X

THE BODY-MACHINE AND ITS WORK

THE most perfect machine in the world is the body of man. The further we advance in our knowledge of it, the more we wonder at the ingenious mechanisms which are crowded into its structure. Almost every decade we discover new operations in it which have a profound influence over our life, yet are so subtle and unexpected that many generations of scientific men were entirely ignorant of them, and it may take still many generations to tell how they bring about their marvellous results. Here, as in other fields, the advance of science creates one mystery while it explains another. But that story of evolution which we studied in a preceding section sheds a clear light upon the body-machine both of animals and of man, and enables us to understand the high efficiency of most of its parts. The machine of the animal body is not only the most perfect in nature; it is immeasurably the oldest. For at least fifty million years—how much longer no man knows—the world-forces have been making the animal body, developing and improving the various organs and co-ordinating their functions. During all these tens of millions of years the machine has been subject to the fiercest stresses and trials, and the human body, as we know it, is the final and finished outcome. We wonder no longer. Time itself makes nothing; but if we grant a vast period of time to the real shaping forces of the universe, acting upon the most sensitive material in the universe, the perfection of the final stage becomes intelligible.

§ 1

Traces of the Past.

We speak of the body as a machine, but it is hardly necessary to say that none of the most ingenious machines set up by modern science can for a moment compare with it. The body is a self-building machine; a self-stoking, self-regulating, self-repairing machine—the most marvellous and unique automatic mechanism in the universe. It differs from our ordinary machines, moreover, in this: when a part becomes superfluous or out of date, it will linger for ages, even for millions of years, in the structure, slowly changing and shrinking on its way to disappearance. It will be useful to begin our examination of the human body from this point of view, especially as some of the first things we notice about it are precisely shrinking structures of this kind.

Why have we hair on our bodies? We need not notice here the specially luxuriant growth on the head, or on the man's lips and chin. This has been artificially fostered or cultivated during the course of man's history. Men, in mating, chose women with rounded forms and smooth chins. Women chose men with strong, muscular forms and, in our own branch of the race at least, hairy mouths and chins. We quite understand that in the course of tens of thousands of years this has evolved rich growths of hair in certain parts. But we have hair on our trunk and arms and legs; there are tiny pits in the skin, out of which hairs grow, all over the body except on the palms of our hands and the soles of our feet. Before birth the human body is, in fact, almost entirely covered with a fine coat of hair.

There is not a word to be said in favour of this part of our wonderful body-machine. It harbours dirt, microbes, and vermin, and sometimes favours skin-disease. As a coat it is ridiculously thin and ragged, and it has been superseded by clothing. Its plain meaning is in the story of life in the past which was told in an earlier part of this work. The hair is a dwindling vestige of the warm fur-coat which mammals developed to meet the conditions of an Ice Age. It is *vestigial*, not rudimentary, as is sometimes said.

The pieces of gristle or cartilage on the sides of the head which we call our "ears" are similar organs. They do not catch waves of sound, as many suppose, and guide them into the real ear inside the skull. They are too flat to do so. But if we compare them with the useful, pointed, movable ear of a horse, we see what they mean. They were once similar organs, but they have fallen out of use and are dwindling away. Underneath the skin we still have seven muscles attached to the shell of cartilage, from which it is obvious that the ear could once be moved in every direction to catch the waves of sound. Now only an individual here and there can use one or two of these muscles. The pinna or "ear-trumpet" is a surviving structure that tells us a little about the body's remote past.

There are very many similar muscles in the body to-day which merely tell us about a strange past. Some men can twitch their nostrils. Some can move their scalps. They do so by means of muscles which in most of us have gone completely out of use. Underneath the skin in very many parts of the body there are dwindling muscles of this kind.

In the inner corner of each eye we have a little pulpy mass which recalls to us even remoter ages of the body's past. It is of no use whatever in the body to-day. To understand it, one has to watch a parrot or an eagle in a cage, and notice how the bird flashes a white film (the "third eyelid") occasionally over its eyeball. Our superfluous bit of tissue is the shrunken remainder of this. We have in our eyelids a better apparatus for sweeping the dust off the eyeball, and the old membrane is disappearing. Man is not, of course, descended from birds, but almost all mammals have a well-developed third eyelid.

