ELEMENTARY PHYSIOLOGY FOR NURSES

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FOR NURSES

BY

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PREFACE.

In bringing forward another addition to the many books on Physiology some excuse is necessary. It is, however, hoped that this little book has some elements of originality, and that it will be found useful to those for whom it is written, *viz.*, nurses. The main idea has been to deal with the subjects with which nurses should be acquainted in a concise manner, at the same time omitting abstruse problems of Physiology which, although of interest, are not essential, and the study of which interferes with the work of a nurse actively engaged in hospital work.

C. F. M.

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CHAPTER I.

INTRODUCTION.

If we examine any animal, for instance a man, we see that there are obvious differences between one part and another. These differences are of two kinds (1) those concerning *structure*, *i.e.*, what the different parts are made of, which constitute the science of anatomy; (2) those concerning *function*, *i.e.*, what these different parts do, and what purpose they fulfil, which form the science of physiology.

For instance the anatomy of the hand deals with the structure of skin, bones, muscles, nerves, etc.; the physiology of the hand deals with the various actions we can perform with our hands. It is, however, impossible to separate physiology from anatomy, for we cannot understand what goes on inside an animal unless we know something of its structure. How could we explain the working of a watch to any one who did not know its structure, or anatomy?

First let us briefly consider the anatomy of our subject. We see at once the external divisions into head, neck, trunk and limbs. The shape of the body is formed by the skeleton or framework, which consists of the skull and vertebral column, a bony tube lodging and protecting the brain and spinal cord ; the shoulder bones, pelvis, bones of the limbs, ribs, etc. The trunk is divided into thorax and abdomen, the division between them being formed by a great transverse muscular partition, the diaphragm. The walls of the thorax are supported by the ribs, while the abdominal walls are only muscular. The thorax contains the heart and lungs ; the abdomen contains the stomach and intestines, kidneys, liver and other organs.

Now let us turn to the subject which more immediately concerns us, *viz.*, function, or physiology. One of the first things which we notice in a living animal is the *necessity for food.* Every one knows that food is necessary to support life, though perhaps every one could not give an explanation of what happens to the food after it is swallowed. The easiest way to find out the use of food is to see what happens if no food is taken. If a man is kept in a pair of scales all day and weighed at intervals he will steadily get lighter till a meal is taken, when he will regain the lost weight.

The rate of loss of weight varies according to what the man is doing ; during active exercise it is greatest, at rest less so, and during sleep least of all. What it is that is lost and why this loss occurs we shall consider later. It is sufficient at present to note that loss of weight is always going on day and night, waking or sleeping. This waste affects all parts of the body, but at unequal rates. Fat goes quickest of all ; bones, teeth and brain very little. It is to make up for this loss of weight, affecting all parts at all times, that food is necessary.

THE DIGESTIVE SYSTEM.

Food has to make good the losses of all parts of the body. The muscles, for instance, waste, and food has to supply the material out of which new muscle is formed; the same with the bones, brain and other parts. When we consider the different structure of the various parts of the body it is obvious that great changes must be effected in the food before it can supply their loss by waste.

There are two chief processes: (1) *digestion*, by which food is rendered soluble, and so capable of entering the substance of the body (for it must be remembered that all food in the stomach is really *outside* the body proper); (2) *assimilation*, a further process by which dead food is rendered fit to form part of living tissues.

The digestive organs consist essentially of (1) a long convoluted tube, the *alimentary canal*, commencing at the mouth and ending at the anus; (2) the *digestive glands* which secrete chemical fluids poured in at various parts of the alimentary canal to dissolve and effect changes in the food. The non-nutritious part of the food, or waste, is passed away as the fæces.

THE CIRCULATORY SYSTEM.

We have seen that all parts of the body require food, and we have briefly considered how the food is dissolved in the stomach and intestines. The next problem is to explain how this food is distributed to the various parts of the body. This is done by the circulatory system, which we may compare to a system of waterworks with pipes supplying a number of houses. In the animal body we have a system of pipes laid on to all parts, by which the soluble digested food is taken from the alimentary canal to all parts of the body. These pipes are the blood-vessels.

The heart is a pump by which the fluid is sent round with sufficient rapidity and regularity for the supply of the needs of the various parts of the body. The heart is the most important part of the body, for when it ceases to beat death ensues. We can feel each beat of the heart, each beat of the engine, by feeling one of the pipes at our wrist, the pulse.

The blood is the fluid contained in the pipes or blood-vessels. Every part of the body is wasting, and the various parts are of different structure, therefore each requires different substances for its renewal and repair. This might be accomplished by a separate set of vessels with a separate heart for each part, but this would be a great waste of matter and energy. A far better plan is the actual one, where the blood contains substances required by all parts, and where each part takes from the blood what it wants.

So far we have only traced the blood to the various parts of the body; clearly it cannot stop there or the pipes would burst; moreover, blood from one part is still available for other different parts. Hence there is a second set of vessels which returns the blood to the heart; these vessels are the veins. Thus there is a constant stream of blood pumped by the heart into the arteries to all parts of the body, taking nutriment to them, returning by another set of vessels, the veins, to the heart again. This is the circulatory system.

THE RESPIRATORY SYSTEM.

Suppose we have a steam-engine, in which all parts are properly made and in good order ; the boiler filled with water and a good supply of fuel. Yet our engine will not start ; something more is necessary, we must light the fires, to convert the water into steam in order to move the piston. So it is with a clock or watch ; it must be set going.

The same applies to an animal ; it must be set going and kept going, and the mode in this case is more like that of an engine than a clock, for it is by burning that the necessary energy is supplied to set an animal going. This burning is a chemical process carried on by the oxygen gas obtained from the air. A constant supply of this gas is required, for if a furnace is closed so that no air can get at it, the fire will go out ; so will an animal die when deprived of oxygen. The wasting of the tissues of an animal is of the same nature as the burning of fuel, *viz.*, a process of oxidation, by which the more complex constituents of the body are reduced to simpler ones, one of the chief of which is carbonic acid gas. As a result of this burning, energy is given out as heat and as muscular action. Hence there are two processes continually going on, a destructive process, called katabolic, and a regenerative, or anabolic process.

The steam-engine is set going by the oxygen of the air, so also is an animal, and the respiratory system is the agent which keeps the animal going. Respiration consists of two events : (1) inspiration, the taking in of oxygen gas ; (2) expiration, the getting rid of carbonic acid gas. The burning of the animal body is less energetic than in a steam-engine, for there is no evolution of light; but there is considerable evolution of heat, for every one knows that the body is warm, and that warmth is kept up by the body itself. Clothes do not keep the cold out, but keep the heat of the body in. A bed is warmed a few minutes after we have been in it by the heat of the body.

As it is the burning of the coal in a locomotive which really makes the wheels turn round, so also it is a similar process which, in ourselves, enables us to move, speak, and think. Just as with a certain amount of coal we can get a certain amount of work out of our engine, and if we want more we must stoke up; so with a man, the amount of work he can do depends directly on the activity of the process of burning going on inside him.

THE EXCRETORY SYSTEM.

As a result of the burning of fuel in the engine there is a certain amount of ash formed. This ash is not only useless, but actually injurious, and if allowed to accumulate will check the fire or even prevent it burning at all. Similarly in ourselves, as a result of the chemical processes which are constantly going on, and by virtue of which we are enabled to do work, certain bodies which we may compare to ashes are formed which must be got rid of. This is effected by the excretory organs. These substances are really harmful, yet they are constantly manufactured within the body itself; in fact, the body is continually trying to poison itself. Excretion is the beneficial process by which this suicidal tendency is kept in check.

Excretory products are chiefly carbonic acid gas and solid matters, of which urea is the most important. The former is got rid of by the lungs, the latter by the kidneys. We saw at the beginning that a man is constantly losing weight, and we see now why this is and what the loss consists of. A man or animal loses weight for the same reason that a locomotive loses weight on a journey—because in order to keep him going there must be a constant supply of heat, obtained by burning; in the case of the engine, of the fuel; in the case of man, of the substance of the body itself. In both cases alike excretory products are formed as a direct result of activity of the engine or the man; in both cases these are injurious and must be got rid of. In the engine it is chiefly carbonic acid and ashes; in the man, carbonic acid and urea. In both cases water is necessary; in the engine this passes out as it entered, practically the same in amount; in man it is partly formed in the body, but chiefly taken in with the food.

These excretory products are first poured out into the blood, and afterwards withdrawn from it by the excretory organs. The blood therefore performs three functions: (1) to supply food to all parts of the body; (2) to carry oxygen to the tissues, and (3) to carry excretory products away from them.

THE NERVOUS SYSTEM.

This is the co-ordinating mechanism by which all the different and mutually dependent parts of the body are brought into communication, and made to work in harmony with one another. If one part of the body is working hard, it must have increased blood supply for the time; both for the supply of food and oxygen, and for removal of waste products. Hence the evil of violent exercise directly after a meal, blood which is required for digestion being withdrawn to supply the extra amount for muscular exertion. Again, muscles must not contract spontaneously, but when we wish them to, *i.e.*, we—that is, our brains—must be in direct connection with our muscles. This is effected by the nerves.

The nervous system consists of two parts: (1) the central, consisting of the brain and spinal cord; and (2) peripheral, the nerves. We may compare it to a telegraph office. Messages are received from all parts to the central office—the brain. The brain can put any two messages into communication with one another. A message may pass through the central office without any one in the office knowing anything about it, *i.e.*, without involving the will. For instance, if our hand is put down on the sharp point of a pin, it is drawn back, but the message is sent without involving the will.

In the following chapters we shall take the several systems one by one, and consider them more in detail.

CELLULAR STRUCTURE OF THE BODY.

Although a detailed description of histology is beyond the scope of this book, it is necessary for the reader to understand the essentials of the microscopic structure of the body. For further details larger works must be consulted.

The human body, like the bodies of all animals except the very lowest, is composed of an enormous quantity of *cells*, these cells varying in structure and size according to the tissue of the body which they form.

The simplest form of an animal *cell* is an irregular mass of *protoplasm*, which is of very complex chemical composition. It is the simplest structure embued with life, and is in fact the physical basis of all animal and vegetable life. The lowest animal and vegetable organisms, such as the *Amœba*, which is found in stagnant ponds, consist simply of a mass of protoplasm

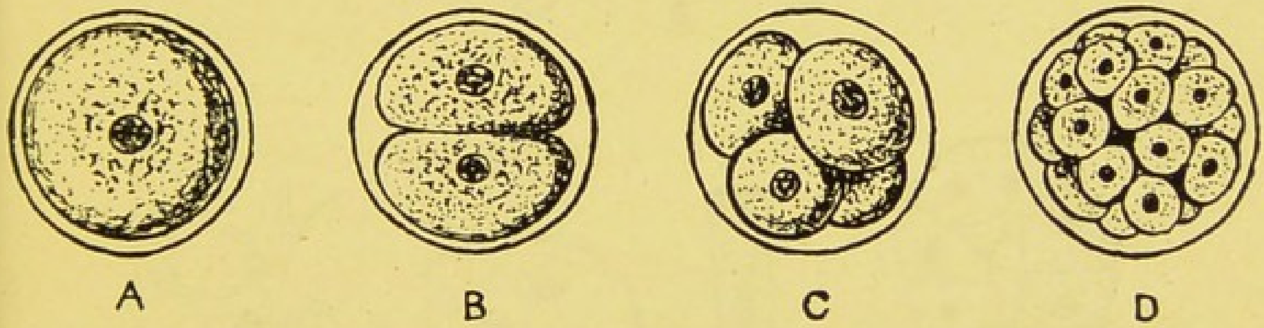

Fig. 1.—Segmentation, or Division, of the Egg of a Mammal into Cells which afterwards Form the Embryo.

A, the egg before division ; B, C, D, successive stages of division (magnified).

of microscopic size. They are in fact single cells, and never attain any more complex structure.

As we pass higher in the animal and vegetable kingdoms the members of the various divisions become more and more complicated, and consist of cells of ever-increasing number and complexity, till the higher animals, including man, are reached ; where the variety of cells of which they are composed is very great. But it must be borne in mind that, however complex the structure of an organ or tissue of the body, it is essentially composed of modified cells.

The simplest kind of cell found in the animal body is the white blood-corpuscle, which can be seen under the microscope in a drop of blood. This is practically the same as an Amœba. Of simple cells such as this the human body in its earliest embryonic stages consists, and these during development become gradually modified into the complex structure of the adult human being.

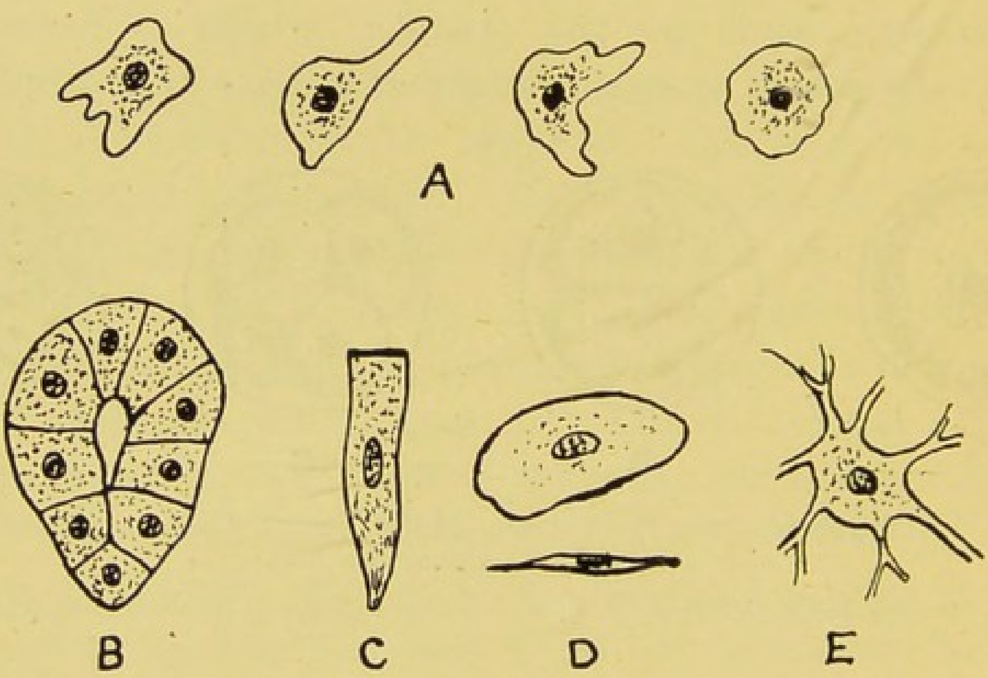

Fig. 2.—Different forms of Cells.

A, amoeba showing changes in shape; B, gland cells, such as found in salivary glands, pancreas, and liver; C, columnar cell; D, squamous cell from epidermis of skin; E. nerve cell with branching processes (magnified).

Thus the muscles consist of cells which have become much elongated and drawn out into long fibres. The nerves again consist of elongated cells placed end to end. The bones consist of cells around which are deposited chemical salts. The brain and spinal cord consist of nerve cells and nerve fibres; the nerve cells having often branching processes connected with the nerve fibres. The skin consists of many layers of cells which become flattened (or *squamous*) at the surface. The stomach and intestines are lined with what are called *columnar* cells, which at many points form the digestive follicles which we shall consider later on.

The figures opposite will give an idea of some of the main varieties of cells met with in the animal body. Each cell has a *nucleus*, or denser part, represented dark in the figures.

CHAPTER II.

THE CIRCULATORY SYSTEM.

THE BLOOD-VESSELS.

As we saw in the last lecture, the main purposes of the circulatory system are as follows: (1) to carry food from the digestive organs to all parts of the body; (2) to carry oxygen from the lungs to all parts of the body; (3) to carry carbonic acid from all parts of the body to the lungs, and other excretory matters to the organs which get rid of them; (4) to maintain the temperature of the body. The circulatory system consists chiefly of a set of tubes, distributed to all parts of the body and filled with blood. The *arteries* carry the blood to all parts of the body; the *veins* return the blood from the body; the *heart* is the pump or engine which receives blood from the veins and drives it into the arteries; the *capillaries* are very fine tubes, only visible under the microscope, connecting the terminal branches of the arteries with the commencements of the veins.

The course of the circulation in any part will be represented by the following diagram, in which the arrows show the direction of the flow of blood.

Almost every part of the body is vascular, *i.e.*, contains blood-vessels, and the closeness of the capillary network is difficult to realise. If we prick almost any part of our body it will bleed, showing that the vessels are so close together that there is not even room for

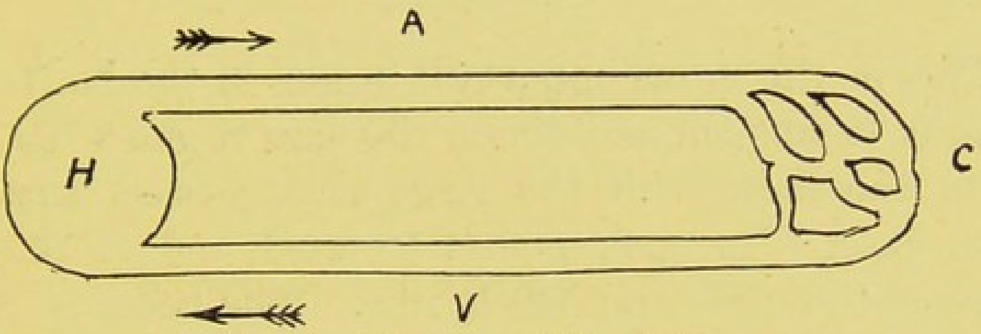

FIG. 3.—Diagram of Circulation.
H, heart; A, arteries; V, veins; C, capillaries.

the point of a needle between them. The non-vascular parts of the body, or those which have no blood-vessels, are the epidermis of the skin, the nails, hair, teeth, and cartilage.

