance and causation of the normal

movements of the body, and it is not surprising that cutting off the parts of the central nervous system specially connected with these senses should seriously affect the reactions of the body as a whole.

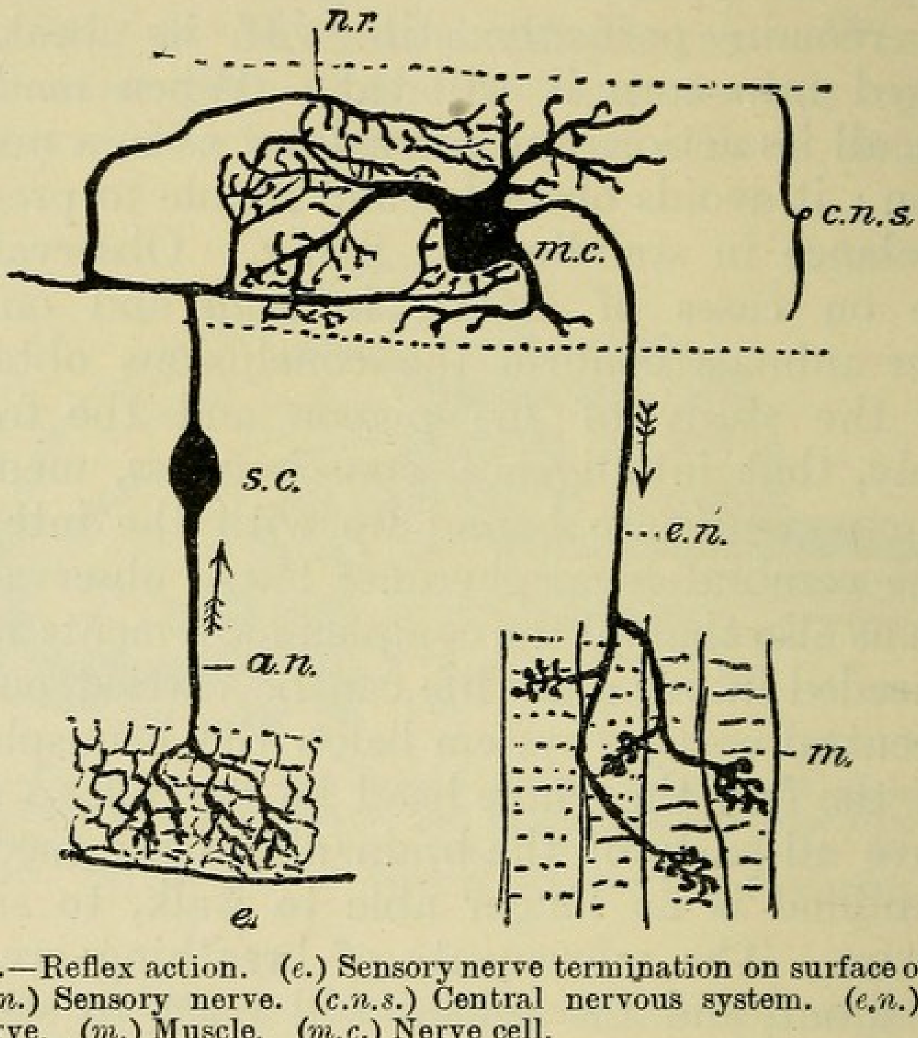


Fig. 29.—Reflex action. (*e.*) Sensory nerve termination on surface of body. (*a.n.*) Sensory nerve. (*c.n.s.*) Central nervous system. (*e.n.*) Motor nerve. (*m.*) Muscle. (*m.c.*) Nerve cell.

If we take a frog in which the whole brain has been destroyed, we have an object in which the adaptive motor reactions of the body can be studied in their simplest form. If such a maimed animal be hung up by its jaw and a toe pinched, the leg of the same side will be immediately drawn up. This simple adaptive reaction is

spoken of as a **reflex action** ; it is at once abolished by destruction of the spinal cord or by division of the nerves going from the leg to the cord. It is evident that in this reflex action there is a chain of processes. The pinch or stimulus sets up changes in the skin nerves, these travel up the nerves of the leg to the spinal cord. Here the changes are reflected down the nerves which pass to the muscles of the limb, causing this to contract and the leg to be drawn up. It is interesting to note that the path of the impulse into the cord differs from the path of the impulse away from the cord. Each spinal nerve, as we have seen, arises by two roots ; if the posterior roots corresponding to any part of the body be cut, this part is at once deprived of sensation, but is still capable of movement in response to stimuli applied to other parts of the body. If, on the other hand, the anterior roots passing to one leg be divided, the animal will still respond to a pinch of this leg by movements of other parts of the body, but the leg itself remains perfectly at rest. It is plain from these observations that the posterior roots contain the fibres which carry impulses from the skin into the spinal cord, and that the anterior roots carry impulses which pass from the cord to the muscles.