We know from fossil remains and from examining the bodies of living reptiles that in remote ages—somewhere about the era of the Coal Forests—there were animals with a third eye, in the top of the head. We find this third or pineal eye in the heads of a few reptiles to-day, but the skin has grown over it, and it is degenerating. In the birds and mammals it has sunk still deeper into the head, and degenerated further. In man it has become a small body, about the size of a hazel-nut, rising from the middle of the brain. We call it the "pineal body." It is a mysterious little organ, and we will not say positively that it has no function. But, whether it has or no, we clearly trace it to the third eye of millions of years ago.

The "vermiform appendix" is a well-known vestigial organ. It is a little worm-like tube, about four inches long, arising as a blind alley at the junction of the small and the large intestine; and as a source of disease (appendicitis) and danger it is notorious. Some have tried to find that it has a use in the body, but the plain fact is that it has been removed from hundreds of thousands of men in modern times, and no harm has ensued in any single case. It is the vanishing remainder of a large, useful chamber in which early vegetarian mammals let myriads of bacteria break up their coarse food.

In short, expert investigators of the human body have found 107 organs, or parts of organs, that have to be understood as more or less vestigial. We have the vestige of a tail in the block of bone at the lower end of our backbone; and sometimes children are born with distinct and movable—though very short—tails. We have bones, muscles, and glands in many parts that are now the almost or quite useless relics of a remote past. Evolution beautifully explains them. The body remains a wonderful mechanism because these were once useful and most cunningly contrived structures.

§ 2

The Ivory Gates of the Body.

Turning now to the body-machine in its active life, we shall find it most interesting to follow the progress of food until it is built into the frame. We can, if we like, do this literally to-day. We can mix an opaque powder, e.g. of bismuth, with a mouthful of easily digested food (such as meal), and then by means of X-rays we can photograph its progress along the alimentary canal until what remains of it is dumped in the waste-chamber. This is useful for some purposes, but in the main we rely on the minute studies of the anatomist and the experiments of the physiologist for our knowledge of that part of man's body that is concerned with the utilisation of the food.

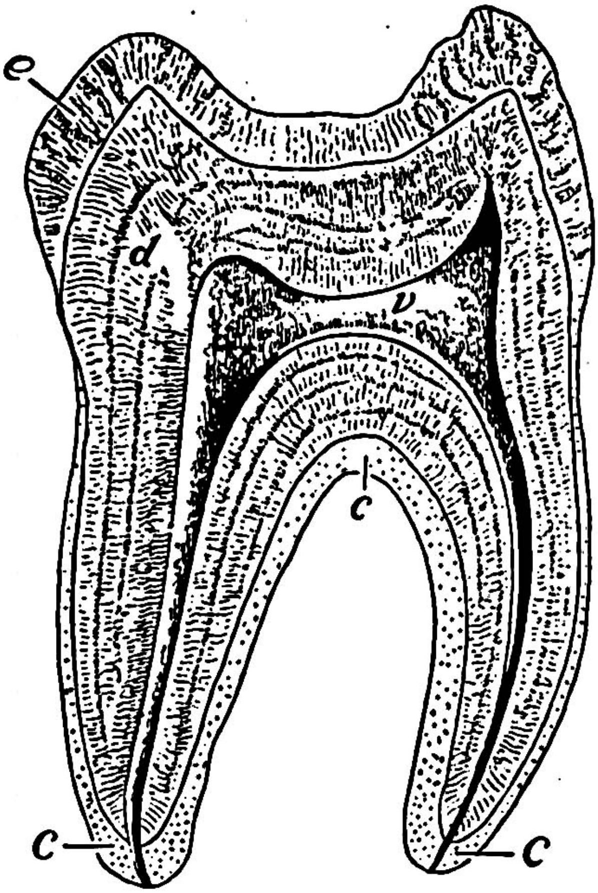
The receiving office, so to say, or the mouth, is itself so deeply interesting and full of ingenious contrivances that a whole section of this work

Photo: Alinari

DR. JENNER (1749–1823) INNOCULATING HIS OWN SON: THE STATUE BY J. MONTEVERDE AT GENOA

He proved about 1796 by a long series of observations and experiments that vaccination with cowpox protects the body from smallpox, either completely or to the extent of diminishing the severity of an attack.

might be devoted to it. Above the mouth are the sentinels, the eyes and nose, which we shall consider later. Then, on the upper surface of the tongue, there are myriads of sensitive little organs, taste-buds, ready to apply a final test to the food. The juices of the food penetrate the thin skin which covers and protects them, and probably have a chemical action on the little nerve-endings in them. If the message which they automatically dispatch to the brain is "O.K." other nerves set in motion the muscles of the lower jaw, and the grinding of the food begins.