The blood-vessels form a closed system of tubes, having no openings in their walls, so that everything that passes either into or out of the blood must pass through the walls of the vessels. The walls of the capillaries are very thin, and the passage of substances through them is easy. The walls of the veins and arteries are thick and tough, those of the arteries being highly elastic, like indiarubber, and stretching readily. But the capillaries are the most important part of the circulatory system, for in them the real work is done.

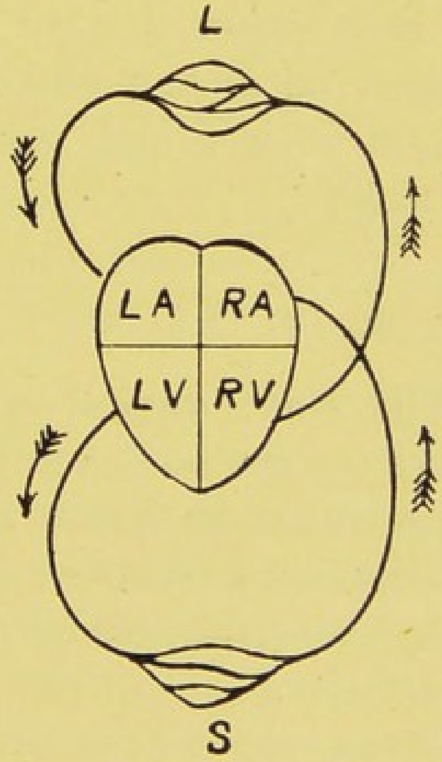

FIG. 4.—Course of the Circulation.

LA, left auricle; RA, right auricle; LV, left ventricle; RV, right ventricle; L, capillaries of lungs; S, systemic capillaries.

THE HEART.

This is the most important organ in the body. In shape it is conical, and about the size of one's fist. It lies in the chest with the large blood-vessels attached to its base. Its apex points forward and to the left, between the fifth and sixth ribs. The heart is really a dilated blood-vessel, as is seen by comparison with the hearts of the lower animals, in some of which it is simply a dilated muscular blood-vessel. The heart is divided into right and left halves by a median partition, each completely separate from the other, and each again divided transversely into two other cavities, an *auricle* and *ventricle.* We have therefore a right auricle and ventricle and a left auricle and ventricle.

COURSE OF THE CIRCULATION THROUGH THE HEART.

The *right auricle* receives blood returned by the veins from the body and sends it into the *right ventricle.* From this it is driven to the lungs. The *left auricle* receives blood returned from the lungs and sends it to the *left ventricle,* which sends it all over the body by the arteries.

The auricles have but little work to do, hence their walls are thin. The ventricles, on the other hand, have more work to do; hence their walls are thick and muscular. As there is greater difficulty in moving the blood through the general system than through the lungs only, the left ventricle is much thicker and more muscular than the right.

THE VALVES OF THE HEART.

We have said that the blood circulates, *i.e.*, flows round and round through the blood-vessels, and always in the same direction, but we have not explained why this should be, or how it is effected.

Supposing we have a system of indiarubber pipes connected with an indiarubber ball and full of fluid. If we squeeze the ball it is as easy for the fluid to flow out one way as the other, but in order to ensure that the flow shall be in one direction only, *valves* are necessary. These valves are flaps opening in one direction only, like the door of a room.

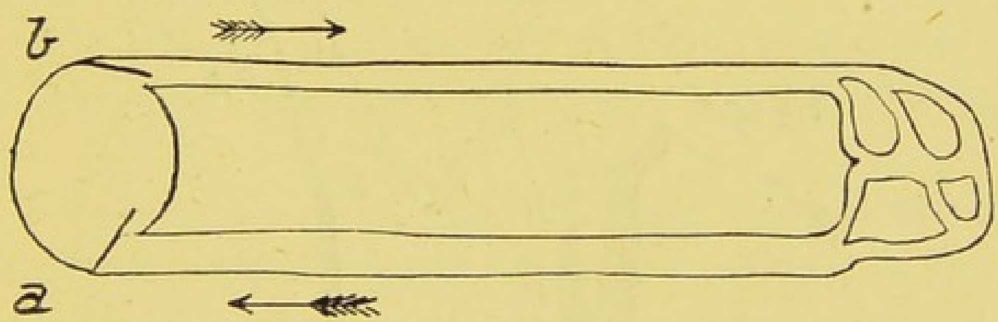

FIG. 5.—The Action of Valves.

Suppose we have one valve only, at *a* (Fig. 5): On squeezing the ball we should empty it along the arteries only, but on letting go the ball a great part of the fluid would flow back again into the ball. If we have a second valve at *b*, on squeezing the ball, we equally send the fluid into the arteries; but when we relax the ball, and owing to its elasticity it dilates, it sucks the fluid from the veins only, and it is no longer possible for fluid to get back from the arteries to the heart, for the valves close instantly owing to the pressure of fluid on them.

THE VALVES OF THE HEART.

These are (1) the *auriculo-ventricular* valves, between the auricles and ventricles; (2) the *semilunar* valves, between the ventricles and the great arteries. Let us consider the two sides of the heart separately.

The *right auriculo-ventricular* or *tricuspid* valve. This is situated in the opening between the right auricle and ventricle, and consists of a fibrous ring round the

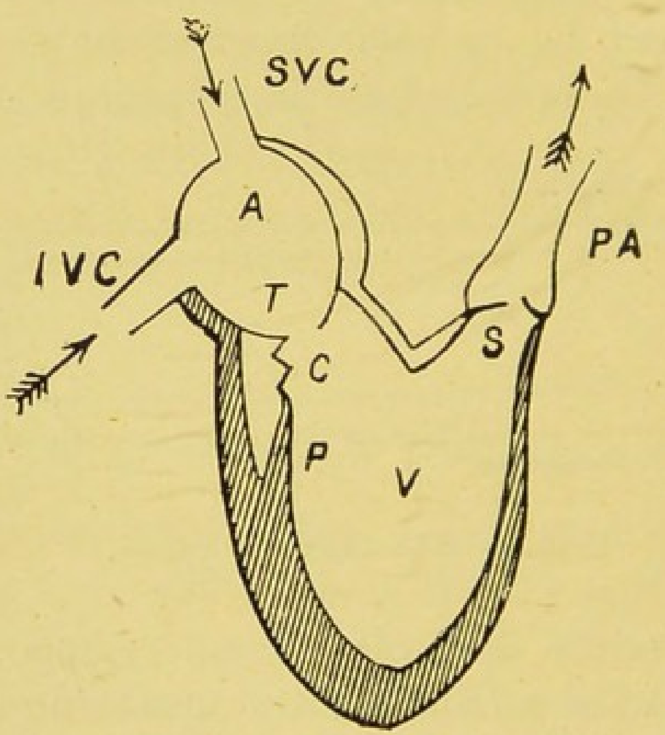

FIG. 6.—Diagram of Right Side of Heart.

A, auricle; V, ventricle; PA, pulmonary artery; IVC, SVC, inferior and superior venæ cavæ; T, tricuspid valve; C, chordæ tendineæ; S, semilunar valves; P, musculi papillares.

aperture, with three flaps round the margin hanging into the ventricle. The edges of the flaps are attached by strong cords—the *chordæ tendineæ*—to the walls of the ventricle, or, more correctly, to the tops of muscular projections from the walls—the *musculi papillares.* The action of the valve is as follows. The auricle contracts first and fills the ventricle, the valve offering no resistance in that direction. The ventricle then contracts, and the blood, getting behind the valve, drives it up so as to close the aperture between the ventricle and auricle, the valves being prevented by the chordæ tendineæ from being driven into the auricle. The ventricle during contraction becomes, as a whole, shorter, so that the valves would have a tendency to be driven into the auricle during the last part of the contraction, if they were not counteracted by the contraction of the musculi papillares, which have the effect of shortening the chordæ tendineæ.

The *semilunar* valves are at the base of the pulmonary artery, and allow the blood to pass readily from the ventricle into the artery, but stop it flowing the other way.

On the left side of the heart we have similarly the *mitral* valve between the left auricle and ventricle, and the *semilunar* valves at the orifice of the aorta, or main artery of the body. They act in precisely the same manner as the valves on the right side of the heart which we have just considered. The action of these valves is readily demonstrated on the heart of a sheep by pouring water through the auricle into the ventricle and noting the floating up of the auriculo-ventricular valve. If we squeeze the ventricle the valves will act perfectly. So with the semilunar valves; if we pour water into the aorta or pulmonary artery they will close at once.

The contractions of the heart occur regularly, rather oftener than once a second, and are rhythmical. The auricles contract first and simultaneously; the ventricles follow afterwards, also simultaneously. Then occurs a pause, during which the auricles are refilling.

THE SOUNDS OF THE HEART.

These may be heard either directly by applying the ear to the chest, or indirectly through the stethoscope. The first sound is long, dull and booming; the second is short and sharp. The two sounds are usually said to be represented by pronouncing the two syllables lubb-dup. The first sound occupies about half the cardiac cycle, and corresponds to the contraction of the ventricles; it is caused partly by muscular contraction, and partly by the vibration of the auriculo-ventricular valves. The second sound occupies one-fifth of the cardiac cycle, and is due to the closing of the semi-lunar valves.

The cause of the rhythmical contractions of the heart is in the heart itself, for if we cut out the heart of a frog it may be kept beating for a day or longer. Further, if we cut up a frog's heart each auricle and each half of the ventricle (for the frog's heart has only one ventricle) will contract independently. This contraction is under the influence of the nervous system, and there are two sets of nerves supplying the heart; the one set, if stimulated, causes it to beat faster, the other set causes it to beat more slowly, or even to stop. Fainting or even death may be caused by sudden joy or grief owing to stimulation of the latter set of nerves.

HEART DISEASE.

In the chief forms of heart disease the action of the valves of the heart is deficient; the valves become altered in shape and size from the effect of disease, and so do not close properly. One of the commonest forms of heart disease affects the mitral valve, between the left auricle and ventricle, resulting in deficient closing of the valves during contraction of the ventricle. The consequence of this is that all the blood in the left ventricle does not pass into the aorta, but some passes back through the mitral valve again into the auricle. This is called *mitral regurgitation*. When we listen with a stethoscope to such a heart, we hear what is called a "murmur," *i.e.* instead of hearing the two normal sounds of the heart the first sound is altered in character, becoming more prolonged and "blowing".

Another common disease affects the semilunar aortic valves causing deficient closure of these and therefore regurgitation of blood back again into the left ventricle from the aorta. This is called *aortic regurgitation*, and causes the second sound of the heart, when heard through the stethoscope, to be replaced by a murmur. We thus see the importance of the sounds of the heart in the diagnosis of heart disease.

THE BLOOD.

Physically the blood is a hot red liquid having a temperature of a little over 98° F. If we examine a drop of blood under the microscope we see :—

1. A colourless fluid, the liquor sanguinis or plasma.

2. The corpuscles. These are of two kinds (*a*) the *red corpuscles*, which are circular flattened discs, thinner in the centre than at the edges, about $\frac{1}{3200}$ inch in diameter. They are yellow when seen singly, but

red in masses. In a cubic inch there are no less than 70,000,000,000: (*b*) the *white corpuscles*. These are larger than the red, but much fewer in number. They are more or less spherical granular lumps of protoplasm, very like an amœba.

Chemically, the blood is an alkaline fluid, and consists of water with solid and gaseous matters in it. The plasma contains albumen (a substance similar to white of egg). The red corpuscles contain *hæmoglobin*, a peculiar substance containing iron, which causes the red colour of the blood.

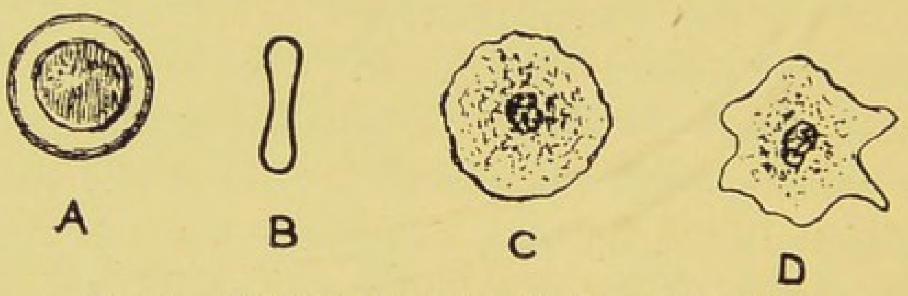

FIG. 7.—Blood Corpuscles (highly magnified).
A, red corpuscle ; B, section of red corpuscle ; C, D, white corpuscles.

As the blood has to convey oxygen to all parts of the body and carbonic acid from all parts, it is evident that both these gases must be contained in the blood. We shall have to consider these more fully under Respiration ; here it is enough to notice that oxygen is specially connected with the hæmoglobin of the red corpuscles.

The blood in the arteries and veins differs ; that in the arteries having more oxygen and less carbonic acid than that in the veins. Hence the difference between venous and arterial blood. There are also differences in the blood of the various parts of the body, blood returning from the stomach being different to that returning from the brain. These differences we shall deal with later on.

COAGULATION OF THE BLOOD.

Coagulation, or clotting, is a most important property of the blood. If blood is drawn into a basin, at the time of drawing it is quite fluid, but in two or three minutes it becomes viscid, and in five or ten minutes a complete jelly, so that the basin containing it can be turned upside down without spilling it. A few minutes later drops of a thin yellowish fluid—*serum*—appear on the top, and increase rapidly, the clot meanwhile shrinking. In an hour the clot is floating on the surface of the serum. The clot consists of a fine network of interlacing fibres formed by a substance called *fibrin.* In the meshes of this network are the corpuscles. The corpuscles are, however, not essential to the clot, for if coagulation be retarded by cold or by chemical means the corpuscles will sink to the bottom before coagulation occurs. If we whip blood with a bundle of twigs, the fibrin separates in long stringy threads, leaving the serum and corpuscles behind. Hence the fibrin which forms the clot is derived from the plasma, and plasma consists of fibrin and serum.

The actual nature of the process of coagulation is uncertain. Fibrin does not exist in the blood as fibrin, but is only formed at the time of coagulation, and is supposed to be formed by some ferment action. (Ferments are bodies capable in small quantity of producing great changes in other bodies without themselves entering into these changes.)

The importance of coagulation is that it checks hæmorrhage, or bleeding, by glueing the cut surfaces together; but for this a small cut might be very dangerous. Blood does not coagulate in health in the vessels during life; but why not, we do not exactly know. Blood, so long as it is in contact with the walls of a living healthy blood-vessel, does not coagulate; but if the wall of the vessel, or the heart, becomes roughened by disease (*endocarditis*) clots may form obstructing the vessels, and if the clot forms on a valve of the heart, it will impede the proper action of the valve, and will be liable to become detached and swept along to some vessel too small to let it pass through. The result of this is known as *embolism*, and is serious, owing to the nutrition of the part supplied by the vessel being cut off; and in an important organ such as the brain it is often fatal. Embolism is one of the causes of paralysis.

In the disease known as *hæmophyllia* there is a deficient power of coagulation in the blood, and people suffering from this bleed to a dangerous and sometimes fatal extent from even slight wounds. Such persons are known in hospital as "bleeders".

GENERAL ARRANGEMENT OF THE LARGE BLOOD-VESSELS.

(1) From the left ventricle arises the *aorta*, which, arching over to the left side, goes down along the back-bone and divides into two branches for the legs. The aorta gives off the *carotid* arteries to the head, and the *subclavian* arteries to the arms. Lower down it gives off large branches supplying the stomach, intestines,

and other organs, and finally divides into the two *iliac* arteries, which supply the pelvis and legs. (2) To the right auricle venous blood from the whole body is returned by two large veins, the *superior* and *inferior vena cava*: the former bringing back blood from the head and arms, the latter from the trunk and legs. (3) From the right ventricle the blood goes by the *pulmonary arteries* to the lungs. (4) To the left auricle the *pulmonary veins* convey the blood from the lungs.

There are thus two distinct circulations, the greater or systemic, and the lesser or pulmonary—the former carrying blood to and from the general system; the latter carrying it to and from the lungs. Blood in any cavity of the heart in order to get back to the same cavity again must go round both systems, and through all the three other cavities of the heart, for there is no direct passage from one side of the heart to the other. The right side of the heart contains venous blood, the left arterial. The time of a complete circulation is about half a minute.

SPECIAL CIRCULATIONS.

(1) The heart itself has a special circulation by means of the *coronary* vessels. The *coronary arteries* arise from the aorta just beyond the semilunar valves and supply the substance of the heart. The *coronary veins*, which return the blood from the substance of the heart, open directly into the right auricle.