By various methods we can trace the course of the fibres running from any part of the body into the spinal cord, and can make out their connections in the cord with the cells whose processes run down in the anterior roots to the muscles. A study of these connections shows us that the reaction which occurs as a result of any stimulus

depends entirely on these connections. The impulse can only pass to certain muscles. The whole central nervous system is, in fact, a complicated junction of ways, all the ways being so ordered as to direct any impulse into the channels where it can excite an activity of muscles which shall tend to the preservation of the animal in the struggle for existence. As we examine the higher parts of the brain, and proceed from the lower to the higher forms of animals, these ways become more and more complex, and allow, therefore, more and more diversity of response according to the conditions of the various parts of the body.

In addition to the nerves which pass from the central nervous system to the skeletal muscles, there are others which pass to the unstriated involuntary muscles of the blood-vessels of the heart and of the intestine. The medulla—*i.e.* the lowest part of the brain—is especially concerned in presiding over and co-ordinating the activities of these vegetative functions of the body. In this part we find the **vaso-motor centre**, which is continually sending out impulses to all the blood-vessels of the body and keeping up the arterial blood pressure. If this centre be destroyed, all the arteries relax and the blood pressure falls. Here also we find a **heart centre,** stimulation of which will, through the vagus nerves, cause slowing or stoppage of the heart. In close connection with the heart centre is the **respiratory centre**, which receives impulses from the lungs along the vagi, and sends impulses down the cord and out by the anterior roots to all the muscles involved in normal breathing. By this

centre breathing can be carried out in the entire absence of the higher parts of the brain. If, however, the centre be destroyed, respiration ceases, and the animal dies. Most of the nerves which run to the blood-vessels and viscera, after passing out in the anterior roots, run in a series or collection of nerve cells called the **sympathetic ganglia** (*v.* fig. 7), and these nerves of vegetative life are generally spoken of together as belonging to the sympathetic system. On opening an animal the ganglia of the sympathetic system can be seen lying in a chain on each side of the middle line and sending fine filaments along the arteries, leaving the aorta, to be distributed to the vessels and all parts of the abdominal and thoracic viscera.

Life is made up of adaptive reactions, of which the motor are the most evident. The character of the reaction is dependent on the direction and connections of the nerve tracts laid down in the central nervous system. We have studied the nature of the changes in the reacting organ—namely, the muscles. It remains, therefore, only to consider the nature of the changes in the receiving organ on the surface of the body, which is the starting-point of the reaction. Of the stimuli which act on the surface of the body some, as in the brainless frog, merely evoke corresponding motor reactions; others, in the intact animal, travel farther, and pass from spinal cord up to fore-brain and to the cerebral hemispheres. They may, and in fact must, evoke some reaction or modify some reaction already provoked, but their arrival at the cerebral cortex brings them into the sphere of consciousness, and in our own case

we say we *feel* something. The physiology of impressions made on the periphery is therefore considered under the heading of Feelings or Sensations.

CHAPTER XIV

FEELINGS

In order that the central nervous system may be able to carry out the continued series of internal and external adaptations which make up the whole of life, it is necessary that it should be made aware by its nerves of events occurring at and affecting the surface of the body, as well as of changes which go on at some distance from the body. Thus the animal must be able to appreciate the presence of food or enemies before they actually come in contact with him, so that he may pursue the one and flee from the other. A mechanical change at the surface of the body can naturally affect directly the nerves or nerve-endings in the skin. Events at a distance from the body can only act on the surface of the organism by setting up disturbances in the medium surrounding the organism. These disturbances may be of various kinds. In the first place we have the vibrations in the ether which make up what we call **light** or radiant energy; in the second place we have the much coarser vibrations in the surrounding air which come to us in the form of **sound**; in the third

place we have the production of chemical substances which spread through the surrounding medium, whether air or water, and so reveal the presence of the substance which originates them. The organs in the surface of the body which receive these various kinds of stimuli are known as the **sense organs**, and the impressions which they make on consciousness in the presence of the cerebral hemispheres are known as **sensations**. It must be remembered, however, that the movements of the animal may be still guided by all these various kinds of impressions in the complete absence of a conscious intelligence, as, *e.g.*, after removal of the cerebral hemispheres.