VERTICAL LONGITUDINAL SECTION (AFTER OWEN) OF A HUMAN MOLAR TOOTH.

The lower part is embedded in a socket in the jaw and surrounded by the gum—the derma of the dense mucous membrane of the mouth. Two roots or "fangs" are shown, surrounded by a thin layer of bone called "cement" (*c*). Through the basal openings shown there enter blood-vessels and nerves. In the centre of the tooth is the vascular pulp-cavity (*v*), from which fine processes extend into the ivory or dentine (*d*). Over the crown there is the enamel (*e*), the hardest tissue in the body.

In modern times a volume could be written on the teeth alone, and it would be a remarkable story. Teeth began ages ago in fishes of the shark and dog-fish type. Their rough scale-covered skin was drawn in to form a lining of the mouth, and long practice in crunching shell-fish, and so on, led to the evolution of the hard scales on the skin into teeth. In the course of time the teeth on the ridges of the jaw were particularly developed, and the others disappeared. But we must not suppose from this brief hint of their origin that teeth are simple things. Each tooth is a remarkable structure. Coats of dentine and enamel are built round a pulpy cavity into which nerves and blood-vessels run, and roots, coated with cement, fix the tooth in its socket. It is strange how few people wonder why our jaws do not ache and jar from the crunching of a hard crust. In mammals there is a provision which obviates this: the teeth do not fit tightly in the sockets. They are "packed" in with a material that lessens the shock of the daily grind.

A special regiment of the cells which make up the body is told off to see to this business of the teeth, and our wonder increases when we see these strange microscopic, unconscious "bone-builders." They have, in the baby, to select, atom by atom, the cement and dentine and enamel which (in other forms, of course) somehow exist in the food of the blood-stream. They have to build the stuff into structures of which our artificial teeth are very clumsy imitations. They have to do this at the right time—to wait until suckling is over and eating begins. Then they have an even more difficult problem to face. The jaws of the adult will be much larger than the jaws of the young, and, naturally, it is not possible to alter these solid structures of enamel and dentine. So the bone-builders absorb the greater part of the first set of teeth, the "milk-teeth," and meantime prepare a new set underneath them. The cast tooth which your child shows you is, as a rule, a mere shell. The microscopic bone-builders have re-absorbed the material.

Yet the teeth, with all their wonders, may be among the doomed structures of the body. Some authorities believe that they will gradually drop into the class of vestigial organs, like the hair,

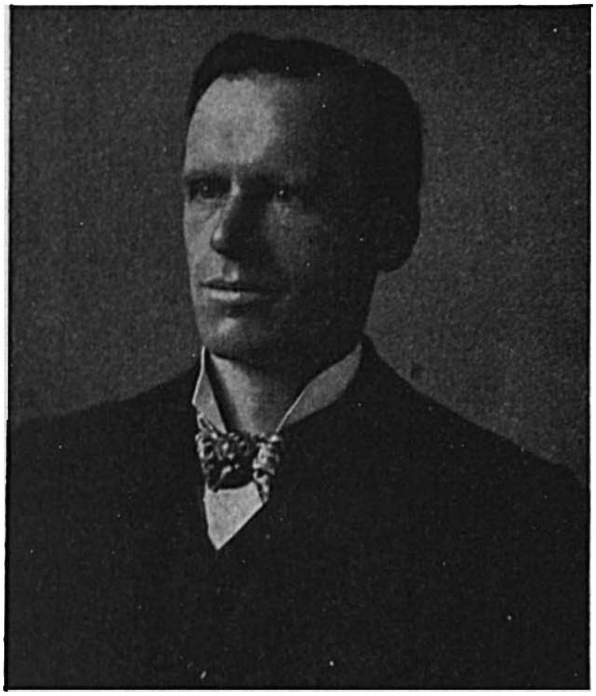


Photo: Elliott & Fry, Ltd.

PROFESSOR E. H. STARLING.