(2) The *portal system* is an important special circulation by which blood from the stomach and intestines is taken, not directly into the vena cava, but collected

into the *portal vein* which enters the liver, breaks up into capillaries, and is collected together again by the *hepatic vein*, which opens into the vena cava below the diaphragm. Hence this blood has two systems of capillaries to pass through; and hence also, which is more important, all food taken up by the blood-vessels from the alimentary canal has to pass through the capillaries of the liver before reaching the heart.

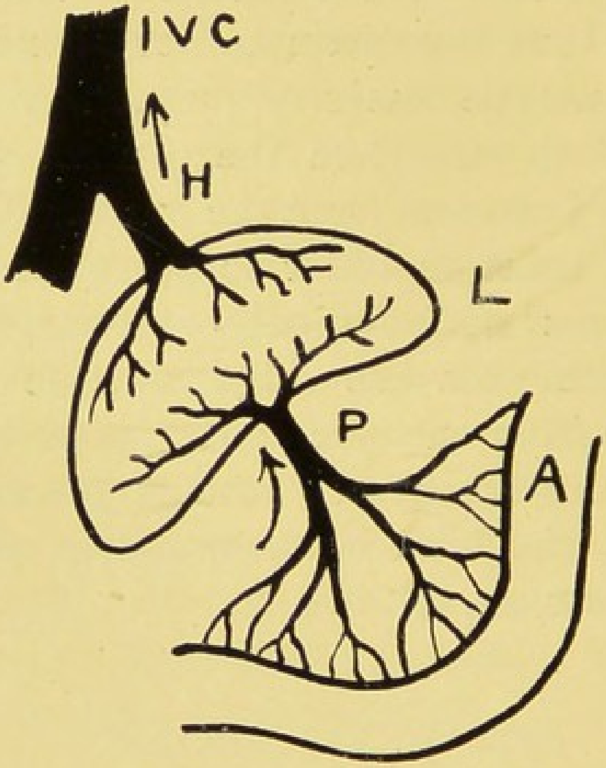

FIG. 8.—Diagram of Portal Circulation.

A, alimentary canal; L, liver; P, portal vein; H, hepatic vein; IVC, inferior vena cava.

PROOFS OF THE CIRCULATION OF THE BLOOD.

This was proved by Harvey in 1628, before the invention of the microscope, on the following indirect evidence: (1) The valves of the heart and of veins only allow flow of blood in one direction; (2) the blood-vessels of an animal can be injected in one way, but not in the opposite direction; (3) if an artery is ligatured it swells up and pulsates on the side next the heart, the part beyond being pale and empty; (4) if an artery is cut across, blood is pumped from the cut end next the heart, little or none from the other end; (5) if a vein is ligatured it swells up on the side farthest from the heart. This evidence was confirmed by the direct evidence of Malpighi, who in 1661 demonstrated the capillary circulation under the microscope.

If the web of a frog's foot is placed under the microscope the capillaries with the white and red corpuscles circulating in them can be seen. The capillaries are seen of various sizes, some only just large enough for one corpuscle to pass, others larger. The frogs' corpuscles are larger than those of man, being $\frac{1}{1200}$ inch in diameter, and oval instead of circular.

The red corpuscles are seen in the middle of the stream, the white near the edges. Alterations in size of the capillaries are very considerable, some channels may become almost obliterated while others open out. All this can be seen in the web of a frog's foot under the microscope.

TONIC CONTRACTION OF ARTERIES.—THE SYMPATHETIC NERVES.

Variations in the size of the arteries are exceedingly important, for they are the means by which the blood supply to any part is regulated. The quantity of blood is constant, yet at one time the brain may want more, at another time the stomach, etc. The small arteries have muscular walls, and are naturally slightly constricted. This "tonic contraction," as it is called, is liable to relaxation or "inhibition" through the nervous system which leads to increased size of the artery and increased supply of blood to the part to which the artery goes. This change is effected very quickly, and a familiar illustration of it is the act of blushing, when a sudden reddening of the surface occurs owing to the dilation of the small arteries through the action of the nervous system.

The nerves which govern the arteries are called the *sympathetic nerves;* they have other functions as well as that governing the arterial system. When the sympathetic nerve in a rabbit's neck is cut the ear flushes at once, owing to the restraining or inhibitory action of the nerve on the small arteries being removed, the vessels becoming increased in size and allowing more blood to pass through them.

Inflammation is somewhat analogous to the above, and is characterised by increased supply of blood to a particular part. The chief signs of inflammation are redness, swelling, heat and pain. The phenomena of inflammation may be studied under the microscope in the web of the frog's foot by applying some irritant such as mustard. First the arteries dilate and the stream of blood flows quicker; secondly, the stream slackens while the arteries are still dilated; this stage is known as *stasis,* during which the small veins, arteries and capillaries become choked with corpuscles. After this occurs migration of the white and some of the red corpuscles through the walls of the capillaries, where the corpuscles can be seen in the tissues intervening between the capillaries, having actually passed through their walls. Finally, when the irritating substance is removed, there is re-establishment of the circulation.

THE RATE OF FLOW OF BLOOD.

This is very different in different vessels, and depends on their size. It is clear that, roughly speaking, the same amount of blood must return by the veins as is sent out along the arteries. The veins are much larger than the arteries, and therefore the flow of blood is slower in them. In the large arteries the rate is twenty inches per second; in the large veins eight inches. At each division of the arteries the area gets larger, and hence the flow of blood slower.

The capillaries, though individually very minute, are yet so numerous that their combined area in any part is greatly in excess of that of the arteries supplying it. Hence the rate of flow is very slow in the capillaries, only about one-hundredth inch in a second, or an inch in about a minute and a half. As a complete round of circulation takes only half a minute and involves two sets of capillaries, it is clear that the capillaries in any part of the body must be very short. We may compare the flow of blood to the flow of a stream of water, which is swift where the bed is narrow; slower as it widens out; hardly perceptible as the stream enters a lake, but swifter again on leaving it.

The pulse is the sudden swelling of an artery due to the heart-beats, for the intervals between successive beats of the pulse and the heart are the same. Yet they are not simultaneous, the pulse coming distinctly after the heart-beat. The pulse is, in fact, a wave of blood passing from the heart along the arteries, and due to the elastic walls of the arteries. The farther away from the heart, the longer is the interval between the heart-beat and the pulse.

BLOOD-PRESSURE.

The arteries are not rigid tubes, but are highly elastic, like indiarubber. Hence, on each contraction of the ventricle, driving a certain quantity of fresh blood into the aorta, room is found for this blood by the expansion of the artery rather than by the whole stream of blood being forced along bodily. Directly the ventricle ceases to contract this pressure is removed and the aorta contracts owing to its elasticity. It behaves, in fact, very much as an indiarubber tube would do. This contraction causes dilatation of the artery farther along, which is thus passed along the artery as a wave, and causes the pulse.

In the veins and capillaries there is no pulse, for since the combined area of the arteries increases at each division, and since the combined area of the capillaries is much greater than that of the arteries, the pulse must be rapidly diminished in force, and from this cause alone might become imperceptible in the capillaries. The capillaries, being very small, offer much resistance to the passage of blood owing to friction. The arteries, therefore, have not time to empty themselves before the next heart-beat comes and consequently they are always over full. The walls of the arteries, being elastic, tend to contract, and so cause the pressure of blood to be constant instead of intermittent, which it would otherwise be if the arteries were rigid tubes instead of being elastic. Therefore there is no pulse in the veins, except when the heart beats unusually feebly.

In certain diseases the walls of the arteries become degenerated and ulcerated, thus destroying their elasticity and weakening their coats. They are then liable to give way before the pressure of the blood at their weakest place, giving rise to a swelling or aneurism.

THE LYMPHATICS.

These form a second set of vessels occurring in all parts of the body, commencing in the interstices between the component parts. They serve to return to the blood nutritious matters exuded, but not used. They also play an important part in the absorption of food, as we shall see in a future chapter. The lymphatics consist of thin-walled vessels of more irregular shape than the capillaries or veins. They open chiefly into a large terminal vessel, the *thoracic duct,* which joins the venous system at the left side of the root of the neck, close to the jugular vein.

DESTRUCTION OF RED CORPUSCLES.

As the duration of a red corpuscle of the blood is supposed to be only three or four weeks they must be continually being destroyed. This destruction goes on probably in the liver, spleen, and the bones; at any rate the colouring matter—hæmoglobin—is excreted by the liver and forms a constituent of the bile.

MANUFACTURE OF BLOOD CORPUSCLES.

This must be always actively going on, and the red marrow of the bones and the spleen appear to be the chief manufacturing centres of the corpuscles of the blood.

CHAPTER III.

THE RESPIRATORY AND EXCRETORY SYSTEMS.

Respiration consists of two chief factors: (1) *inspiration*, effecting the introduction of oxygen; (2) *expiration*, effecting the elimination of carbonic acid.

The essential structure of a breathing organ is a moist vascular surface exposed to air or water; *e.g.*, the gills of a fish. In this way there is a direct interchange of gases, partly by chemical attraction and partly by physical diffusion. In the lower, and especially in smaller animals, the general surface of the body is sufficient for respiration, but in the higher animals special respiratory organs are required.

There are two chief plans by which respiration may be accomplished. One is to take the blood to some particular place, where it can be aerated; the other is to take air directly into all parts of the body, as is done in insects, by a system of air tubes permeating the body.

RESPIRATORY ORGANS IN MAN.

These consist essentially of the lungs and windpipe; the former being situated in the thorax and filling it, except for the heart and great blood-vessels; the latter being placed in the neck. The trachea or windpipe ends above in the larynx or organ of voice. The trachea is kept open by cartilaginous rings in its walls, and below divides into two bronchi, one for each lung; these divide again and again till they open into little sacs, the air cells, in the substance of the lungs. The air cells are small sacs with very thin walls opening out of the smallest bronchial tubes, and in the thin septa between the adjacent air sacs the blood capillaries are exposed to air on each side. The pulmonary blood-vessels form a fine network of thin-walled capillaries surrounding the air cells, like the network of string round a child's ball.

THE MECHANISM OF RESPIRATION.

By this is meant the way in which air is pumped in and out of the lungs. Let us first glance at the structure of the thorax or chest, which contains the organs of respiration. We find this to consist of a bony framework formed at the sides by the ribs, behind by the backbone, and in front by the sternum, or breast-bone. The base of the thorax is formed by the diaphragm, a muscular partition between the chest and abdomen.

The mechanism of respiration in man consists in the alternate expansion and contraction of the thoracic cavity. Every one knows that in taking a deep inspiration the chest becomes inflated and expanded, and increases in girth two inches or more. It is not that the air sucked in expands the chest, but that the chest expands and thereby sucks the air in. The expansion of the chest is of a double nature, partly costal, or due to the ribs, partly diaphragmatic, or due to the diaphragm.

1. *Diaphragmatic.*—The diaphragm is an arched dome-like muscle, tendinous in the centre, and attached all round its margin to the ribs, backbone and sternum. Its contraction causes it to become more flattened, and hence enlarges the cavity of the chest and diminishes the pressure of air in the lungs till it falls below the pressure of the atmospheric air. Air then rushes in through the windpipe to make up for this diminished pressure inside the chest.

2. *Costal.*—The ribs are curved rods of bone, movably joined behind to the vertebral columns and attached in front to the sternum. There are twelve ribs on each side. The first seven are attached to the sternum directly by separate cartilages ; the next three indirectly by the cartilage of the seventh rib ; the last two or floating ribs do not reach it at all. The ribs are directed downwards and forwards and not horizontally ; on this fact their action depends.

Connecting the ribs together are the *intercostal muscles,* external and internal. The external intercostal muscles are directed downwards and forwards ; the internal downwards and backwards. In action they may be compared to an oblique elastic band passing between the ribs : this will when contracting strive to assume the shortest position, which will be when at right angles to the ribs. Hence when the intercostal muscles contract they must raise the ribs, as shown in the following diagram. By this action the thorax is enlarged and air is sucked in. Both costal and diaphragmatic respiration go on simultaneously, the costal being more marked in women, the diaphragmatic in men.

Expiration is chiefly due to elastic recoil. The muscles cease to contract and the parts resume their former shape and position. This action is aided perhaps, by the internal intercostal muscles as well.

We must not suppose that the lungs are emptied of air, or anything like emptied, at each expiration, or that air drawn in at each inspiration goes right into the

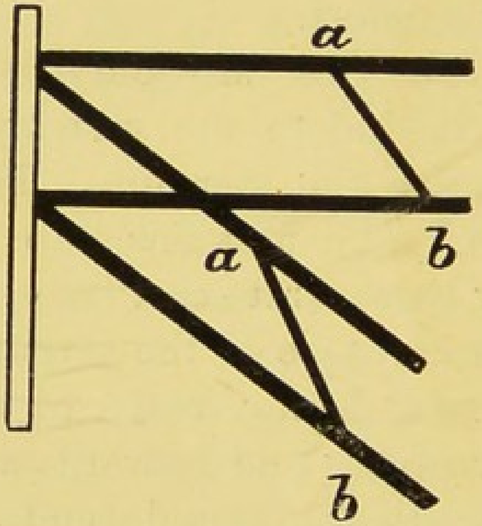

FIG. 9.—Diagram showing Action of External Intercostal Muscles in Raising Ribs when Contracted.

a-b, Elastic band representing the muscle.

air cells. In an ordinary inspiration 20 to 30 cubic inches of air enter the chest and pass out again at expiration. This is known as *tidal* air. Besides this a further amount can be taken in by forced inspiration, and an additional amount expelled by forced expiration. The former is known as *complemental air,* and may be 100 to 130 cubic inches; the latter is reserve or *supplemental* air, and is about 100 cubic inches. Besides this there is always a certain amount of *residual* air which cannot be got rid of after forced expiration. This is also about 100 cubic inches.

In normal or quiet breathing about 200 cubic inches—residual and reserve air—are stationary, and about 20 to 30 cubic inches of tidal air are exchanged at each respiration. This tidal air will only get into the larger bronchial passages, and will certainly never

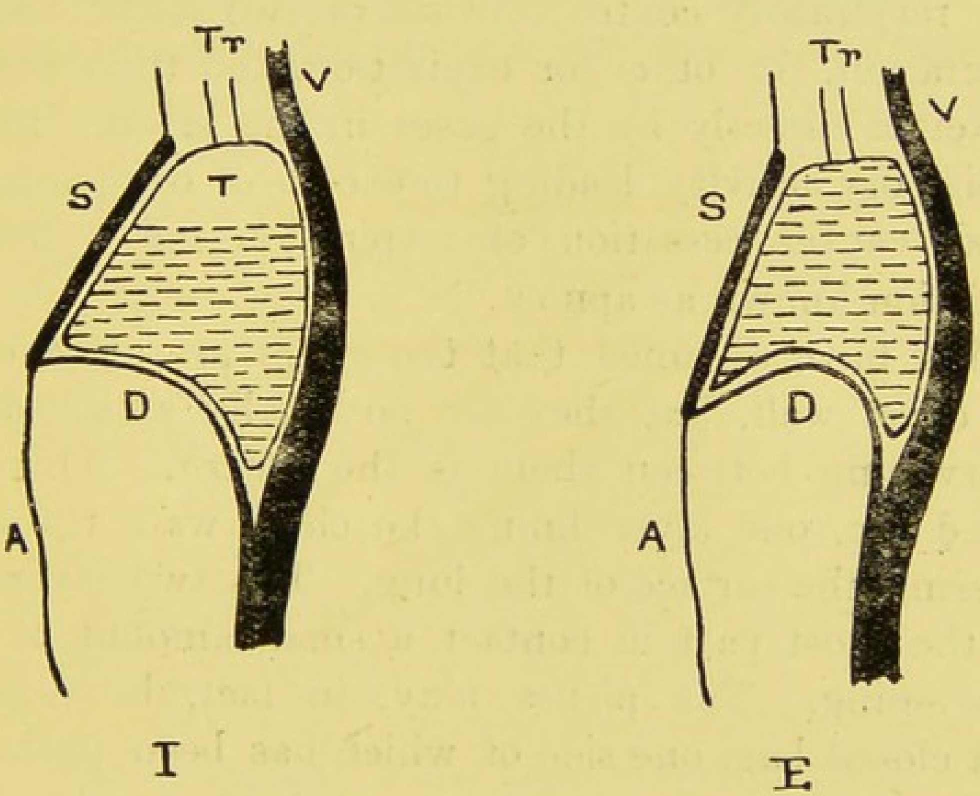

FIG. 10.—Diagram of Chest.

I, during inspiration; E, during expiration; A, abdominal muscles; D, diaphragm; S, sternum; V, vertebral column; Tr, trachea; T, tidal air; the shaded part represents the stationary air.

reach the air cells directly. The interchange is effected by diffusion between the residual air in the lungs and the tidal air taken in at inspiration.

The rhythmical action of respiration goes on unconsciously in ordinary quiet breathing about 15-18 times a minute. It is much quickened by muscular exertion, and is slower during sleep. It is much quicker in infants than in grown-up people. This rhythmical action differs from that of the heart in that the lungs themselves do not do the work but merely follow the chest wall. It is governed by a nervous centre, the respiratory centre, situated in the lowest part of the brain, the medulla. From this centre messages are sent to the various muscles concerned. The respiratory centre consists of two parts, one for inspiration, the other for expiration, and their activity is excited directly by the gases in the blood. Forced respiratory activity, leading to excess of oxygen in the blood, causes cessation of respiration for a time, a condition known as apnœa.