Five distinct senses are generally described—namely, the senses of **touch**, of **taste**, of **smell**, of **hearing**, and of **sight**. To these we ought to add certain sensations which take their origin in the body itself as a result of its movements. These are: the **muscular sense**, which informs us of the position and the degree of contraction of our muscles; and the **sense of equilibrium**, which, taking origin in a specialised part of the internal ear, tells us of the position of our head in space and the direction of passive movements of the body.

The sense of **touch** is somewhat complex, since it probably includes at least four different kinds of sensation. The sense of touch proper, which is excited by direct contact of external objects with our skin, tells us of the position, size, and consistency of an object. The sense of **temperature**, which includes a cold sense and a heat sense, informs us of the temperature of bodies in contact with the

skin in their relation to the temperature of the skin itself, anything which is cooler than the skin giving rise to a sensation of cold. Finally we have, as the result of injury to or very strong stimulation of the skin, the sense of **pain**. This sense is directed, not so much to giving accurate information of the properties of external objects, as to serve as a note of warning to the organism, and a call to instant removal of the part affected from its surroundings. By the pain sense is set the limit of experience, beyond which the animal or organism cannot go without injury or destruction to itself. In order to receive all these different sensations, the skin and the subcutaneous tissue are richly endowed with nerve-endings: some of these nerve-endings consist of simple tree-like branchings of the nerve-fibres, others are specialised collections of cells between which ramify nerve-fibres. We have not yet succeeded in assigning to each of the manifold varieties of nerve-endings met with in the skin the exact type of sensation which it is its function to produce.

The **tongue** presents all over its surface little elevations or papillæ, and at the back part these papillæ are especially large and are surrounded by a circular pit (circumvallate papillæ). In the walls of this pit are the so-called **taste buds**—little pear-shaped masses of epithelial cells, each of which has a process projecting through the orifice of the bud into the cavity of the mouth, while at the deeper end the bud receives ramifying nerve fibres from one or more of the cranial nerves. All tastes can be reduced to one

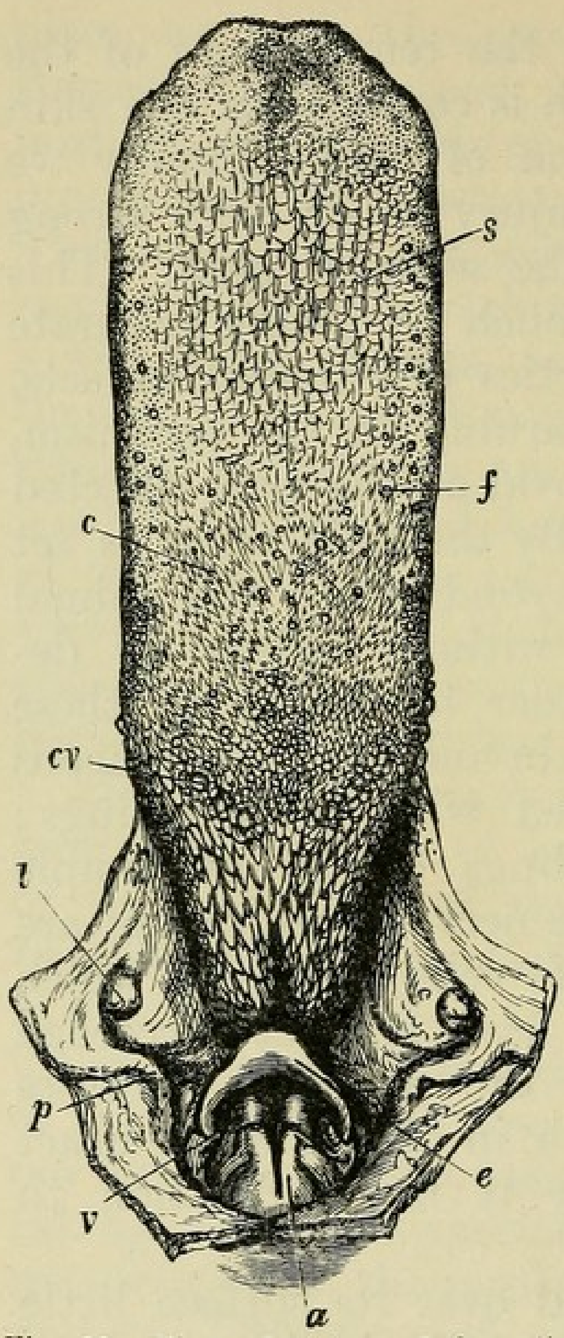


Fig. 30.—View of tongue of the cat). (*a*) Opening of windpipe (glottis). (*e*) Epiglottis. (*f*) Papillæ. (*cv*) Circumvallate papillæ. (*t*) Tonsil.

of the four primitive sensations—sweet, bitter, sour, and salt. The flavours, which are more important even than the tastes for our appreciation of food, depend entirely on the sense of smell. A man who has, by disease, lost his sense of smell, can perceive very little difference, other than that of consistence, between an apple and an onion.