One of the leaders of modern physiology. He has made contributions of the highest importance towards an understanding of the chemical correlation or harmonious working of the body, notably by his study of internal secretions. Professors Bayliss and Starling have done much together.

though they will give a vast amount of trouble as they grow weaker. Their purpose is to break up the food into smaller particles, and in modern civilisation this is done in the preparation and cooking of the food. So the teeth are already going. In ancient skulls and among savage peoples the teeth are often much worn away by sheer hard work; in conditions of civilisation much-worn teeth are rare. The jaws have not the hard work they once had; they therefore get a smaller supply of blood, and the teeth grow weak and less numerous. Normally we have thirty-two teeth, but in many people the so-called "wisdom teeth" (which might very well be called unwisdom teeth, as they are superfluous) do not develop. On the other hand, a few people have thirty-six teeth, and when we turn to the monkeys we find that some of them have this number. We are, in fact, slowly shedding our teeth, in fours, along the corridors of time, and it may be that in the distant future man will be toothless. Perhaps, however, a fresh enthusiasm for physical vigour will save the race from any such degeneracy.

But our "grinding-stones" are only part of the mechanism of the mouth. As soon as the grinding begins three pairs of glands pour saliva into the food. Here again we have an automatic nervous machinery of a remarkable kind, for, as everybody knows, the mere sight of food may set the glands at work, or "make your mouth water." In the glands themselves the microscopic cells which make the saliva are such remarkable chemical machines that we cannot yet understand them. They not only help to make a soft pulp of the food—the saliva is 99 per cent water—but they pour into it certain chemicals which begin the digestion of starchy food, converting it into a kind of sugar. That is one of the reasons for thorough "mastication." One must not suppose that it does not matter, since the food is so short a time in the mouth that there cannot be much chemical action on it. The chemical action of the saliva *goes on*, for half an hour or more, while the food is in the stomach. A great deal of illness is due to neglecting to mix plenty of saliva with our bread, etc., before it leaves the mouth.

§ 3

The Process of Digestion.

When teeth and salivary glands have done their work, and the taste-buds on the tongue have had their moment of satisfaction, the mouthful of pulp is swallowed. "Swallowing seems such an easy and automatic act that we are quite unaware of the elaborate system of signals, side-shunts, and level-crossings which have to be manipulated to permit the busy traffic of the pharynx to pass unchecked." Food does not "go down," as children think. The whole mouth changes. Certain sensitive spots at the back of the mouth—electrical press-buttons, we may call them—give the signal that the food is ready. The powerful muscles which closed the back of the mouth while we were masticating, relax. The lower jaw is pressed against the upper. The soft palate forms an inclined plane.

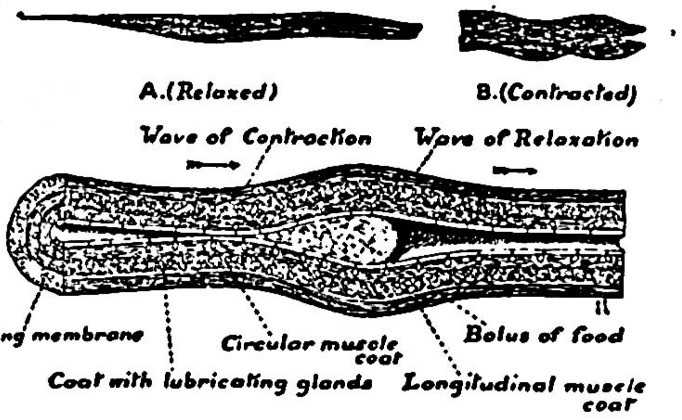
Other muscles close the airways to the nose and the great airways to the lungs. The whole complex machine acts together and pumps the food into the first part of the alimentary tube, the pharynx. Only very rarely does a little food "go the wrong way"—into the air-passage—and then another set of muscles automatically blow (or cough) it out. The mouth is a rather complicated cavity. How many communications it has—with the nasal passage by the posterior nostrils, with the ear-passages by the Eustachian tubes, with the pharynx, and with the windpipe through the guarded glottis. It is obviously very important that the mouth be kept in good order.

The food now enters upon a very long journey. Most people are surprised to hear that the alimentary tube is yards long in a man or woman of medium height, about twenty-eight feet long from the mouth to the vent. But few people reflect—there would be far less misery and discomfort in the world if they did—what digestion really means. Our food has to be broken up, physically and chemically, and even then it cannot pass into the blood. From the pulpy mass myriads of tiny organs have to select the matter which the body needs, and let the remainder pass away. So the food has to pass slowly through twenty feet of a long tube, the small bowel or small intestine, to give these "selectors" the chance of taking the nourishment from it.

However, let us begin at the beginning. The food passes to the stomach down a one-foot tube (in a man of medium height), the upper part of which is known as the pharynx, and the lower part as the gullet or œsophagus. As we said, it does not slide down.