We have assumed that the lungs are attached to the chest wall, but they are not really attached, for intervening between them is the *pleura*. This is a closed sac, one layer lining the chest wall, the other covering the surface of the lung. The two layers are for the most part in contact, a small amount of fluid intervening. The pleura may, in fact, be regarded as a closed bag, one side of which has been pushed in by the lungs.

THE PLEURA.

The action of the pleura is as follows. The pressure of air within the lung when at rest is the atmospheric pressure, *i.e.*, 15 lbs. to the square inch. This pressure will tend to keep the lung against the chest wall, *i.e.*, to keep the two layers of the pleura in contact. Counteracting this is the elasticity of the lungs, the walls of which are constantly on the stretch, and tending to shrink away from the chest wall. This force is about $\frac{1}{4}$ lb. to the square inch, and is hence completely outbalanced by the pressure of the air in the lungs. Now, suppose a hole is made into the pleural cavity, air will enter and press directly on the surface of the lung. We have now a pressure of 15 lbs. tending to keep the lung against the chest wall, and a pressure of 15 lbs. + $\frac{1}{4}$ lb. tending to cause it to collapse, *i.e.*, the pressure on the outer surface of the

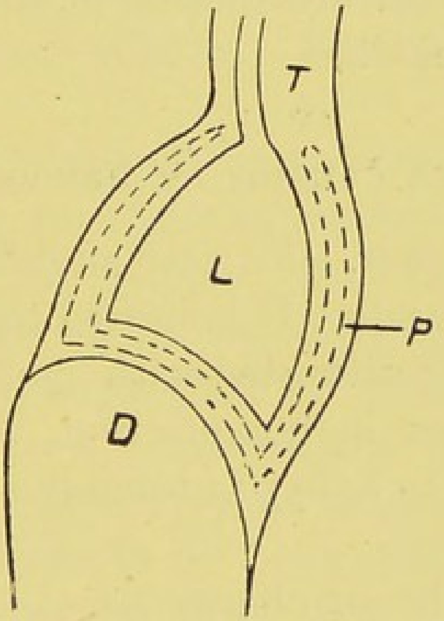

FIG 11.—Diagram of lung surrounded by the pleura.
L, lung ; P, pleura ; D, diaphragm ; T, trachea.

lung is greater than on the inner, and hence the lung collapses. This is the effect of a knife wound of the chest wall penetrating the pleura ; the lung collapses, and does not follow the movements of the chest walls as before.

In *pleurisy* or inflammation of the pleura the surfaces of the pleura are roughened, and friction occurs between them. This rubbing of the two surfaces may be heard with a stethoscope. In further stages of pleurisy serous watery effusion may accumulate to a great extent between the two surfaces, and press on the lung, causing partial collapse and hence laboured breathing. In *pneumonia* or inflammation of the lung, there is solidification of the lung tissue, and so difficulty of breathing, accompanied by high fever. *Bronchitis* is inflammation of the air passages from exposure to cold and irritant matters, and generally affects the larger bronchial tubes. *Phthisis*, or consumption, is associated with actual destruction of the lung tissue and the formation of cavities.

CHANGES CAUSED BY RESPIRATION.

Changes in the Air.—Expired air differs from inspired in three chief respects. It is heated to the temperature of the blood; it is saturated with moisture, and it has undergone changes in composition. The quantity of moisture expired in a day is roughly about a pint, but may be more.

The gases of the air change thus :—

	Oxygen.	Nitrogen.	Carbonic acid.
Inspired air	21	79 .	0·03
Expired air	16	79 .	5·00

Thus the nitrogen is unchanged; there is a loss of about 5 per cent. of oxygen and a gain of 5 per cent. in the form of carbonic acid. About 18 cubic feet of oxygen are absorbed in the lungs per day, and about 18 cubic feet of carbonic acid given out. The carbonic acid is best estimated as charcoal, and amounts to eight ounces a day. Thus a man is a kind of human chimney constantly polluting the atmosphere, about

350,000 tons of carbon as carbonic acid being expired by the human population of the globe in a day, to say nothing of other animals as well.

If a man is put in a closed chamber the oxygen will be steadily diminished and the carbonic acid increased. This will after a time cause difficulty in breathing and ultimately death by suffocation. In such a case the blood is only imperfectly purified, and both arteries and veins are full of venous blood. This at first causes increased respiratory activity; then convulsions from the brain becoming affected; finally, unconsciousness and death.

Deficiency of oxygen is more important than excess of carbonic acid; for if air is replaced by nitrogen gas no accumulation of carbonic acid occurs, but in the absence of oxygen an animal is soon suffocated. On the other hand 10 or even 20 per cent. of carbonic acid may be present in the air without producing serious effect, if the quantity of oxygen is increased sufficiently. Hence the evil effects of overcrowding are obvious. The proper amount of space that should be allowed every man is 800 cubic feet, and this should be accessible directly or indirectly to the atmosphere.

CHANGES IN THE BLOOD CAUSED BY RESPIRATION.

We have seen that the blood is not alike in all parts of the body. We have noticed the broad distinction between arterial blood and venous blood, the former being richer in oxygen and food, the latter containing more carbonic acid. There are further differences of great importance in various parts and at different times.

As the nature of the water in a river will depend at any place on the supply of pure water by streams, on the animals dwelling in it, and on various matters received from the banks and discharged into it by drain-pipes, so it is with the blood. If we compare the stream returning from a muscle at rest or in activity; from the stomach during digestion, and in the interval between meals, we find considerable changes in the blood at different times.

Let us confine ourselves to the changes effected in the lungs. Venous blood from the right auricle is of a dark purple colour; arterial blood from the left auricle is bright red. This change is effected in the lungs, and depends on gases, for if we shake up venous blood with air or oxygen it becomes arterial, and if we shake up arterial blood with carbonic acid it becomes venous after a time. The amount of gases in the two cases is shown thus:—

100 Volumes of blood yield ...	O	Co_2	N
1. Arterial blood	20	39	1-2
2. Venous blood	8-12	46	1-2

It will be seen that arterial blood contains nearly twice as much carbonic acid as oxygen, while venous blood has about five times as much.

RELATION OF OXYGEN TO THE BLOOD.

The oxygen is not simply dissolved in the blood, but is in chemical combination with the hæmoglobin of the red blood corpuscles, which has a great affinity for it. The hæmoglobin gives up oxygen to bodies having a stronger affinity for it, *i.e.*, to the tissues of the body, and goes back to the lungs for a fresh supply. Poisoning by carbonic oxide (a different gas to carbonic acid gas) is due to the fact that hæmoglobin has a greater affinity for carbonic oxide than for oxygen, and hence combines with it by preference, thereby causing death from absence of oxygen.

RELATION OF CARBONIC ACID TO BLOOD.

The carbonic acid is contained in the plasma, not in the corpuscles, and is probably in part dissolved, but in part in loose chemical combination, possibly as carbonate of soda.

CHANGES IN THE TISSUES.

The tissues of the body are probably the real seat of the manufacture of carbonic acid and other waste products. We may, with Dr. Michael Foster, compare a part of the body to a city traversed by streets, representing the blood-vessels; the people in the streets representing the corpuscles. Although there is much activity visible in the streets yet the real work of the city is done in the houses. The streets are merely channels of communication through which supplies of raw material are received from distant parts, and waste products together with products of activity removed to other parts.

So with the body the plots of tissue are probably the seats of activity and the blood-vessels channels of communication like the streets.

TEMPERATURE OF THE BODY.

Heat is set free wherever metabolism (*i.e.*, chemical changes in living tissues) occurs, and the temperature of our bodies is maintained by the chemical processes going on in them. It is increased by muscular or mental exertion and by glandular activity, as is shown by the fact that the blood coming from the largest gland in the body, the liver, is the warmest in the body.

The regulation of temperature is in some unknown way under the control of the nervous system which controls the *production of heat.* The evidence of this is that the temporary application of moderate cold raises the bodily temperature and *vice versâ;* also cooling of the external surroundings increases the production of carbonic acid and the consumption of oxygen and also increases the temperature of the body.

The temperature is further regulated by means of the skin. Heat causes the cutaneous vessels to dilate, and also causes an increase of sweat by acting on the nerves governing the production of sweat. Now, the more blood that passes through the skin the greater will be the loss of heat by radiation ; and the greater the amount of sweat, the greater will be the loss of heat due to its evaporation. Cold, on the other hand, contracts the vessels of the skin and diminishes the amount of sweat, thus diminishing the loss of heat from the skin. The skin is thus the great means of regulating the loss of heat from the body.

EXCRETORY ORGANS.

The importance of these we have already considered.

We saw that the body was perpetually manufacturing poisonous bodies within itself, and that the duty of the excretory organs was to get rid of these bodies. We also saw that these products were formed as a result of oxidation, whereby more complex bodies were split up into simpler ones. Of these bodies carbonic acid is the most important, and this is excreted by the lungs, which are excretory as well as respiratory organs.

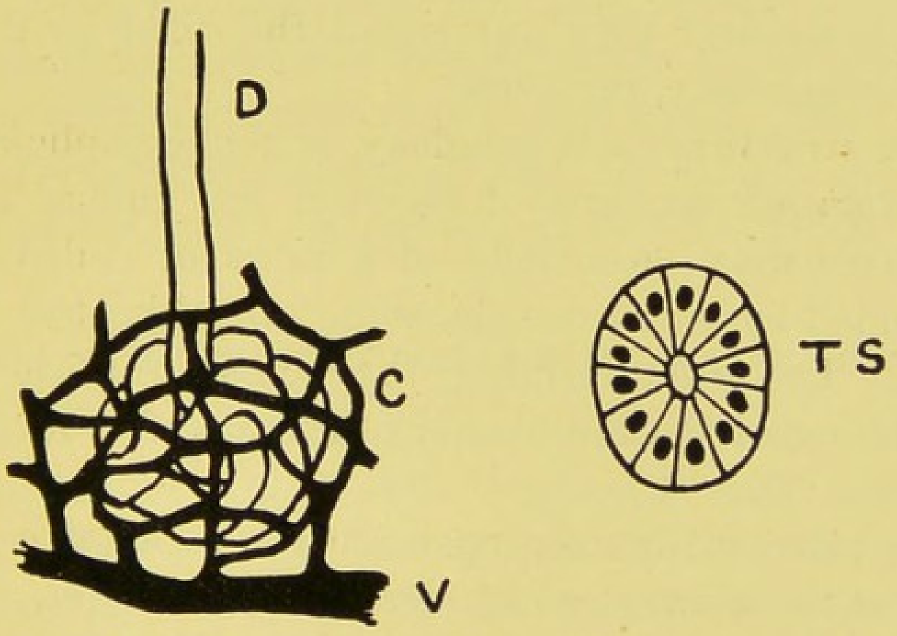

FIG. 12.—Sweat gland surrounded by capillary net-work C leading to vein V (magnified).

D, duct of gland; TS, section of gland showing excretory cells (further magnified).

The Skin is another of the main excretory organs, and gets rid of a considerable amount of water by means of the perspiration, together with other waste products in smaller quantities. In the skin are situated the *sweat glands* which consist of coiled tubes surrounded by a network of capillary blood-vessels and having a tube, or duct, leading to the surface. The blood circulating through the capillary network pours out its surplus water, together with other waste products, into the sweat gland, and from this it is discharged on the surface of the skin as sweat, or perspiration. The skin thus excretes a large amount of water per day, even without our noticing it, since it normally evaporates as soon as it reaches the surface. In hot weather or after severe exertion, as we all know, the amount is much increased.

The Kidneys.—These are the main excretory organs of the body, and they get rid of the chief product of nitrogenous waste, *viz.*, *urea*.

The structure of the kidney is too complicated to give a detailed account of here; it will suffice to say that it consists essentially of a mass of coiled tubes surrounded by blood-vessels, something like the sweat glands. The cells forming the walls of these tubes separate urea from the blood in the capillaries surrounding them.

The tubes ultimately open into a receptacle in the centre of the kidney, which leads to the ureter, and by this the excretory matter in the form of urine is conveyed to the bladder, and so got rid of. Water is got rid of also by the kidneys, forming the bulk of the urine. The lungs and skin also excrete water, and the amount of water excreted by the kidneys varies with that got rid of by the skin. Hence the diminished amount of urine passed in hot weather and the increased amount in cold weather.

CHAPTER IV.

THE DIGESTIVE SYSTEM.

THE purposes of digestion are (1) to separate the nutritious from the non-nutritious matter in the food ; (2) to dissolve the nutritious part so that it can enter the capillaries and be carried all over the body ; (3) assimilation of the dissolved nutriment by the tissues.

GENERAL ANATOMY OF THE DIGESTIVE ORGANS.

The alimentary canal is a tube with muscular walls commencing at the mouth, connected with which are the lips, teeth, tongue and palate, and next to which is the pharynx. Beyond the pharynx there is no control over the food, and we cannot help swallowing it when it reaches this point. The entrance to the windpipe is guarded by the epiglottis, which prevents food falling into the larynx when we swallow (for the food has to pass over this before it reaches the pharynx). After the pharynx comes the œsophagus, a tube leading to the stomach.

The Stomach is 10 or 12 inches long and 4 or 8 in diameter, and is divided into cardiac and pyloric ends, which we shall see have different functions. The stomach is a muscular bag lined by mucous membrane which secretes the gastric juice. At one end, the cardiac end, so called because it is close to the heart, the œsophagus opens into it; at the other, or pyloric end, it leads to the commencement of the intestines.

The Intestines consist of the *duodenum,* 10 to 12 inches long; the *small intestine,* 19 to 20 feet long; the *large intestine*, 5 to 6 feet in length; the *cæcum* and *vermiform appendix*, 4 to 6 inches long. The whole of the intestine is a muscular tube lined with mucous membrane secreting digestive fluids at its upper part, the duodenum and small intestine, and terminating below in the rectum and anus, by which the fæces or waste parts of the food after digestion are passed away.

The Digestive Glands.—The general purpose of these is to manufacture the fluids by which digestion is effected. The simplest glands are those in the mucous membrane of the stomach and intestines; they are simple pits, single or branched. More complex glands are the *salivary glands*, which secrete the saliva; the parotid situated between the ear and the jaw; the submaxillary and sublingual under the jaw and tongue respectively.

The Liver is a large and compact gland weighing about three pounds. It forms a fluid—the *bile*—which enters the duodenum, or first part of the small intestine, through the bile duct. Connected with the bile duct is the gall bladder, which is a kind of reservoir holding the bile.

The Pancreas, or "sweetbread," lies in a loop of intestines formed by the duodenum. The duct conveying its digestive juice joins the bile duct just before the latter reaches the duodenum.

CLASSIFICATION OF FOOD STUFFS.

These, considered chemically, may be referred to four chief heads. The various parts of the body consist of carbon, hydrogen, oxygen and nitrogen, combined in various proportions, and of complex structure, together with certain salts—potash, soda, lime, etc.—and water. Water makes 57 per cent. of the weight of the body. These complex bodies are further divided, according to the presence or absence of nitrogen, into *nitrogenous* and *non-nitrogenous*. The various food stuffs are :—

1. *Proteids*, consisting of carbon, hydrogen, oxygen and nitrogen. These are contained in the lean part of meat, the white of egg, the gluten of flour and the casein of milk.

2. *Fats, or Oils, or Hydrocarbons.*—These have more hydrogen than is required to combine with oxygen to form water. They comprise all the animal and vegetable fatty matters and oils, *e.g.*, butter.

3. *Amyloids or Carbohydrates.*—These comprise the sugars and starches. They are contained in rice, oatmeal, arrowroot, potatoes, etc.

4. *Minerals.*—These consist of various salts, and are especially common in green vegetables.

The first thing to note is that the proteids are absolutely essential, for the body is constantly wasting, and one of the chief waste products is urea, which contains nitrogen. Therefore proteids must be supplied to replenish the constant loss of nitrogen. Otherwise a man will live on his own body, for he cannot live on fats and amyloids alone.

Proteids contain both carbon, hydrogen and oxygen, as well as nitrogen, and hence they alone can sustain life, but they are not economical. A man requires about 300 grains of nitrogen and 4000 grains of carbon a day. Supposing he were fed on lean meat only, one pound would give him the 300 grains of nitrogen required, but four pounds would be necessary to give the 4000 grains of carbon; hence he would have to digest about four times the necessary quantity of meat. It is far more economical to make up the other 3000 grains of carbon by half a pound of fat or a pound of sugar. Most substances we use as food are mixed, and contain several kinds of food stuffs. Thus butchers' meat contains a considerable quantity of fat, and bread contains a proteid—gluten—together with starch, sugar and a trace of fat. The most economical combination is about two pounds of bread to three-quarters of a pound of meat per day. Speaking generally, an adult human being requires about one pound of carbohydrates; a quarter pound of proteids, and one-sixth pound of fat per diem.

THE PHYSIOLOGY OF DIGESTION.

The food entering the mouth is first masticated by the teeth. It is next acted on by the saliva secreted by the *salivary glands*. These glands contain a substance called *ptyalin*, which converts starch into sugar, and so renders it diffusible. Saliva has no action on proteids or fat. The food then enters the stomach and is acted on by the gastric juice. When the stomach is empty its mucous membrane is pale; the stimulation of food causes it to become red, by determination of the flow of blood to it. This causes the glands to become active and drops of gastric juice exude into the stomach. Contractions of the muscular walls cause the food to roll about and get mixed with the gastric juice.