The sense of **smell** resembles the two foregoing in that it gives information concerning the nature of stimuli arising in the surface of the body itself, and so presides over the appreciation of food. It has also important analogies with the senses of sight and hearing, in that the sensations of smell can to a certain extent be *projected* —that is, they are appreciated as arising from objects outside the body, and as giving information as to the nature of these objects. In the lower animals—*e.g.*, the dog—this aspect of the sense of

smell is most important, the movements of such an animal in search of prey being more guided by its sense of smell than by any other sense. If we regard smell as the *projected* chemical sense, it must be looked upon as the most primitive of all sensations. Even bacteria are directed in their movements by the chemical differences in their surrounding media. They will move towards solutions which are of value to them as food, and will move away from harmful substances. In ourselves this use of smell has been almost entirely replaced by sight, and the connections of the smell nerves in the brain and the part of the brain connected with this sense are less extensive than in the lower animals.

The organ of smell is situated in the upper part of the cavity of the nose. Here the mucous membrane presents little spindle-shaped cells which are at the same time sensory cells and nerve cells. Each of these cells sends a process up to the surface, where it can be acted upon by substances in the air filling the nasal cavities ; and another process inwards, which is an actual nerve-fibre and passes through the thin layer of the bone separating the nasal from the cranial cavity to be connected with a distinct lobe of the brain.

The Sense of Hearing

The organ of hearing is much more complex than any of those we have already studied. It consists of three parts—the external, the middle, and the internal ear. Sound is originated by the vibrations of any bodies. These vibrations are transmitted

to the air or any elastic medium, and they have to be imparted in some way to the endings of the nerve supplying the internal ear. The use of the external ear is simply to collect the sound waves in the surrounding air. These waves travel