Sir Arthur Keith describes very graphically the transport of a bolus of food towards the stomach. "The instant that a bolus has been pushed through the doorway leading from the pharynx, and that doorway has closed, we see a ring of contraction form behind the bolus and commence to creep slowly downwards, forcing the bolus in front of it. The bolus, on entering the œsophagus, has touched a 'button,' and the ring of contraction is the result. As the bolus is driven forwards it comes in contact with a succession of such buttons, with the result that it is kept moving onwards. Not only so; a ring of relaxation precedes the bolus and eases the passages." [1]

The earliest stomach in the animal world was merely a straight tube through which the food passed, but in the course of evolution it has grown larger and larger at this spot until (in man) we have a large storage chamber in which the food will be churned up and mixed with acid and ferment during several hours. The stomach goes up close to the heart on the left side, but its large upper part is less concerned with digestion. The muscular movements which push the food about, so as to expose every part of it to the digestive juices, begin about half-way down the stomach and travel, in waves, towards the bottom. There are three coats of muscle, and they are at work all day long mixing the pulpy contents. The stomach of a healthy and sensible man will get through its work in about four hours, and, if he postpones his next meal, it will, like Oliver Twist, call for more. It develops a peculiar writhing motion



Reproduced by permission from Keith's "The Engines of the Human Body" (Williams & Norgate).

A PORTION OF THE ŒSOPHAGUS OR GULLET LAID OPEN TO SHOW A BOLUS OF FOOD PASSING DOWN.

It will be seen that the muscular wall of the gullet relaxes in front of the bolus of food and contracts behind it.

A, a small fragment of the outer muscular coat magnified to show the individual spindle-shaped muscle fibres of which it is composed in a relaxed state. B, the same muscle fibres or spindles, greatly enlarged, showing the contracted state.

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[1] Sir Arthur Keith, *The Engines of the Human Body*.

in its muscles, and this is telegraphed to the brain by the nerves. You feel "hungry."

The inner wall of the stomach is richly supplied with blood, and is lined by the myriads of minute glands which produce the "gastric juice." As soon as you sit to table, the sight and smell of the roast mutton send their messages to a certain nerve-centre, and from this a silent message or stimulation goes to the glands. When the food touches the taste-buds on the tongue, the messages multiply. The blood gathers in the wall of the stomach, and the little tubes use its nourishing solution in order to make the digestive juice which they pour out upon the food. With a large part of our food the stomach does not deal. Digestion only begins in it. Sugars, starches, and fats are passed on to the next department. It is chiefly the nitrogenous or protein food—flesh, fish, eggs, etc.—that is here broken up still further and prepared for absorption. The stomach itself absorbs only a little of the food. A glass of wine—as the head of an inexperienced maiden may tell her—is absorbed into the blood very quickly, and part of the digested meat is passed into the blood-system through the stomach; but the main part of the food passes into the twenty-foot laboratory of the narrow "small intestine," to be further digested and absorbed.

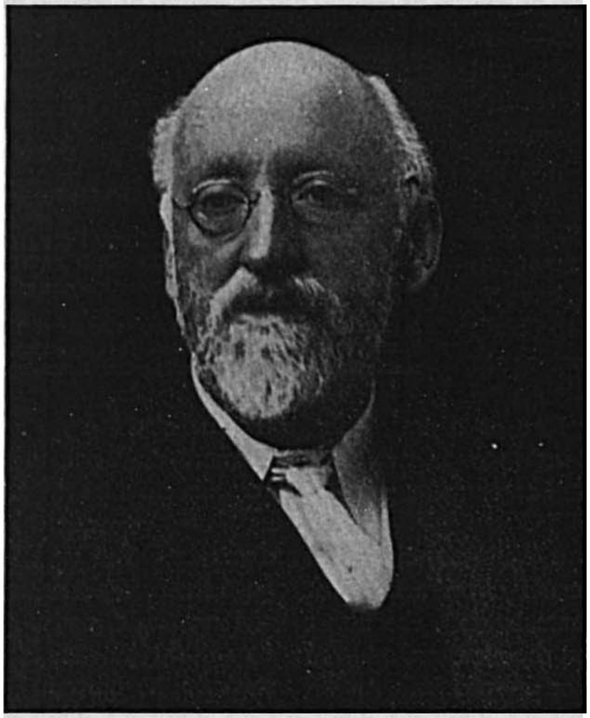


Photo: Russell, London.