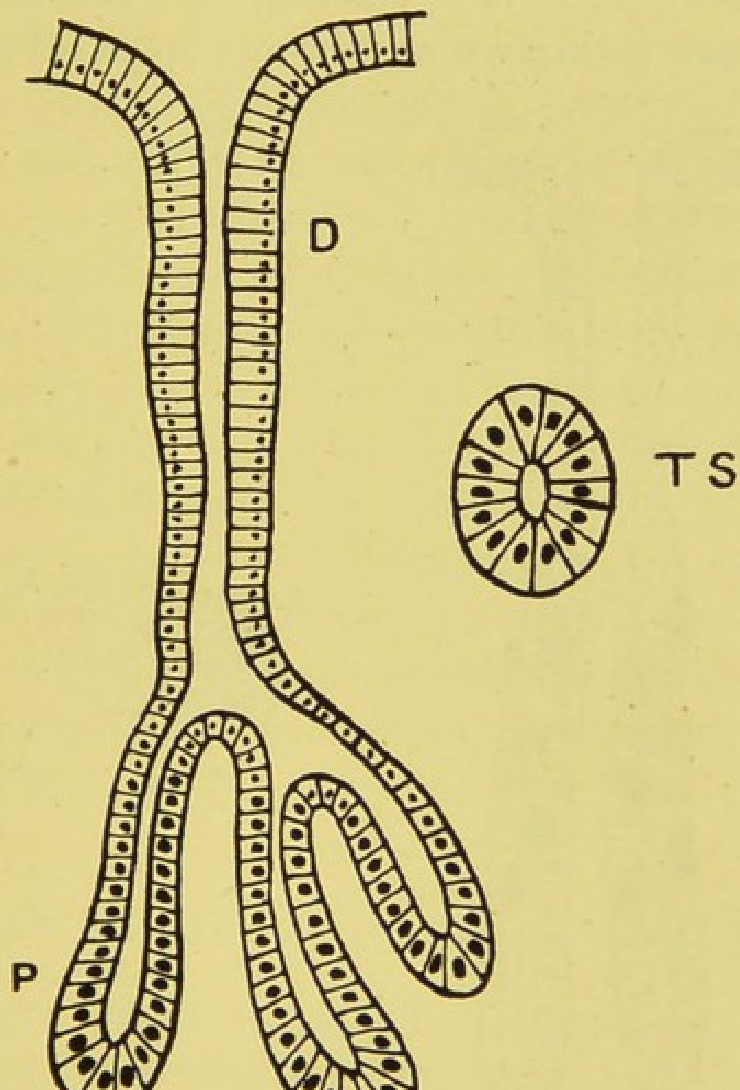

FIG. 13.—Section of Gland from Pyloric End of Stomach (magnified). P, pepsin-forming cells ; D, duct ; TS, transverse section of gland.

Action of the Gastric Juice.—The digestive action of the gastric juice is due to two factors—*hydrochloric acid* and *pepsin*. If a small piece of the fresh stomach of an animal is put in a tube with acidulated water and pieces of white of egg or meat and kept warm, the latter will become digested. The gastric juice converts proteids into soluble substances known as peptones, which can pass through the walls of the stomach into the blood. It has no action on fats or amyloids. In the stomach the food is thus reduced to the consistency of pea-soup, and is known as *chyme;* part of this is at

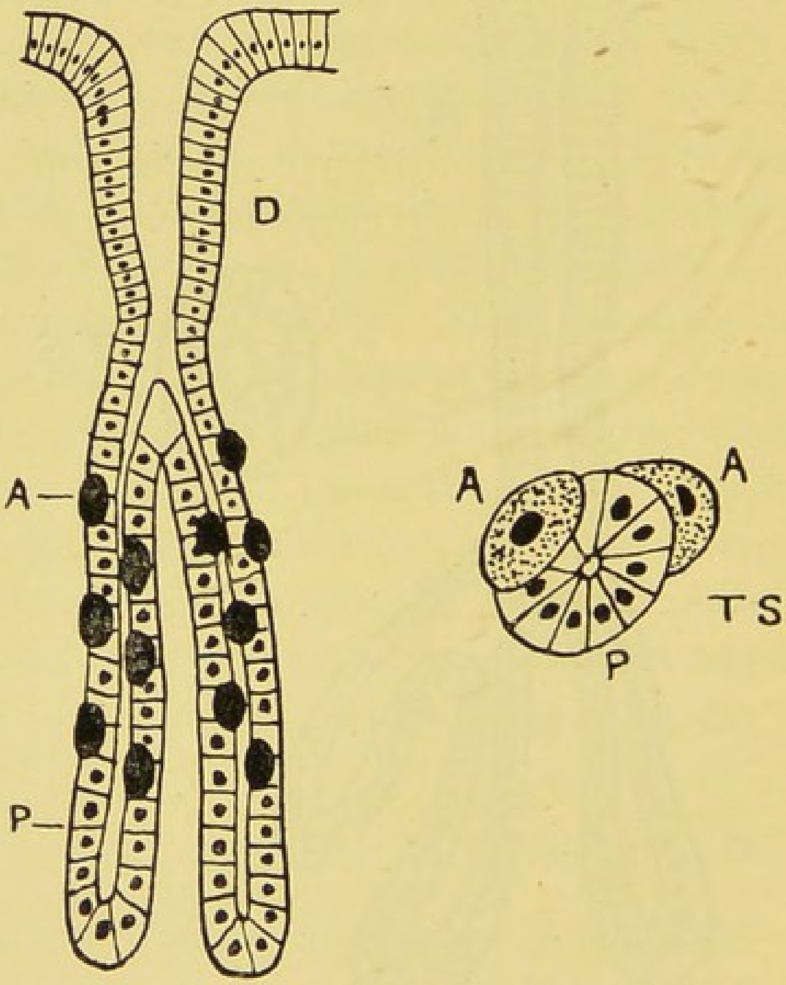

Fig. 14.—Section of Gland from Cardiac End of Stomach.

P, pepsin-forming cells; A, acid-forming cells; TS, transverse section of gland (magnified).

once absorbed by the blood-vessels and part is sent on into the duodenum. Pepsin is formed by the glands at the pyloric end of the stomach; hydrochloric acid by those at the cardiac end.

The *pancreatic juice* is alkaline and is the most important of all the digestive juices. It acts on all the food stuffs, converting proteids into peptones, starch into sugar, and also digests fat by a process known as emulsification, by which the fat is broken up into very minute particles.

The *bile* is alkaline, and is constantly being formed. It is not wholly digestive, but is largely excretory in nature as shown by the evil effects of its retention in the system, causing jaundice. Its main actions are to aid in the emulsification of fats and to neutralise acidity. It also has an antiseptic action. Its use has, however, been probably over-rated, for it has been shown that a man can get along very well when all the bile passes outside his body without entering the intestines, as sometimes happens in operations on the gall bladder for obstructive disease of the bile duct.

The *intestinal juice* is secreted by the glands in the intestine. Its action is similar to the pancreatic juice, but less active.

THE ABSORPTION OF DIGESTED FLUID.

The mucous membrane of the small intestine is set with minute club-shaped processes or *villi*, like the pile of velvet. Inside each of the villi is a *lacteal* or lymphatic vessel. The lacteals absorb fat from the food, and the milky fluid in the lacteals is called *chyle.* The chyle is carried to the lymphatic vessels, and ultimately to the thoracic duct; and so into the venous system. Surrounding the lacteal vessel is a network of capillaries of the arterial system, and into these peptones and sugars are absorbed from the food. These are carried to the liver by the portal vein. In the large intestines the watery parts of the food become rapidly absorbed, and the contents assume the appearance of fæces.

The Action of the Liver.—It is important to note that all the blood from the alimentary canal goes to and through the liver before reaching the heart. The uses of the liver and the changes which occur in the blood

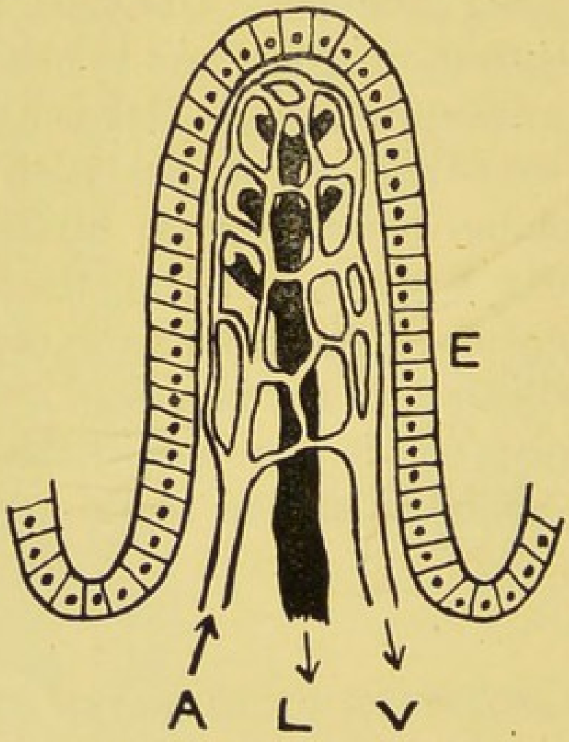

FIG. 15.—A Single Villus of Intestine showing Lacteal Vessel surrounded by Capillaries.

A, small artery, and V, small vein connected with capillaries; E, columnar cells covering villus (magnified).

passing through it are not yet well understood. It will suffice to say that, besides the formation of bile which is excreted into the intestine, the liver forms a substance called *glycogen*, which is readily converted into sugar and which passes into the blood in that form. The liver may thus be regarded as a storehouse of carbohydrates which it serves out to the body as required.

Assimilation.—This is the process by which living organisms are capable of incorporating the substances obtained from their food into their own tissue, and making them an integral part of their own bodies. This process is probably effected in the cells of the tissues themselves. The substance required for assimilation may be obtained from animals or plants. The proportions of the constituents in vegetable foods more nearly approach the required one than do animal foods. Speaking generally, vegetable foods are relatively deficient in nitrogen, and animal foods in carbon. A judicious combination of the two affords the requisite quantities, with the least excess of any one ; *i.e.*, with the least waste of energy on the part of the digestive organs. The diet best suited to the body should contain one part of nitrogenous food to $3\frac{1}{2}$-$4\frac{1}{2}$ of non-nitrogenous. It would be a great mistake to live on beef alone or on potatoes alone. The relative amounts of nitrogenous and non-nitrogenous parts in various foods is shown in the following table :—

	Nitrogenous.	Non-nitrogenous.
Veal	10	1
Beef	10	17
Mutton	10	27
Cow's milk	10	30
Human milk	10	37
Wheaten flour	10	46
Oatmeal	10	50
Potatoes	10	100

Let us conclude this chapter with a consideration of what happens during the digestion of a meal of beefsteak, potatoes, bread and water. (1) The beef is first masticated in the mouth and then mixed with the saliva, but no digestion takes place till it reaches the stomach. Here it is attacked by the gastric juice and broken up and dissolved. By the movements of the stomach all parts of the food are rolled about and come in contact with its walls. The proteids of the meat are converted into peptones by the gastric juice and taken up by the capillaries of the stomach. From the stomach the partly digested matter is squeezed into the intestine, and attacked by the pancreatic juice, and more peptones formed and absorbed by the intestines. The fat of the beef is not acted on till it reaches the duodenum. There it is broken up by the pancreatic juice and bile into tiny drops, which are absorbed by the lacteal vessels in the villi of the intestine. The salts in the meat, being soluble, are absorbed quickly. (2) Potatoes: These contain a great deal of starch, a little proteid, some salts, and a trace of fat. The starch is at once converted into sugar by the saliva in the mouth, and again by the pancreatic juice in the intestine. The digestion of the proteid part of the potatoes is similar to that of the meat. (3) Bread: This contains about 50 per cent. of starchy matter, and 8 per cent. of proteids, also some fat and salts. The digestion of these takes place in the same way as the above. The food absorbed by the lacteals is forced directly into the veins; that taken up by the blood-vessels is first carried to the liver, where it undergoes important changes, thence it is taken to the vena cava, and so to the right auricle of the heart.

CHAPTER V.

THE NERVOUS SYSTEM.

The nervous system consists of two main parts, the *central* and *peripheral*, the former comprising the brain and spinal cord, the latter the nerves going to all parts of the body. The general purpose of the nervous system is to bring all parts of the body into relation with one another, and to enable the parts to work in harmony.

When examined microscopically the nervous system is seen to consist of two kinds of elements, *nerve cells* and *nerve fibres*. We may compare the nerve cells to an electric battery, which generates an impulse, and the nerve fibres to the wires, which convey the impulse.

The central nervous system develops very early, and is really part of the skin. At an early stage in the development of the embryo a groove appears, which becomes gradually closed in above to form a hollow tube along the back of the embryo. This tube forms the brain and spinal cord.

The Spinal Cord is oval in section. At its upper end it passes gradually into the brain; its lower end terminates in a tapering point. The substance of the spinal cord consists of two kinds of matter, called the grey and white matters. The grey matter forms the more central part, and contains the nerve cells; the white matter forms the outer portion, and consists mainly of nerve fibres.

The Brain consists of (1) the *cerebral hemispheres*, which are of large size with a convoluted surface ; (2) the *cerebellum*, or small brain, situated underneath the former ; (3) the *medulla oblongata*, which is continuous with the spinal cord. The *ventricles* of the brain are spaces continuous with the central canal which runs down the spinal cord.

FUNCTIONS OF THE SPINAL NERVES.

The spinal nerves, of which there are 31 pairs, arise from the spinal cord, and supply all parts of the body. They pass out through holes between the vertebræ. Each spinal nerve arises by two roots—a posterior and an anterior. These separate roots unite together before leaving the vertebral column. The nerve fibres are distributed—some to muscles, some to the skin, some to glands.

(1) Irritation of a spinal nerve, for instance, one supplying the arm, causes twitching of the muscles to which it sends branches, and also pain referred to the nerve endings in the skin of the part supplied by it.

(2) Irritation of the posterior root of the nerve causes pain only.

(3) Irritation of the anterior root causes contraction of the muscles only. Hence the distinction between motor nerves and sensory nerves, which are separate in the two roots of each spinal nerve, but combined in the main trunk of the nerve, the posterior root consisting of sensory nerves, the anterior of motor ones.

(4) Section of a spinal nerve causes both motor and sensory paralysis (Fig. 16*a*). The nerve no longer has any power over the muscles supplied by it, and sensation of pain is lost.

(5) Irritation of the distal (or farther) end of the cut spinal nerve causes the muscles to contract (Fig. 16*h*).

(6) Irritation of the proximal end (the end nearest the brain) causes pain (Fig. 16*k*). This pain is referred to the part of the skin to which the nerve is distri-

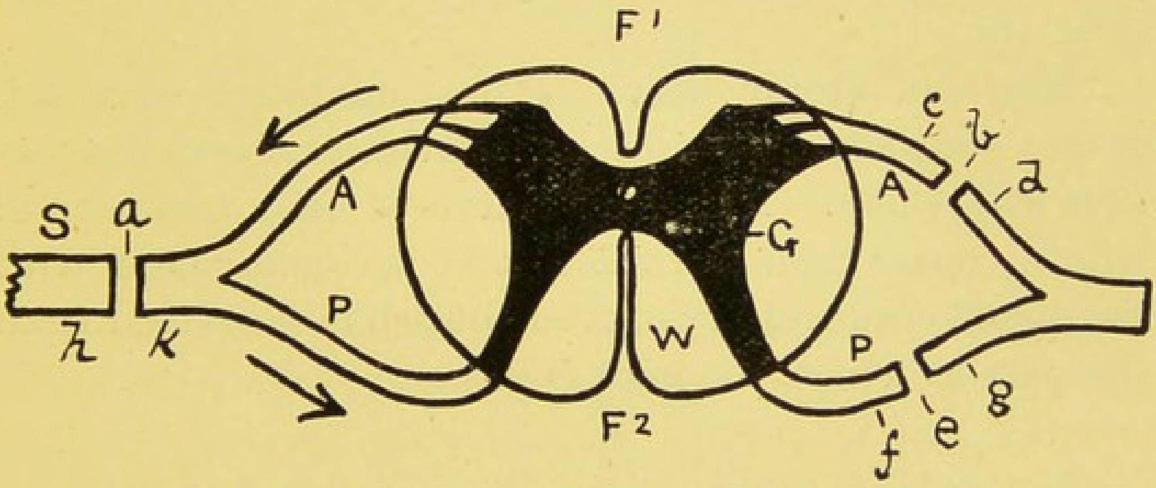

FIG. 16.—Diagram of Section of Spinal Cord and Spinal Nerve.

G, grey matter of cord; W, white matter; S, spinal nerve, formed by A, anterior or motor root and P, posterior or sensory root; F1, anterior fissure; F2, posterior fissure.

buted. Thus, after amputation of a leg, the patient will often imagine he feels pain in his toes, owing to some irritation of the end of the nerve in the stump. The nerve formerly gave sensation to the toes, and the message sent to the brain is still referred to the toes, owing to former habit.

(7) Section of the posterior root of a spinal nerve causes sensory paralysis, or loss of sensation in the parts supplied by it (Fig. 16*e*).