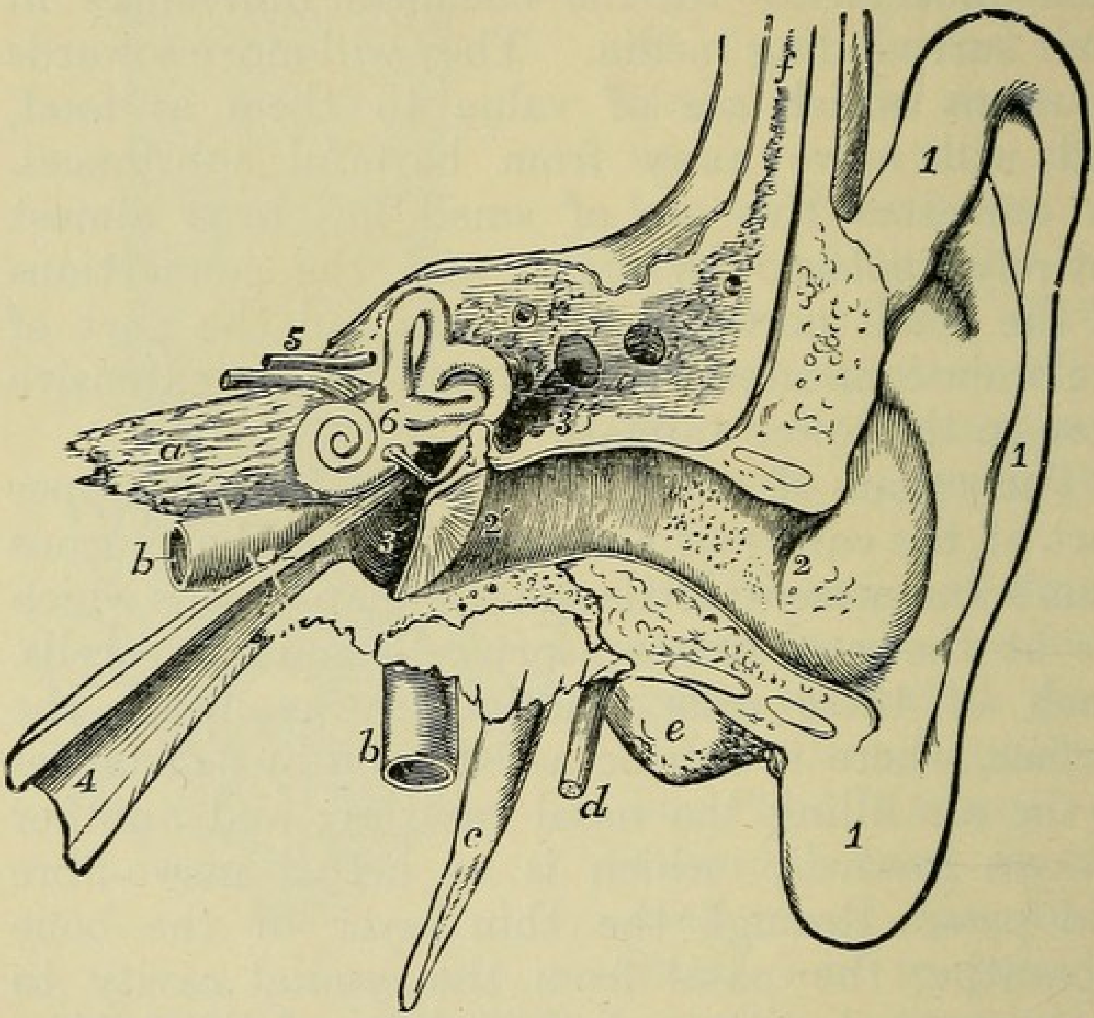


Fig. 31.—Diagrammatic view of the organ of hearing of man. 1, External ear. 2, Auditory canal. 3, Middle ear. (Between 2 and 3 is the drum.) 4, Eustachian tube connecting middle ear with throat. 5, Auditory nerve. 6, Internal ear.

along the canal and impinge on a little membrane at the bottom of the canal, known as the **drum** of the ear. In the middle ear we find three little bones which are called the hammer, the anvil, and the stirrup. The handle of the hammer is

attached to the inner side of the drum. The base of the stirrup is inserted into an oval opening in the wall of the internal ear, and the chain of bones is so connected that any vibrations or movements of the drum are transmitted along the chain to the base of the stirrup in the oval opening. Within the internal ear is a branched cavity filled with fluid, known as the perilymph,

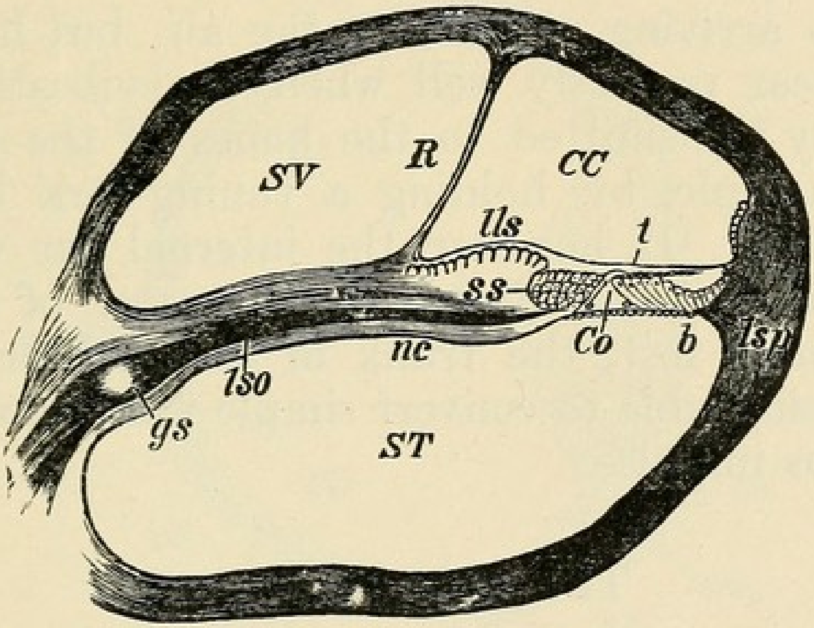


Fig. 32.—Section through a turn of the cochlea. (*Cc*) Middle canal of cochlea, (*CO*) Organ of Corti. (*lso*) Nerve-fibres of auditory nerve. *ST* and *SV* contain perilymph.

and suspended in this bony cavity is a membranous sac, also filled with fluid. The part of this sac connected with hearing is known as the middle canal of the **cochlea**. In the walls of this canal the auditory nerve ends in a complicated arrangement of cells known as the **organ of Corti**. The vibrations of the perilymph, which are caused by the movements of the stirrup bone, excite these nerve-endings and so set up in the auditory nerve a nervous impulse, which, on arrival

at the brain, gives rise to a sensation of hearing. It is evident that this sensation will vary according to the extent of the vibration (*i.e.* the loudness of the sound), the number of vibrations in the sound (*i.e.* the pitch of the note), and the complexity of the vibrations, so that we can appreciate whether a single note or a complete chord is sounded on a piano. If the external ear were stopped up, the patient would be deaf so far as concerned sounds arriving at him by the air, but he could still hear perfectly well when the vibration was directly transmitted to the bones of the skull, as for example by holding a tuning-fork between the teeth. If, however, the internal ear with its nerve-endings be destroyed, the sense of hearing is entirely lost, the trunk of the auditory nerve not being able to convert simple vibrations into a nervous impulse.