PROFESSOR W. M. BAYLISS.

One of the leaders of modern physiology. He has made contributions of the highest importance to the study of internal secretions, digestion and the action of ferments, electric phenomena associated with vital processes, the production of heat in the body, and the regulative functions in general. His *Principles of General Physiology* is one of the great books of the science. Professors Bayliss and Starling have conducted many investigations together.

It is amazing how few people have even a rudimentary knowledge of this fundamental part of their being. Stomach and bowels are hopelessly confused, and our poor organs, magnificent as they are, are treated with inconceivable crudeness even by educated people. It is easy for everybody now to obtain a list giving the exact digestibility and nutritive value of different kinds of foods. It should be known to everybody that the work of these myriads of minute chemical laboratories in the stomach has drawn the blood from the brain for a time, and it is unnatural and unhealthy to attempt brain-work during or after a meal. Half the physical misery of life could be cured by a little knowledge and restraint.

§ 4

A Remarkable Mechanism.

A brilliant physiologist, Professor Metchnikoff, startled us some years ago by stating—almost snorting—that the human alimentary system is a miserable out-of-date machinery that ought to be scrapped. Even the stomach, he said, was superfluous. Very few men of science agree with him, but when we understand what he was driving at, we see that he had hold of a very important idea. Professor Metchnikoff meant that we can "digest" our food in advance by means of chemicals, and get rid of all the great length of intestine which is so liable to disease. At present we take in great masses of superfluous stuff, but there will some day be extraordinary changes in man's diet. In the meantime the organs are there and we have to feed accordingly; but it does not follow that this will continue.

Photo: Rischgits Collection.

THE SCHOOL OF ANATOMY, BY REMBRANDT.

At the base of the stomach, where the alimentary canal again becomes a tube—the beginning of the small (or narrow) intestine—there is a very powerful ring-muscle, which guards the exit. Nature has provided for healthy living. The unprepared food, if we live well, cannot run into the bowel. Mere contact of food against this muscle only draws it tighter. There has to be, apparently, some sort of chemical action by food which is quite ready, then the muscle relaxes, and a spray of the pulp shoots into the bowel. We can see the occasional gush when we are following the digestion by means of X-rays.

Photo: Rischgitz Collection.

SIR JAMES YOUNG SIMPSON (1811-1870),

who introduced in 1847 the use of chloroform as an anæsthetic. He was Professor of Midwifery in the University of Edinburgh and was indefatigable both in research and in practice.

In the first section of the narrow intestine, the duodenum, very important work goes on. Here we find a remarkable sort of mechanism which has only been discovered by recent science. The automatic machines of the body generally work by nervous action. The sight of roast beef is "wired" to the brain by the eyes, and a reflex (or reflected) nervous action sets the salivary glands and the stomach glands at work. This is a sort of automatic telegraphic system. But there is also in the body something like a postal service; it is one of the most wonderful discoveries of modern physiology. When, for instance, the acid food (or chyme) from the stomach touches the walls of the lower bowel, the glands in this wall form a certain chemical (called *secretin*) and pour it into the blood. The blood takes it rapidly all over the body, *but there is only one organ (or perhaps two) waiting for it.* In this case the pancreas (or sweetbread) receives the chemical message, and sets more vigorously to work pouring an increased supply of digestive juice into the intestine. These marvellous messages which are, as it were, posted in the blood are called "hormones," and, as we shall see later on, we find them again and again accounting for very remarkable results in the body.

The liver and the pancreas are really outgrowths from the alimentary tube; sections which have become detached, special departments, with ducts leading to the bowel. Each pours about a pint of fluid daily into the bowel, to assist the work of digestion. The liver has very special work to do, and we shall notice it presently. Here we need only say that the bile which it pours into the bowel—sometimes so abundantly that some forces its way into the stomach, and you get "bilious"—is not a digestive juice, but it helps to prepare the fats in the food. The pancreatic juice, on the other hand, is a real digestive juice, and the starches and sugars and fats, as well as the nitrogenous foods, are now dissolved and made into emulsion, and prepared, in short, for absorption. The juices of the pancreas and of the intestine include powerful ferments, or *enzymes*. These are substances which cause chemical changes by their mere presence, *without being used up in bringing about these changes.* One of them deals with the starches and sugars in the food, another with the fats, another with the proteins, like white of egg.