(8) Irritation of the distal end of this root causes

nothing (Fig. 16*g*); but irritation of its proximal end causes pain, because the fibres are all sensory ones, passing upwards towards the spinal cord and brain (Fig. 16*f*).

(9) Section of the anterior root causes paralysis of the muscles supplied by the nerve (Fig. 16*b*).

(10) Irritation of the distal end causes movements of these muscles (Fig. 16*d*); irritation of the proximal end causes nothing, because the fibres in this root all pass outwards from the spinal cord to the muscles (Fig. 16*c*).

Hence a motor nerve is one, irritation of which causes contraction of muscles, provided it be in connection with them. A sensory nerve is one, irritation of which causes pain, provided it be in connection with the spinal cord and brain, even though it be severed from the part in which the pain is felt.

FUNCTIONS OF THE SPINAL CORD.

(1) Section of the spinal cord causes complete paralysis, both of motion and sensation, in the parts below the point of section.

(2) Irritation of the distal end causes movement of all muscles supplied by nerves arising from the cord below the point of section. Irritation of the proximal, or upper end, causes pain.

So far the spinal cord appears as a large nerve of mixed motor and sensory function, and if we pursue our experiments and make sections of the spinal cord higher and higher we shall obtain similar results. It therefore follows that the brain, and not the spinal cord, must be the centre whence all motor impulses originate, and where all sensory impressions are felt. For if the nervous connection between the brain and a part of the body is cut anywhere, voluntary power of movement and sensation are lost at once in this part. Thus, when you bend your finger the motor impulse starts somewhere in the brain, travels down the spinal

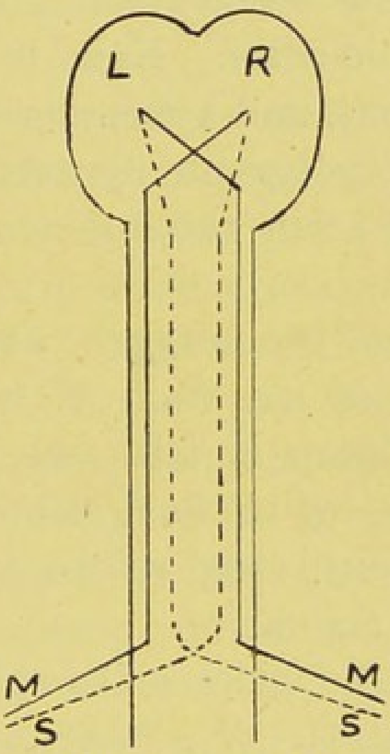

FIG. 17.—Diagram of the Course of Nerves from the Brain.
L and R, left and right sides of brain ; M, motor nerves ; S, sensory nerves.

cord and along the nerves going to the muscles which move the finger, and causes them to contract. Again, when you pinch your finger, the irritation in the finger is propagated along sensory nerves to the spinal cord, and up to the brain, and it is not till the brain is reached that pain is felt. If the nerve connection is severed anywhere along the track no pain is felt; while if the track is disturbed or irritated at any point pain will be felt in the finger.

We may illustrate this by comparison with telegraph wires and a telegraph office. Supposing there is a central office in London with wires radiating in all directions to the surrounding towns, separate wires going to each town, the telegraph operator in London would from long practice get into the habit of associating a message received along a particular wire with a special locality, and would refer a message received by that wire to that locality. Now, if the wire supplying this locality was cut, and a message sent from an intervening point, the telegraph operator would still think the message came from the town where the wire was cut.

So in the case of the nerves. After amputation of a limb, pain caused by irritation of the cut nerve during healing of the stump is felt, not in the stump, but apparently in the leg or foot, although this has been removed. The pain being referred to the parts normally supplied by the nerve.

So far we have considered the spinal cord as a mere conductor of impulses. We have now to define more correctly the path along which the impulses travel. If the spinal cord is cut half-way across, say on the right side, there results motor paralysis on that side, and sensory paralysis on the left side. Therefore the sensory nerves of the right side must run up the left side of the spinal cord. The fact is that all the nerves cross over to the opposite side of the body after passing out of the brain and spinal cord. The sensory nerves cross over as they enter the spinal cord; the motor nerves cross over in the medulla oblongata, or lower part of the brain. Thus the right half of the body is connected with the left half of the brain, and *vice versâ*. This is shown in the accompanying diagram.

THE FUNCTIONS OF THE BRAIN.

We have already seen that the brain is the real centre for both voluntary motions and sensations. That we really feel in our brains is evident from the effect of a blow on the head or from a dose of chloroform, under which circumstances the brain is sent to sleep for a time, while the nerves and muscles are not affected. The brain is also the centre for all the higher emotional and intellectual activities, it is the seat of the mind, also of the special sensations of sight hearing, etc., and it is in the brain that the nerve centres governing the respiratory movements are situated.

The Cerebral Hemispheres.—If the cerebral hemispheres are removed from a frog, the effect is that the frog shows no voluntary movement. It will respond to the stimulus of irritation, but does nothing of its own accord. It breathes naturally, and will sit on a table in a natural position. When thrown into water it swims vigorously until a landing place is found. When placed on its back it turns over at once. It croaks when its flanks are touched. In fact its movements are the same as in an uninjured frog, except that they require an external stimulus to call them forth. If the whole brain is removed from a frog it does not breathe, but lies flat on a table in an unnatural position. When thrown into water it sinks like lead, and when placed on its back remains there without an effort to replace itself.

The functions of the cerebral hemispheres in man are known directly only from the effects of wounds or disease; indirectly from comparison with animals. The parts of the surface specially associated with the movements of the leg, arm, face and trunk, and other parts associated with sight and hearing have been localised by the effects of disease and by comparison with lower animals. The anterior part, or the frontal lobes of the brain, are probably the seat of the higher intellectual powers. In the *medulla oblongata*, the lowest part of the brain where it joins the spinal cord, is a large number of nervous centres of great importance; *viz.*, the centre governing respiration, the vasomotor centre governing the arterial system, and other centres governing the actions of coughing, vomiting, swallowing, etc.

The Cranial Nerves.—Arising from the brain are twelve pairs of nerves most of which have important functions to fulfil.

1. The *olfactory nerve* is the nerve of smell, and is distributed to the mucous membrane of the upper part of the nasal cavities.

2. The *optic nerve* is the nerve of sight and is connected with the retina of the eye. Stimulation of this nerve causes a sensation of light. Disease of the nerve or pressure upon it by tumours causes blindness.

3. The *oculomotor nerve* supplies most of the muscles of the eyeball.

4. The *trochlear nerve* supplies one muscle of the eyeball (the superior oblique).

5. The *trigeminal nerve* is one of the most important. It supplies sensation to the face, eyelids, and the

conjunctiva and cornea of the eye. It also supplies the lachrymal gland, which secretes the tears. The trigeminal nerve includes the *gustatory* nerve, or chief nerve of taste supplying the tongue. Its lower branches supply the teeth and also the muscles of mastication. The trigeminal nerve is thus a mixed nerve, containing both motor and sensory fibres. It is the chief nerve affected by neuralgia. Toothache is caused by irritation of this nerve from decayed teeth.

6. The *abducens nerve* supplies only one muscle of the eyeball (the external rectus). Paralysis of this nerve causes internal squint.

7. The *facial nerve* is entirely motor and supplies the muscle of the face.

8. The *auditory nerve* is the nerve of hearing and is distributed to the internal ear.

9. The *glossopharyngeal nerve* is another nerve of taste for the posterior part of the tongue. It supplies sensation to part of the pharynx and also motor fibres to some of the muscles of the pharynx.

10. The *vagus* or *pneumogastric nerve* is very important since it supplies the lungs and heart, and the stomach. It also supplies the muscles of the larynx and sensation to that organ as well. The vagus nerve, as we saw previously, is the inhibitory nerve of the heart.

11. The *spinal accessory nerve* supplies two muscles, the sterno-mastoid in the neck, and the trapezius muscle of the back. Irritation of this nerve is one of the main causes of wry-neck.

12. The *hypoglossal nerve* supplies the muscles of the tongue.

REFLEX ACTION.

The spinal cord, which we have hitherto regarded as merely a conductor of impulses to or from the brain, is really much more than this. If in a frog we destroy the brain or divide the spinal cord high up and then pinch the skin of the part (to irritate a sensory nerve) the leg is drawn up and kicked out violently. Here the will is not involved, but the spinal cord acts as a nervous centre, putting the ingoing and outgoing im-

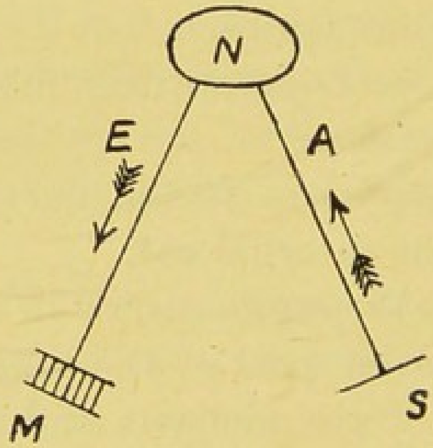

FIG. 18.—Diagram of Reflex Action.

N, nerve centre ; A, afferent nerve ; E, efferent nerve ; S, skin ; M, muscle.

pulses into direct communication—in the same way that in a telephone office two people may communicate through the office without any one in the office knowing what is going on. The purposive character of this reflex action is remarkable. If a frog under the above conditions has a drop of vinegar or other irritant placed on the thigh it attempts to rub it off with the same leg to which the irritant is applied ; and if this leg is held it will attempt to rub it off with the other leg. This is a good example of what is known as reflex action, where the essential elements are a nervous centre, a nerve conveying afferent or in-going impulses, and a nerve conveying efferent or out-going impulses, as shown in the diagram.

Reflex action may involve the brain, though not the will; for instance, winking at a flash of light, or coughing from a foreign body in the glottis. In such cases all the essentials of reflex action are present, but the will is not involved.

THE SYMPATHETIC SYSTEM.

This is an accessory nervous system in connection with the viscera and blood-vessels. It consists of branches from the spinal nerves, which form a series of nervous chains, with nerve ganglia (or aggregations of nerve cells) and large nerve plexuses in the abdomen. The vaso-motor nerves regulating the size of the blood-vessels belong to this system, and exercise a constant action over them. These, in their turn, are under the influence of the cranial and spinal nerves, which have the power of inhibiting them, *i.e.*, can cause the vessels to expand by withdrawing the normal restraining action of the sympathetic nerves. A good example of inhibitory action is furnished by the branch of the pneumogastric nerve which goes to the heart. This nerve when irritated causes the heart to beat more slowly, or even to stop beating altogether, a state of affairs which may occur in sudden emotion.

THE SENSE ORGANS.

Sensations may be divided into two sets: (1) Those concerning ourselves only, or subjective. Those concerning bodies of matters outside ourselves, or objective.

Subjective Sensations.—These are either general, in which case they are vague, indefinable, and not easily located; for instance, the feeling of weariness, sleepiness, faintness, etc.; or special, such as headache, stomachache, toothache, etc., due to a definite disturbance of some part of the body. Subjective sensation is not easy to deal with; all we can say is that the seat of real sensation is the brain, which is proved by the effects of a blow on the head, the effects of sleep, chloroform, etc.

Objective Sensations.—These are more definite, and more easily and satisfactorily dealt with, because they can be referred to actual causes, which are often visible and tangible. Under this head come the impressions which we receive through the various sense organs. The purpose of sense organs is to make us acquainted with the presence and nature of objects outside ourselves, and hence are necessarily formed from the skin. It is necessary to bear in mind that, however complicated they may be, they are actually formed by specialised tracts of the skin, the peculiarities being due partly to modification of the skin in different places, partly to the properties of special nerves, and partly to parts of the brain to which the impulses are sent.

The "Five Senses".—Seeing, hearing, smelling, and tasting are tolerably definite, but it is not so with "feeling". Under this head a number of very definite and distinct sensations are usually confused, and under the sense of feeling are commonly included the senses by which we distinguish between hard and soft bodies and rough and smooth, and between hot and cold bodies. Again, the sense by which we distinguish between light and heavy weights and the sense of pain are different from each other and from the former.

The Sense of Touch is possessed by all parts of the body, but very unequally. It depends on the integrity of the epidermis, for if this is removed, as by a blister or a burn, contact with a foreign body causes pain and not a tactile impression. In the skin are special nerve-endings, known as *tactile corpuscles,* connected with the fine ramifications of the nerves. These nerve-endings are unequally distributed in different parts, and their relative amounts in different parts of the body can be tested by means of blunt compasses. At the tip of the tongue the two points of the compass can be felt as two distinct points when 1-24th of an inch apart. At the tip of the finger the distance is 1-12th of an inch; on the cheek, 1 inch; on the neck, 2 inches; while on the back the points have to be 3 inches apart before two sensations are felt (the points being felt as one sensation).

The Sense of Pressure.—The forehead, temple, and back of the hand are the parts most sensitive to the pressure sense, and these parts can distinguish between weights in the ratio of 29 to 30.

The Muscular Sense is the consciousness of the amount of muscular exertion necessary to support a body, or to exert pressure on it. If we hold a weight in our hand when the hand is supported on a table, we are conscious only of the pressure exerted on the hand by the weight, or the sense of pressure. If, however, the hand is unsupported, we are also conscious of the force necessary to support the weight. This is the "muscular sense," as distinguished from the sense of pressure. It is this sense which guides all our muscular actions and all the movements of the body. The muscular sense is finer than the sense of pressure, and can distinguish between weights in a ratio of 39 to 40.

The Sense of Temperature.—This is relative rather than absolute, as is shown by the following experiment. If we take three basins of water, one hot, one cold, and the third lukewarm, and put one hand into the hot water and the other into the cold water, and then put both hands into the lukewarm water, the latter will feel cold to the one hand and hot to the other. There are supposed to be special nerve-endings in the skin which are sensitive to the different degrees of temperature, apart from those which are sensitive to touch.

The Sense of Taste.—This is situated chiefly in the tongue, probably aided by the palate. This sense is very inaccurate. In order to taste a substance it must be in solution, and the tongue must be moist, for a piece of sugar on a dry tongue will not be tasted. Much of the sense of taste, as it is generally known, is really due to smell, and it is to this that the various flavours of wines are largely due. We all know how a cold in the nose destroys to a great extent the sense of taste. There are special nerve endings for taste situated in the papillæ covering the tongue and connected with two of the cranial nerves, *viz.*, the trigeminal and the glosso-pharyngeal.

The Sense of Smell.—In order to smell a substance it must be in a gaseous or vaporous condition. The sense of smell is conveyed to the brain by the olfactory nerve, which is distributed to the upper part of the mucous membrane inside the nose. The sense of smell is not well developed in man, but in some animals, such as deer, and in some dogs, it is very acute.

CHAPTER VI.

THE EAR AND THE SENSE OF HEARING.

THIS is far more definite and of greater interest than the senses considered above. It is this sense that enables sounds to be appreciated by the brain. Sound is caused by vibrations communicated by the air or by a solid body. There must be some medium by which the vibrations are communicated, for sound cannot travel in a vacuum.

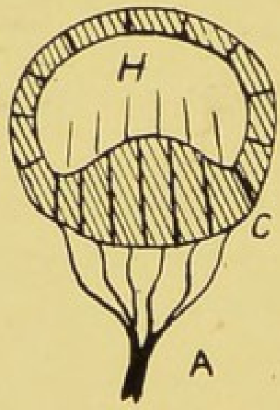

FIG. 19.—Diagram of simplest form of ear.

A, Auditory nerve sending branches to the columnar cells (C); H, Hair-like processes of auditory cells.

THE EAR.

The simplest form of ear, such as is found in some of the lower animals, snails, jelly-fish, etc., is a little closed sac embedded in the body and having at one part columnar epithelial cells, which are furnished with hair-like processes, and to which the ends of the nerve of hearing are connected. The sac is filled with fluid.

In the higher animals and in man the ear is essentially similar, but far more complicated.

The Ear in Man.—The essential part is the *internal ear* embedded in the skull. This in its early stages of development is a simple sac like the ear of the snail, but during development it becomes complicated and divided into several parts. The sac is filled with fluid called *endolymph;* surrounding it in its bony cavity in the skull is more fluid, the *perilymph.* The

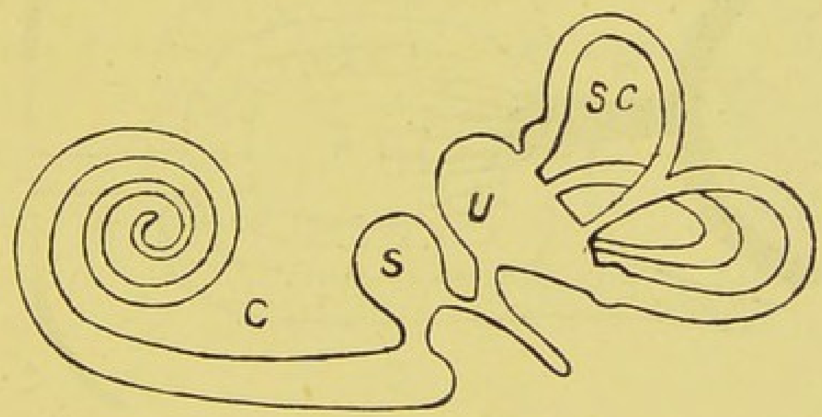

FIG. 20.—Diagram of internal ear.
U, Utriculus; S, Sacculus; C, Cochlea; SC, Semi-circular canals.

main part of the internal ear or *vestibule* is divided into two sacs—a smaller one, the *sacculus,* and a larger one, the *utriculus.* From the sacculus arises the *cochlea,* a spiral with two and a half turns. From the utriculus arise three *semi-circular canals,* which are situated in three planes at right angles to each other. The *ampullæ* are dilations at the ends of the semi-circular canals where they join the utriculus. Special nerve endings are situated in the sacculus, utriculus, cochlea, and ampullæ.