The Sense of Sight

Under normal circumstances rays of light from all surrounding objects are arriving at our body. In order that they may affect consciousness or guide our reactions, some means is necessary for bringing an accurate representation of these external objects, in proper relationship one towards another, in contact with the endings of some nerve specially modified for converting light-waves into nervous impulses. The apparatus for this purpose is furnished by the **eye**. In the eye we have practically a photographic camera, provided with a system of lenses by which an inverted image of external objects may be focussed upon

the sensitive plate at the back of the eyeball—viz., the **retina**—which is itself the flattened terminal expansion of a special nerve, the **optic nerve.** The eyeball, roughly globular in shape, is enclosed in a tough fibrous wall, known as the **sclerotic coat.** In front this wall bulges so as to resemble a watch-glass placed on a sphere. This bulging

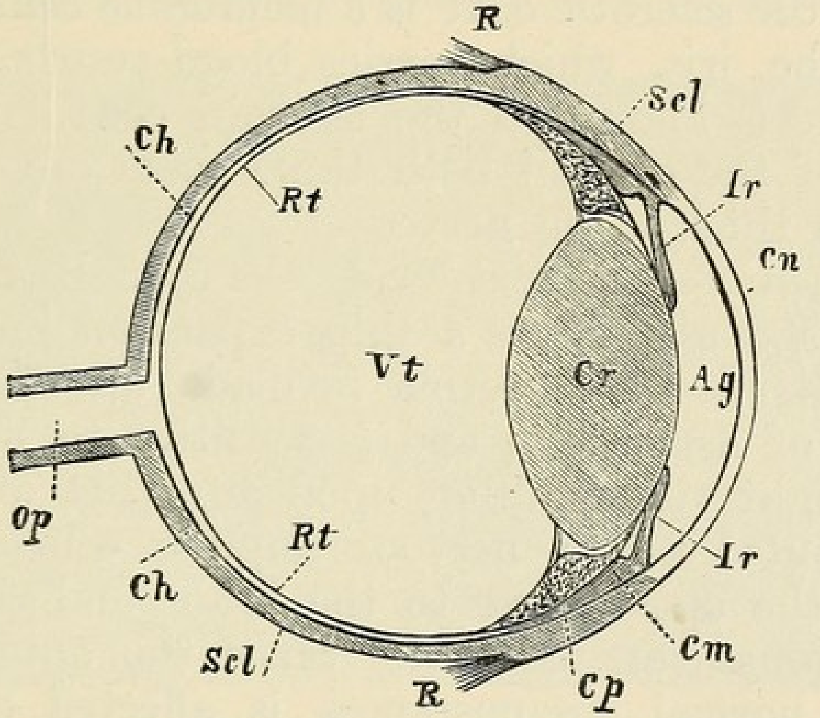


Fig. 33.—Diagram representing a vertical section of the cat's eye. (*Scl*) Sclerotic coat. (*Cn*) Cornea. (*R*) Attachment of eye-muscles. (*Ch*) Choroid coat. (*Cp*) Ciliary processes. (*Cm*) Ciliary muscle. (*Ir*) Iris ; (*Aq*) Aqueous humour ; (*Cr*) Lens. (*Vt*) Vitreous humour. (*Rt*) Retina. (*Op*) Optic nerve.

portion of the sclerotic is perfectly transparent, and is known as the **cornea.** Through it rays of light can pass to the back part of the eyeball. Behind the cornea is a circular curtain, the **iris,** in the centre of which is a small orifice, the **pupil.** The iris contains pigment cells which make it impervious to light. In its substance are imbedded two sets of muscle-fibres, one of which contracts

while the other dilates the pupil. The iris represents the stop in a photographic camera. When the light entering the eye is bright, or when accurate vision is necessary, as in looking at near objects, the pupil is contracted; when, on the other hand, the light is dim, the pupil is widely dilated—just as in a camera we use the widest stop when we attempt to photograph in a bad light. Inside the sclerotic coat is a membrane continuous with the iris, which carries blood-vessels to the eye, and is known as the **choroid coat.** At the back of the eyeball both these coats are pierced by the thick optic nerve.