The chyme—the pulped and semi-digested

food—moves slowly along the bowel. In the bowel wall are muscles which contract, and drive the contents slowly onward at about one inch a second. But the interior wall of the tube is now lined, not only with glands, but with little outstanding fingers, like (on a microscopic scale) the pile on fine velvet. The surface is, moreover, puckered into folds, to give a larger area, and myriads of the tiny fingers or *villi* dip into the chyme and absorb the nourishing matter. Altogether about sixteen square feet of absorbing surface are given in the small intestine, and it is there that most of our nourishment is taken into the blood or the lymph. The rest passes on into the "large intestine," a very much wider tube at its lower extremity.

It is just at this junction-point of small and large intestine that the vermiform appendix is given off from the tube. Its opening into the bowel is very narrow, and sometimes bits of hard food, such as fruit-seeds, get into it and set up inflammation. Now in certain vegetarian animals like the rabbit the appendix is at the end of a large and useful blind alley or cæcum. A good deal of vegetable matter is wrapped up in cell-walls of cellulose, and the digestive juices we have described have very little power to deal with cellulose. It has to be broken up by bacteria, in such a chamber as the rabbit's blind gut or cæcum. The human vermiform appendix is a remnant of the large magazine in which some coarse-feeding ancestor of man had the cellulose of his food dealt with by bacteria.

Most people are inclined to shudder when they hear of bacteria in their bodies, but it is only certain kinds of bacteria that pour poisons into the blood and cause disease. Each one of us houses billions of friendly bacteria in the large intestine. They do us no harm, however, but break up the cellulose (the husks of grain, etc.) and multiply prodigiously in the fetid, fermenting mass in the intestine. Some physiologists think that we should be better without the large intestine, but, while there is little food absorbed from it, much of the water we take up is absorbed there. In any case, there the structure is, and the wise man takes plenty of cereals, fruit, and green vegetables in his food, to keep it in a state of healthy activity.

§ 5

The Vital Fluid.

Let us return to the nutritive material which has been taken up into the system. The tiny organs on the bowel wall which absorb it pass most of it directly into the blood-vessels which they contain. It becomes part and parcel of the blood, and will now, after passing through the liver, be pumped round the body *for the various organs to select from it the nourishment they need.*

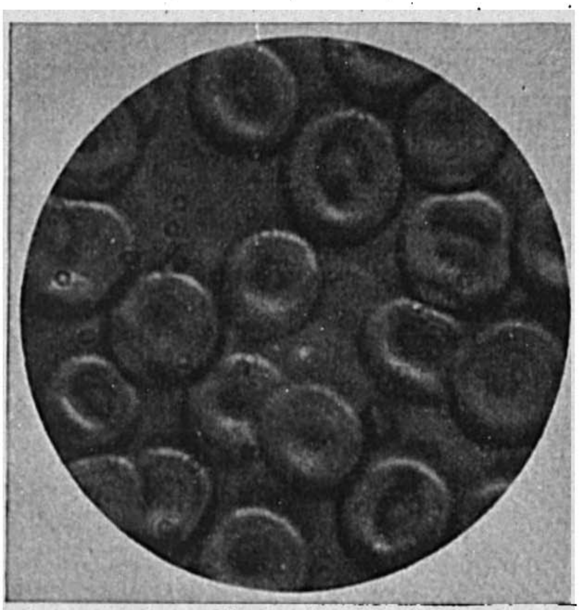
But blood is not the simple matter which it seemed to our ancestors; indeed, it has proved of late years to be full of subtle interest. If you prick your finger with a needle, and put a small drop of blood under the microscope, you see myriads of little disks, many of them in rows like columns of pennies, in a watery or yellowish fluid. The fluid—the serum or plasma—is the liquid food of the body and the medium for conveying away the soluble waste matter. The red disks or "corpuscles" are the bodies that convey oxygen from the lungs to the tissues. There are about five millions of them in every cubic millimetre of the blood of a healthy man—a woman's allowance is half a million less—and it is these which give the blood its red colour. We have about twenty-five trillions of them in all.

Thus the microscope discovered a new and unexpected complexity in the blood, and further research has shown that it is the iron-containing pigment in these red corpuscles which is chiefly concerned in the carriage of oxygen. There is very little iron in the blood, and it is absurd to think that we increase its quantity (once it is normal) by eating things "with iron in them," as people say. But what iron there is may be called a precious metal in the human body, and the red corpuscles have it in a form that still more or less baffles the chemist. There are believed to be something like two thousand atoms to the molecule in the red pigment (hæmoglobin) of the corpuscle! These disks, or corpuscles, are formed, mostly, in the red marrow of the bones, and, after serving for a few weeks, they are broken up in the liver or the spleen.