The Mechanism of Hearing.—If a tuning-fork is struck and placed on the head sound is heard very distinctly. The vibrations are communicated directly to the bones of the head and so to the perilymph, the internal ear and the endolymph. There the vibrations affect the auditory nerve endings and give rise to the sense of sound through the auditory nerve to the brain. Thus we can hear without any external ear at all. But in the usual way in which we hear, what we may

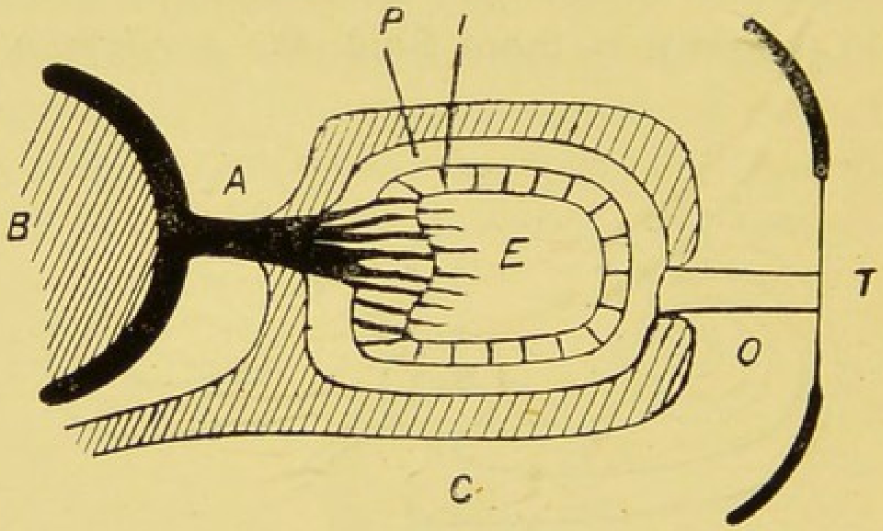

FIG. 21.—Diagram of the mechanism of hearing.

B, Brain; A, Auditory nerve, giving branches to the auditory cells with hair-like processes; E, Endolymph; P, Perilymph; C, Bony capsule of ear; O, Ossicle; T, Tympanic membrane; I, Internal ear.

call accessory apparatus is used, the chief arrangement of which is as follows:—

Passing from the external ear, or pinna, to the back of the nasal cavity is a tubular passage divided into two parts by a membranous partition, the *tympanic membrane.* The outer part, or external auditory passage is an inch and a quarter long. The inner part consists of the *tympanic cavity,* or middle ear, and the *Eustachian tube,* which opens into the pharynx, just behind the nasal cavity. In the tympanic cavity are the *ossicles*, a chain of three little bones stretching across the cavity from the tympanic membrane to a hole in the bony capsule surrounding the internal ear. These bones are very delicately adjusted so as to communicate vibrations.

Mechanism of the Accessory Apparatus.—The tympanic membrane receives the vibrations of sound, and communicates them to the ossicles; these pass them on to the perilymph, and so to the internal ear. The external ear is of no real use, and we can hear perfectly well without it.

The mode in which sound vibrations are conveyed to the brain is best shown by considering a simpler auditory apparatus than that of man, in whom the organ of hearing is so complicated. For this purpose I propose to take the frog, and in order to make the matter still more simple to consider it in a comparatively early stage of development, *i.e.*, when all the parts are present, but before they have become complicated. In the frog the essentials are the same, but in place of three ossicles, or small bones connecting the tympanic membrane with the internal ear, there is only one.

The above diagram will show clearly how the vibrations of sound are conveyed from the tympanic membrane by the small bone, or ossicle, to a small membrane (called the *fenestra ovalis*) situated in the bony capsule surrounding the internal ear. By the vibrations of this small membrane the sound is conveyed to the perilymph, internal ear and endolymph, and so to the auditory cells which are connected with the auditory nerve, and so to the brain. In man the essential principles are the same, but we have three small bones instead of one, and the internal ear is far more complicated. In the frog also the tympanic membrane is on a level with the skin, instead of being situated about an inch away from it down the auditory canal, as in man.

The Semi-Circular Canals.—The definite arrangement of these in three planes at right angles to each other is very striking, and was at first supposed to be concerned with the sense of direction of sound. This is probably incorrect. Injury or disease of the canals causes giddiness, headache and occasionally peculiar rotary movements of the body, but hearing is not affected. It is therefore supposed that they have something to do with the co-ordination of movement and the balancing of the body.

The Cochlea.—This is a spiral tube lying in a bony canal, across which it stretches. Its minute structure is too complicated for us to consider here, and the reader must refer to the larger text-books of anatomy. It will suffice to say that running along the spiral cochlea is a structure known as the *organ of Corti*, which consists of peculiarly modified cells arranged in longitudinal rows, and connected with filaments of the auditory nerve. It is the organ of Corti which is supposed to be concerned in the communication of sounds to the auditory nerve, but in what manner is not exactly determined.

CHAPTER VII.

THE EYE AND THE SENSE OF SIGHT.

The act of seeing is of a threefold nature, and has a threefold purpose to fulfil: (1) Appreciation of light and darkness; (2) appreciation of colour; (3) appreciation of the shapes, sizes, and distances of objects.

STRUCTURE OF THE EYE.

The eye is a nearly spherical globe, about an inch in diameter, and consisting of several coats. The outer coat, or *sclerotic,* is strong and fibrous; in front it is transparent, and forms the *cornea.* Inside the sclerotic is the *choroid*, a dark membrane containing much pigment and many blood-vessels. The choroid is continued forward as the *iris*, which is perforated by the pupil. The *retina*, or innermcst layer, is the most important, and is connected with the optic nerve. Behind the iris is the *crystalline lens*, convex on both surfaces. The iris and lens divide the eye into two chambers, an anterior and posterior. Filling the posterior chamber is the *vitreous humour*, a jelly-like substance; in the anterior chamber is the *aqueous humour*, which is of fluid consistency.

THE NATURE OF LIGHT.

Light is propagated as a series of waves in the same way as sound, but much quicker. Sound travels at the rate of 1100 feet a second, while lights travel roughly at the rate of 190,000 miles a second. Light differs

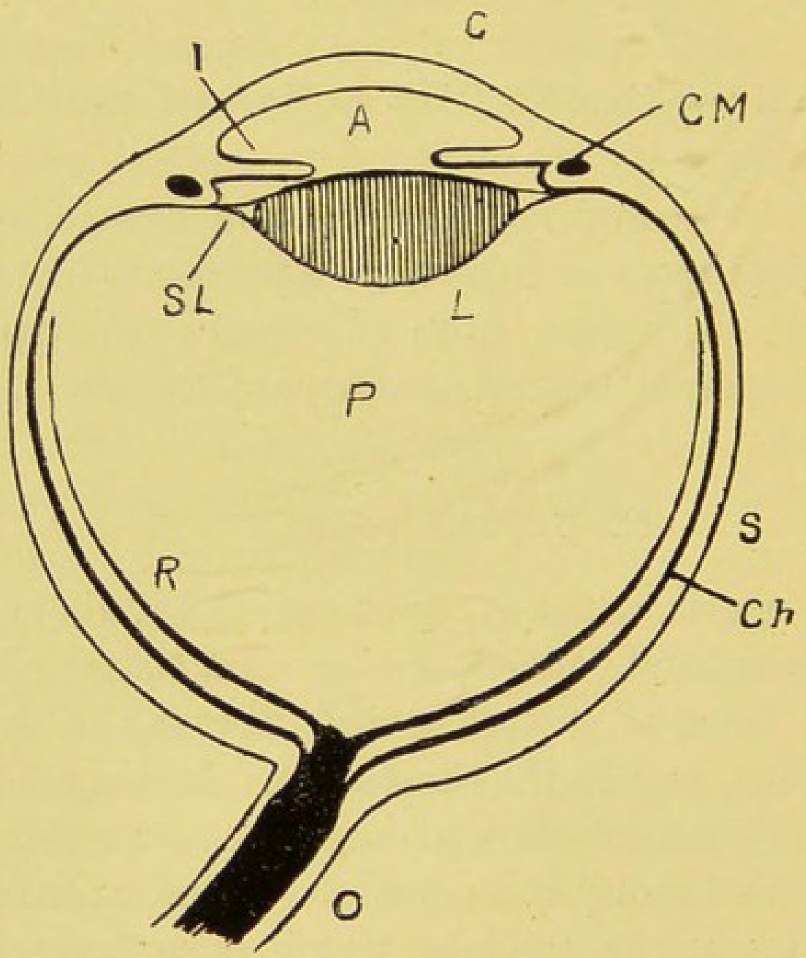

FIG. 22.—Diagram of eye.

C. Cornea. S. Sclerotic. Ch. Choroid. R. Retina. O. Optic nerve. L. Lens. A. Anterior chamber. P. Posterior chamber. I. Iris. CM. Ciliary muscle. SL. Suspensory ligament of lens.

from sound in that it can travel perfectly through a vacuum. All luminous bodies are constantly emitting waves of light in all directions and in all planes. Non-luminous bodies are rendered visible by light reflected from their surfaces.

THE USES OF THE VARIOUS PARTS OF THE EYE.

The Lens.—The use of a lens is to bring rays of light to a focus, and when an object is placed in front of the lens, corresponding to each spot of the object is a definite focus or image behind the lens. The position of this image depends on the distance of the object from the lens. This can be shown by throwing the image of a candle on to a screen by means of a glass lens: the image will be seen to be inverted, as is shown in the diagram.

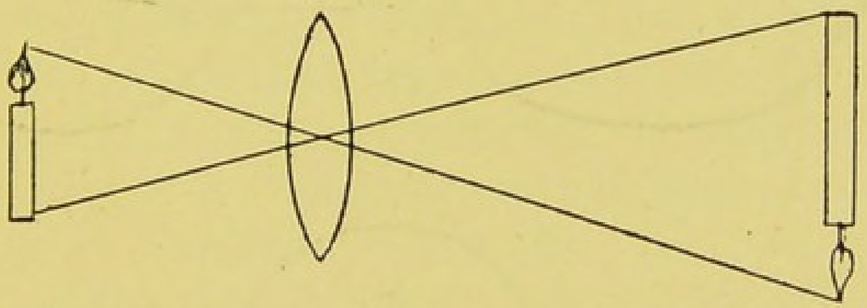

FIG. 23.—Inverted image of candle produced by lens.

The condition of clear vision is that the image shall fall exactly on the retina; if it does not fall exactly, the image appears blurred and indistinct. In a normal eye there is distinct vision, because the image falls exactly on the retina, but in short-sighted people the image is blurred when beyond a certain distance. The reason of this is that the eye in a short-sighted person is too long from back to front, and consequently the image is formed in front of the retina. This defect is corrected by using spectacles with concave lenses, which throw the image farther back so as to reach the retina. In the case of long sight the opposite state of affairs exists, the eye is too short and the image falls behind the retina. This is corrected by using spectacles with convex lenses to bring the image farther forward.

Accommodation.—It is necessary for distinct vision that the image should fall on the retina. Now the

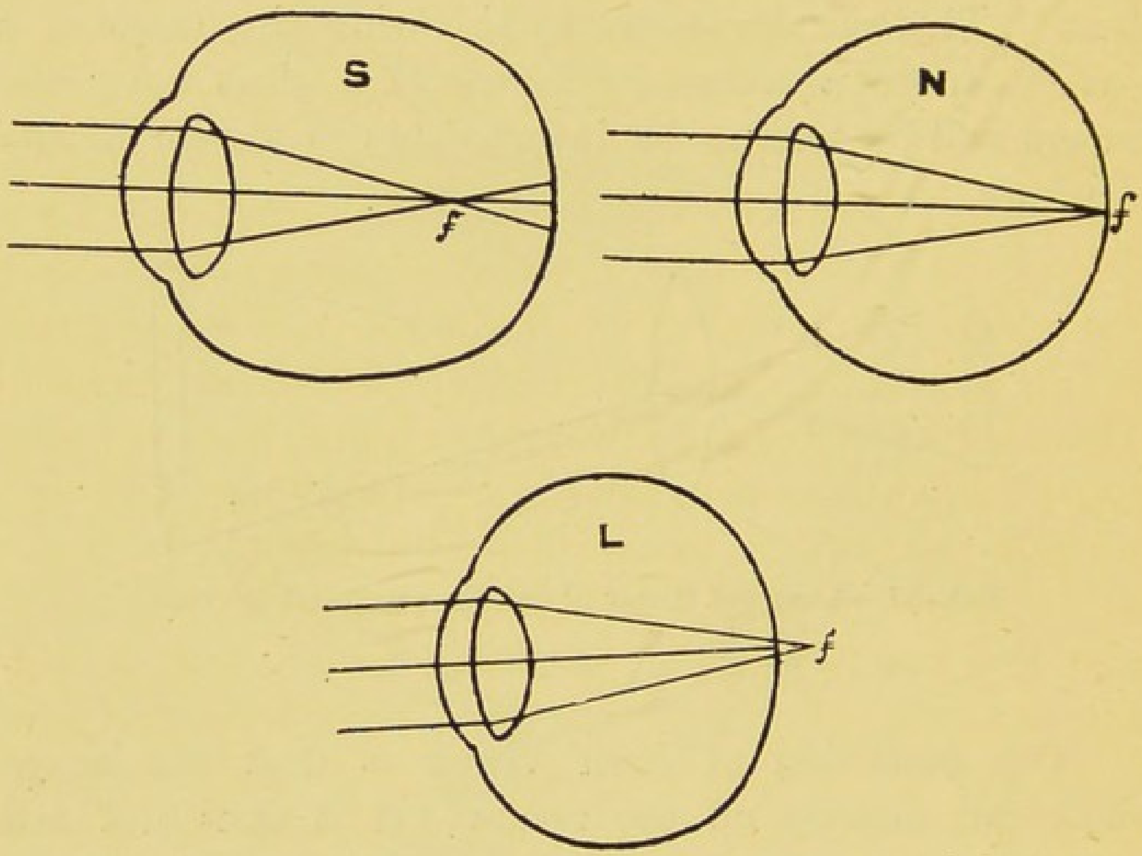

FIG. 24.—Diagrams of normal and abnormal eyes.

Normal Eye (N.), short-sighted eye (S), and long-sighted eye (L). In N the rays of light are brought to a focus (f) by the lens exactly on the retina. In S they come to a focus in front of the retina. In L the focus is behind the retina.

position of the image varies with that of the object. Compare with the candle and screen; if the candle is a long way off the lens the image is formed at a definite distance from it; if the candle is moved nearer the lens the image is now farther from it. For each position of the object there will be a corresponding position of the image; as the object approaches the lens the image recedes from it.

Hence, if the eye were made of glass there would be only one distance at which we could see distinctly. This is obviously not the case. We can see objects at a distance and objects close to us, but we cannot see both at the same time; there is a distinct effort in ooking from one to the other, and this effort is accommodation. What happens in the eye is that the lens changes shape according to the distance of the object looked at. Suppose the lens is accommodated for a distant object, the image of a near object will be behind the retina. For a near object the eye is long sighted, which we have seen is corrected by convex lenses. This is done in the eye itself by making the lens more convex when near objects are looked at.

The mechanism by which this is effected is thus: At the junction of the choroid and iris is the *ciliary muscle*, a circular ring of muscle round the edge of the iris and attached to the sclerotic. The lens is enclosed in an elastic capsule, which is always on the stretch, thus tending to flatten the lens. Contraction of the ciliary muscle relaxes the capsule of the lens, and allows it to become more spherical, and hence its anterior surface more convex. Thus the lens alters its degree of convexity according to the distance of the object, and can thus focus objects at different distances distinctly on the retina.

There is a distinct effort necessary in order to accommodate. If we hold a book at a distance and gradually bring it nearer to the eyes, we can still see it clearly, but as it gets nearer the effort becomes greater and greater, till it becomes impossible. The near point of vision is about five inches from the eye, this is the nearest point at which objects can be seen distinctly. The far point, in a normal eye, is infinity.

Presbyopia.—In old age the near point recedes from the eye owing to diminution in the elasticity of the lens and loss of power of the ciliary muscle. Distant vision is, however, as good as ever. Presbyopia is corrected by using convex glasses when reading.

Inversion of the Image.—The image on the retina is upside down. There is no doubt about this, for we can see the image of a candle inverted by looking at a sheep's eye, with the back part of the sclerotic cut away. Why, then, do we not see objects upside down? We must not suppose that we look at the image which is on our own retina, or that the retina is the seat of vision. The brain is in the seat of the sensation of vision, as of all other sensations, and stimulation of a certain part of the retina causes a message to be sent to the brain, which thus knows what part has been stimulated and no more. In fact, it is simply a matter of experience. Supposing an object lies on our right side, the image will be on the left side of the retina, and by experience we know that stimulation of the left side of the retina can only be caused by light from an object on our right side.