Immediately after entering the eyeball the optic nerve spreads out to a thin expansion known as the **retina.** The retina is made up of special layers of nerve-cells, and is sensitive to light, so that light-waves falling upon any part of it are transmuted into a nervous impulse which passes along the optic nerve to the brain, and gives rise to a **sensation** of light. Since the optic nerve under normal circumstances is affected only by changes in the retina caused by the entrance of light into the eye, any impulse passing along it, however excited, is also interpreted on arrival at the brain as a light impulse. Hence, if we shut our eyes and press through the eyelid on the eyeball, the direct excitation of the retina so caused produces a sensation of light.

In a camera it is important to focus accurately at will near or distant objects. The image of a near object is farther behind the lens than the image of a distant object. In the camera we compensate these differences by moving the sensitive

plate nearer or farther away from the lens. In the eye the analogous accommodation is effected by changes in the lens. The lens of the eye is suspended by the **suspensory ligament** from the **ciliary** processes of the choroid coat, and lies just behind the iris. When the eye is at rest the lens is stretched laterally, and is therefore flattened on its front surface. When we wish to look at near objects we are conscious of a certain effort

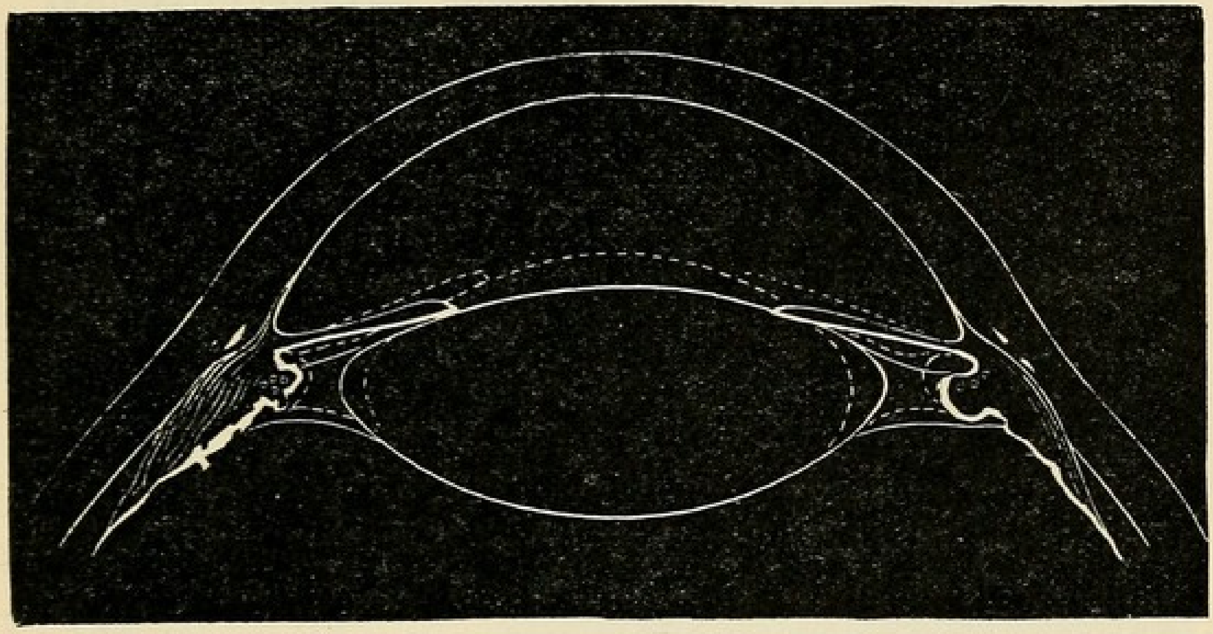


Fig. 34.—Diagram representing by dotted lines the alteration in the shape of the lens on accommodation for near objects.

in the eye. This feeling of effort is due to the contraction of a band of muscles (the ciliary muscles) which pass from the front part of the sclerotic coat to be attached to the choroid coat just behind the attachment of the suspensory ligament of the lens. When these muscle-fibres contract, they draw the choroid coat forwards and inwards, so relaxing the suspensory ligament and allowing the lens to bulge forwards. The lens thus becomes more convex, its focal distance is therefore

diminished, and rays of light coming from near objects are now focussed on the retina instead of, as in the resting eye, falling behind the retina. We have, therefore, in the eyeball an apparatus in which a clear real image of external objects is formed on the sensitive retina, the focus of the apparatus and the amount of light entering the lens being regulated by distinct mechanisms which, to a certain extent under the control of the will, are to a still larger extent governed automatically through the nervous system, according to the distance of the object and the amount of light coming from the object.

We find that the vision is most acute when the image of the object falls upon the central spot of the retina, the so-called **yellow spot.** As we direct our attention from one object to another, it is necessary that the eyeball shall be moved, so that the images of these objects shall in turn fall on the central point of the retina. To this end each eyeball is provided with six muscles, slender bands which by their contraction are able to move the eye upwards, downwards, inwards, or outwards. The two eyes normally work together, so that the object of attention shall have its image formed on the central spot of both retinæ. If, through any failure of the eye muscles, this coincidence of images does not take place, the result is double vision, and a man so affected is said to 'squint.' In many cases such a disorder can be corrected by the use of suitable glasses.

If the eyeball is too long, the images of distant objects will fall in front of the retina,

and since no effort of accommodation can flatten the lens, it is impossible to get a clear image of distant objects. People with such eyes are said to be short-sighted, and their disorder can be counteracted by furnishing them with spectacles with concave glasses. These glasses will cause a divergence of the rays entering the eye, so that parallel rays from a distance can now be focussed on the retina. When the eyeball is too short, the image of a distant object falls behind the retina, and an effort of accommodation is necessary to focus the image on the retina. With near objects it will become impossible to change the focus of the eye sufficiently to bring an image of the objects on to the retina. Such eyes are spoken of as long-sighted, and people with this defect have to wear convex glasses in order to increase the convergent power of their visual

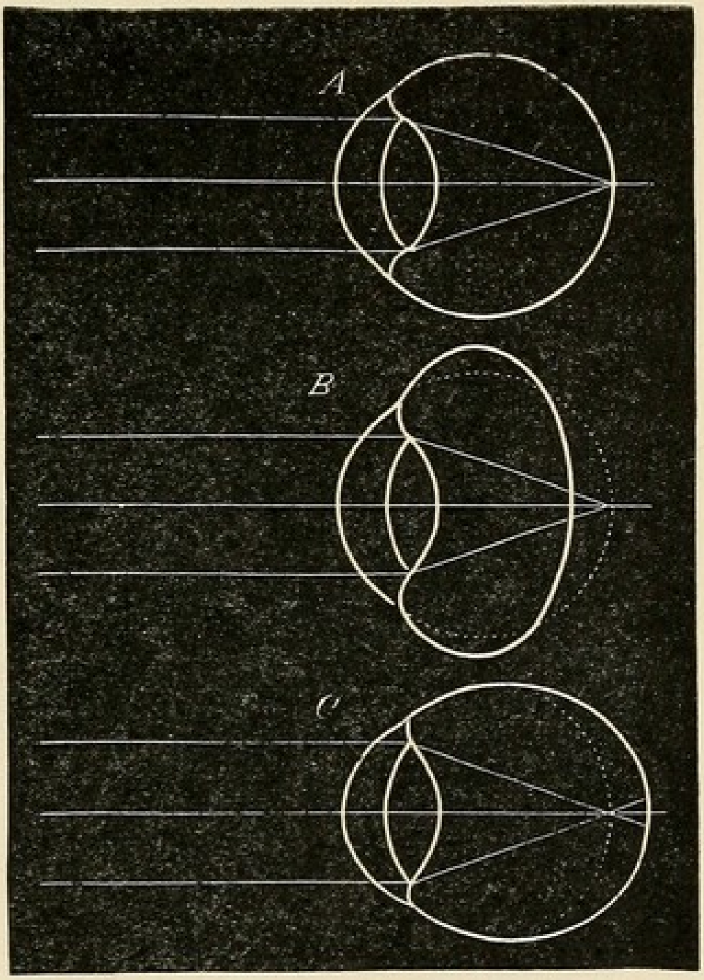


Fig. 35.—Diagrams of course taken by parallel rays in entering normal eye (*A*), long-sighted eye (*B*), and short-sighted eye (*C*).

apparatus. With advancing age the lens of the eye becomes more and more rigid. Hence, when the pull of the suspensory ligament is relaxed by the ciliary muscle, the lens can only bulge forward to a small extent. In this case the accommodation for near objects is therefore lessened, and the limit of near vision will become less and less with advancing age. There is no interference with the appreciation of distant objects; but for near objects, as for instance in reading, the patient will need to use convex glasses to supplement the defective focussing power of his own eyes.

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