The infant has to learn all this for itself. Hold an object before an infant and see the unavailing efforts it makes to seize it. These are partly due to imperfect co-ordinating power over the muscles, and partly to imperfect knowledge of what its visual sensations are. Just as with sensory nerves an impression received along a particular nerve is always referred to a particular part of the body, so with the eye an impression on a certain part of the retina is referred to an object in a particular direction, because experience has shown that this must be so.

Persistence of Images.—The impression made on the retina does not subside at once, but lasts about one-eighth of a second on the average. In the case of very bright impressions the persistence is much longer, as we know ourselves by looking at the sun. This is the principle of the zoetrope, or wheel of life, which represents a series of figures in successive phases of the acts of running, leaping, etc. These, when made to pass rapidly before the eye, are by a mental process combined into a continuous series, owing to persistence of the images.

The *iris* acts as a diaphragm, cutting off the marginal rays of light, and so rendering vision more distinct. The iris contain muscular fibres, and has the power of contracting and dilating. In the dark it dilates, and in the light it contracts, thus causing alteration in the size of the pupil and so in the amount of light admitted to the eye.

APPRECIATION OF COLOUR.

Light, like sound, consists of waves ; sound waves being transmitted by the air, or by a solid body such as wood ; waves of light being transmitted by the "æther," a hypothetical substance filling space.

Just as in sound we distinguish between less rapid and more rapid waves ; longer waves produced by a slowly vibrating wire causing a deep bass note, shorter waves of a rapidly vibrating wire causing treble notes; so with light we distinguish between waves of different wave length, and these differences of wave length are appreciable to us as colours, each colour being formed by waves of different length. Red has the longest waves, corresponding to the bass note of sound waves, violet the shortest, corresponding to the treble note of sound waves.

In white light waves of all colours are present, but

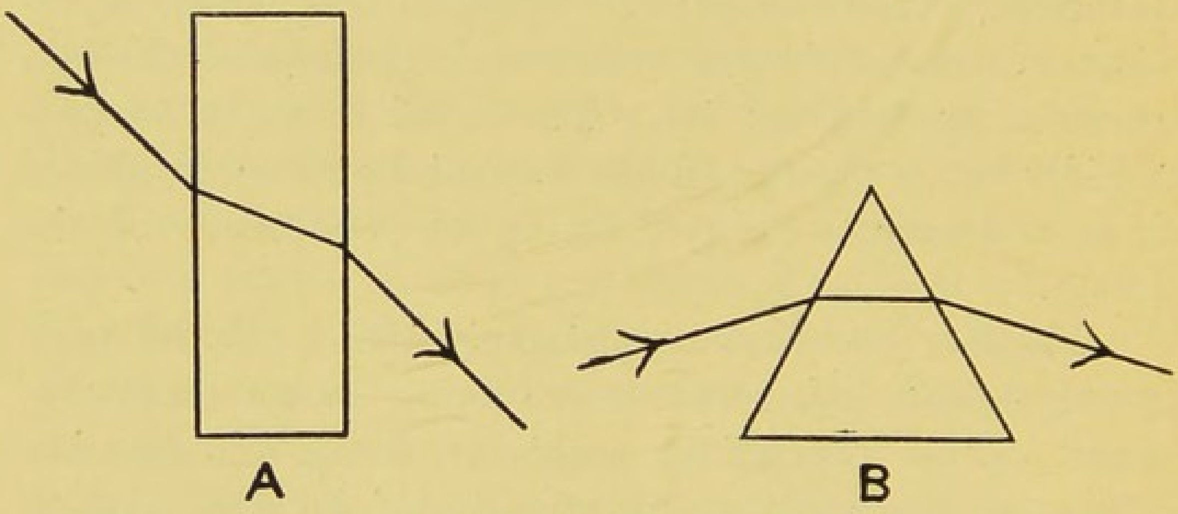

FIG. 25.—Refraction of Light.

A, through a plate of glass; B, through a glass prism.

the mixture gives rise to the combined effect of white. That this is the case can be shown by passing ordinary sunlight through a glass prism (a triangular rod of glass), when the light will be broken up into its component colours forming what is called the *spectrum*. The colours of the spectrum are in definite order, red being at one end and violet at the other, yellow, green, and blue being intermediate. In nature the colours of the spectrum are seen in a rainbow.

Refraction of Light.—The explanation of the spectrum depends on the fact that light when passing from one medium to another becomes bent or *refracted.* For instance, a ray of light passing from air to water is bent so as to be less slanting after entering the water; or if it comes out of the water it becomes more slanting on reaching the air. The same happens when light enters the surface of a plate of glass. If, however, the glass is wedge-shaped (prism), the light instead of going on in the same direction after leaving the glass, becomes bent towards the base of the prism.

Now when white light falls upon a prism it is separated into its component colours, because each

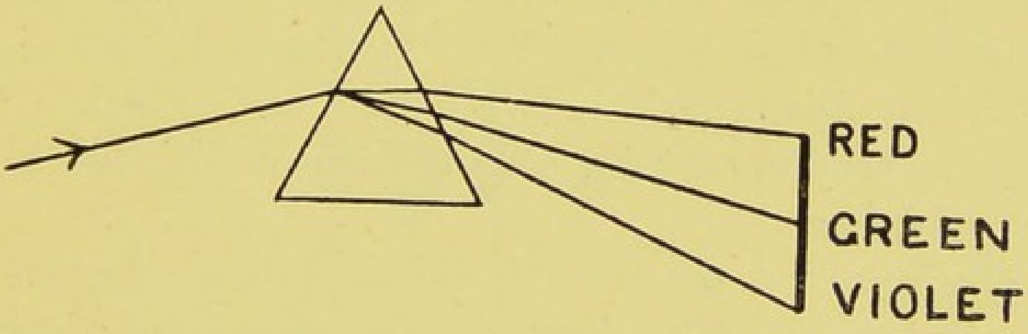

FIG. 26.—Spectrum caused by Refraction of White Light through a Prism.

colour, being of different wave length, is refracted or bent out of its course to a different extent; the violet rays are the most refracted, the red the least. This is shown in the figure above.

Complementary Colours.—After looking for a time at an object the eye is fatigued. If we look at a white spot on a black ground for a time, and then suddenly look at a moderately lighted surface, say the ceiling of a room, we shall see a dark spot. And if a coloured surface is looked at the complementary colour will be seen. The complementary colour is white minus the particular colour concerned, *i.e.*, the colour which will make white with the colour in question. For instance, red and green are complementary colours, for red and green light when brought together by a prism will make white light. So orange and blue are complementary. Thus when a red spot is looked at for some time, and the eye then looks at the ceiling, a green spot will be seen there. The explanation being that the eye becomes fatigued for red, and when rested sees its complementary colour.

Colour-blindness.—In some people the range of colour perception is less than normal, and such people are called colour-blind. The most usual form is inability to distinguish between red and green. The cause is very uncertain, and is too complicated to be discussed here.

Structure of the Retina.—The retina consists of several layers. The innermost is the layer of nerve fibres from the optic nerve. The outermost layer is that of the *rods and cones.* Intervening between these are several layers called nuclear and molecular. The most important layer is that of the rods and cones, and this layer is probably connected indirectly with the fibres of the optic nerve, although such a connection is difficult to demonstrate.

In the retina are certain parts of special interest. The *blind spot* is the entrance of the optic nerve, and is insensitive to light; hence the nerve fibres themselves, curious though it may seem, are blind. The blind spot can be demonstrated very easily in ourselves. Make two black marks on a piece of paper about four inches apart, look at the left-hand mark with the right eye while the left eye is closed and move the paper nearer to the eyes; at a certain distance the right-hand black

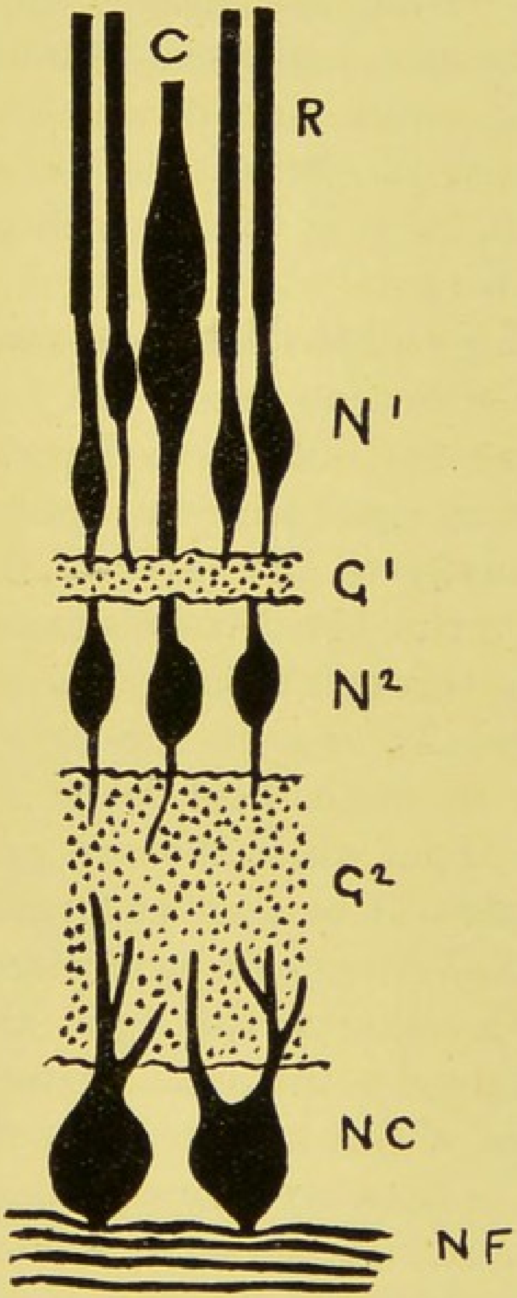

Fig. 27.—Diagram of Retina.

R, rods; C, cone; N1, N2, outer and inner nuclear layers; G1, G2, outer and inner granular layers; NC, nerve cells; NF, fibres of optic nerve (highly magnified).

mark will disappear from sight, when it falls on the blind spot, reappearing again when the paper is moved still nearer the eyes.

The *yellow spot* is that part of the retina in the axis of direct vision, or the optic axis. In this the cones are very abundant, but there are no rods, and the other elements of the retina are absent, except the nerve fibres. The yellow spot is the seat of most acute vision, for it falls in the direct line in which we look at an object. Therefore, the cones are the most sensitive part of the retina, for it is these which are most abundant in the yellow spot.

It is interesting to note that light must traverse the thickness of the retina to reach the rods and cones, because these are the outermost layer. The blood-vessels of the retina enter with the optic nerve, and are distributed internally to the layer of rods and cones. Hence shadows of the blood-vessels must be formed by the light passing through them to the rods and cones. These can be actually seen in ourselves by entering a dark room with a candle held below the level of the eye, and moved about while the eye gazes at a blank wall. The vessels will be seen as a radiating network on the wall. They are known as Purkinje's figures.

The effect of pressure on the optic nerve is to cause a sensation of light, for the optic nerve is accustomed to carry messages of this kind only; consequently any stimulation of if or blow on it causes a sensation of light. Hence the seeing of " stars " when a blow on the eye is received.

Vision with Two Eyes.—Although there is a separate image formed by each eye, yet the brain in its normal condition is conscious of only a single image. This is again the effect of experience. The outer side of one eye must work with the inner side of the other eye, and if the light is so directed that light from one object falls on points of the retina not accustomed to work together we shall see double. But by experience each half of each eye works together with the opposite half

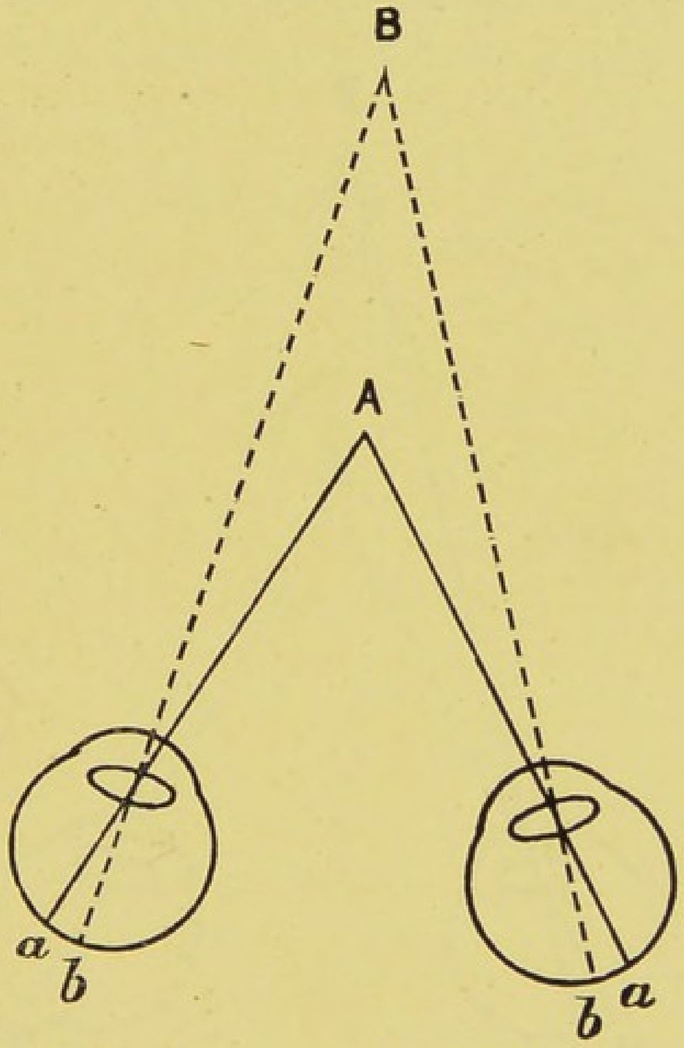

FIG. 28.—Diagram showing eyes focussed for near finger A. The distant finger B, gives images (bb) which fall on non-corresponding parts of the retina (*viz.*, both on inner half of retina).

of the other eye, and the brain by experience learns to associate the points of the retina which receive the image of one eye with the points of the retina of the opposite half of the other eye, thus combining the two images. If we hold one finger at arm's length, and another closer to the face, and focus our eyes for either finger, the other will appear double. The explanation is that, when the eyes are focussed one on finger, light from the other finger will fall on two non-corresponding parts of the retinas of the two eyes, *i.e.*, on parts which are not accustomed to work together.

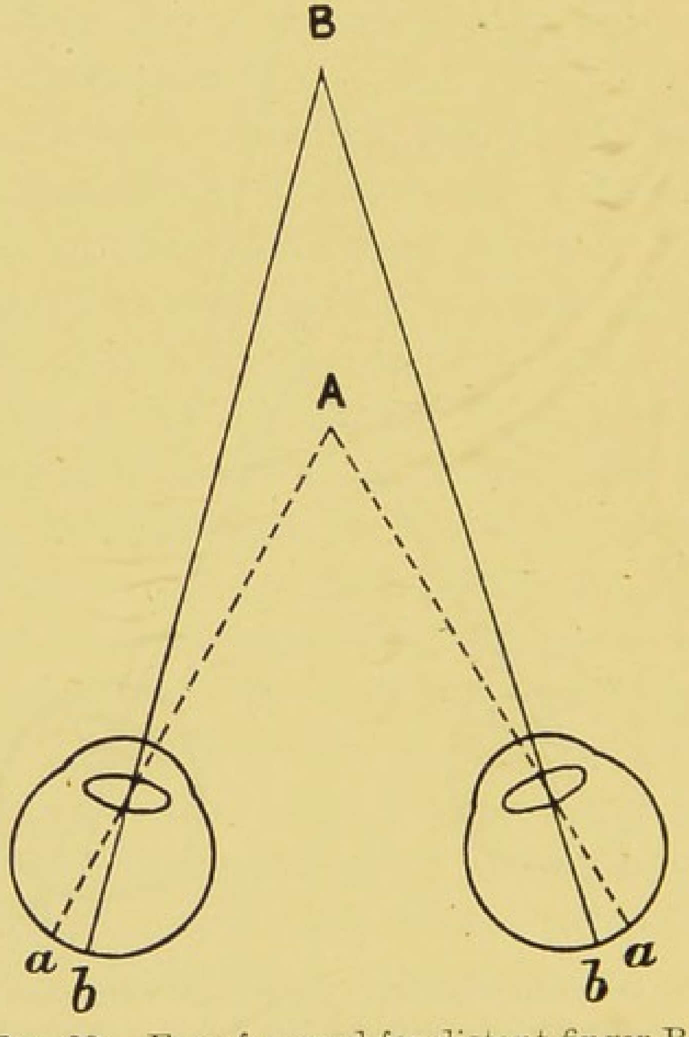

FIG. 29.—Eyes focussed for distant finger B.

Here the near finger gives images (aa) both on outer sides of retina and hence non-corresponding.

The images in the two eyes are not identical, as we can see by looking at a solid object a little distance off, and closing each eye alternately; a different view is obtained by each eye. By this means the effect of solidity is obtained by the brain combining the two views obtained from both eyes.

Distance is estimated by the degree of convergence of the two eyes when focussed on an object. When a man loses one eye this power of estimating distance is lost to a great extent, but is regained largely by the muscular sense of the ciliary muscle during accommodation.