But this is only the beginning of the interest

Warfare in the Body.

of the blood. In the drop which we observe under the microscope there are, as we said, myriads of red corpuscles. in a yellowish fluid. It was found out some years ago that the serum is quite congenial to its own corpuscles, but that if we mix into it a little of the blood of some animal of a different kind, the serum of the first animal destroys the red cells of the second animal. Thousands of experiments were made, and it was found that the degree of action of one kind of blood upon another depended on the nearness or remoteness of relationship of the two animals. If they were nearly related, there was no destructive action. Naturally, the opportunity was soon sought to apply this new test of "man's place in nature," and it was found that his blood mingled amiably with that of the anthropoid apes!



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RED BLOOD CORPUSCLES OF MAN.

Each cell or corpuscle is a circular disk, on an average about $\frac{1}{3200}$ of an inch in diameter, and about one-fourth of that in thickness. More than a million will lie on a square inch. The broad faces are not flat, but slightly concave; so the corpuscles are thinner in the middle than at the margin. When seen edge-on they look like rods. Their colour is faint yellowish-red, due to the pigment hæmoglobin, which has a great affinity for oxygen. The mammalian red blood corpuscle does not show any nucleus except in the early stages of development. The white blood corpuscles are larger, nucleated, and irregular. The red blood corpuscles are mostly made in the marrow of the bones and mostly destroyed in the liver and spleen.

There is a third element in our drop of blood under the microscope, and this is the most interesting of all. Here and there in it, though hundreds of times less numerous than the red disks, there are what are called "white corpuscles," microscopic colourless roundish specks. When we study these specks closely, we find that they behave just like the very primitive microscopic animal known as the *Amœba*. They push out parts of their substance, and glide along. If there are bacteria in the blood, one of these corpuscles may be seen making its way to one of the intruders and slowly folding its substance round it. After the microbe is engulfed, digestion soon follows.

In other words, there is in the blood, besides the army of oxygen-carriers, a great army of defenders against bacteria. Let a tissue be injured somewhere, and the injurious bacteria find a footing and begin to multiply at an appalling rate. We are threatened with disease, if not death. The bacteria may destroy the tissue, or pour poison into the blood. But the "white knights" now gather from all parts to defend the body. They are brought, of course, by the flow of the blood, but they seem to have some sort of chemical sense for bacteria, and they crowd in the particular tissue which is threatened. A great struggle ensues, and the patient's temperature rises to "battle heat." If the white corpuscles succeed in devouring the microbes before they multiply to a dangerous extent, we are saved. But bacteria multiply at a terrible speed, and sometimes they beat the corpuscles and we pass into a perhaps dangerous illness.

Biologists had hardly ceased to wonder at this new romance of the blood when others were discovered. Bacteria produce a poison (or *toxin*) with which they taint the blood. But it was found that the blood produces an "anti-toxin," a chemical for neutralising the toxin; and after years of experiment the anti-toxin was prepared in the laboratory and injected into the blood. It also became possible to help the white corpuscles in the fray, or spur them on to it, so to speak, by preparing a sort of sauce—an *opsonin*, the man of science calls it—from dead bacteria and injecting it into the blood. The opsonin makes the living bacteria more attractive or palatable to the corpuscles, and our "brave defenders" go to work more vigorously. Sir Arthur Keith, in *The Engines of the Human*

Photo: Rischgitz Collection.

HARVEY DEMONSTRATING THE CIRCULATION OF THE BLOOD TO CHARLES I.

(From a Painting after Robert Hannah.)

William Harvey, 1578–1657, a graduate of Cambridge, who studied under Fabricius, the great anatomist of Padua. He demonstrated about 1616 that the blood passes through the body in a "kind of circle"; but he did not know of the capillaries which connect the arteries and the veins. He insisted on experiment as a basis of knowledge, and he made important observations on the development of the chick.

Body, refers to "the immense and movable armies of microscopic corpuscles which can be mobilised for police or sanitary duties. They swarm in the blood stream as it circulates round the body . . . it is extremely probable that one variety of them, if not more, are really errand-boys on their way to deliver messages or parcels, and that the gland masses which are built up in and around lymph channels serve both as nurseries for the upbringing of such messengers, and also as offices from which they are dispatched on their errands."

§ 6

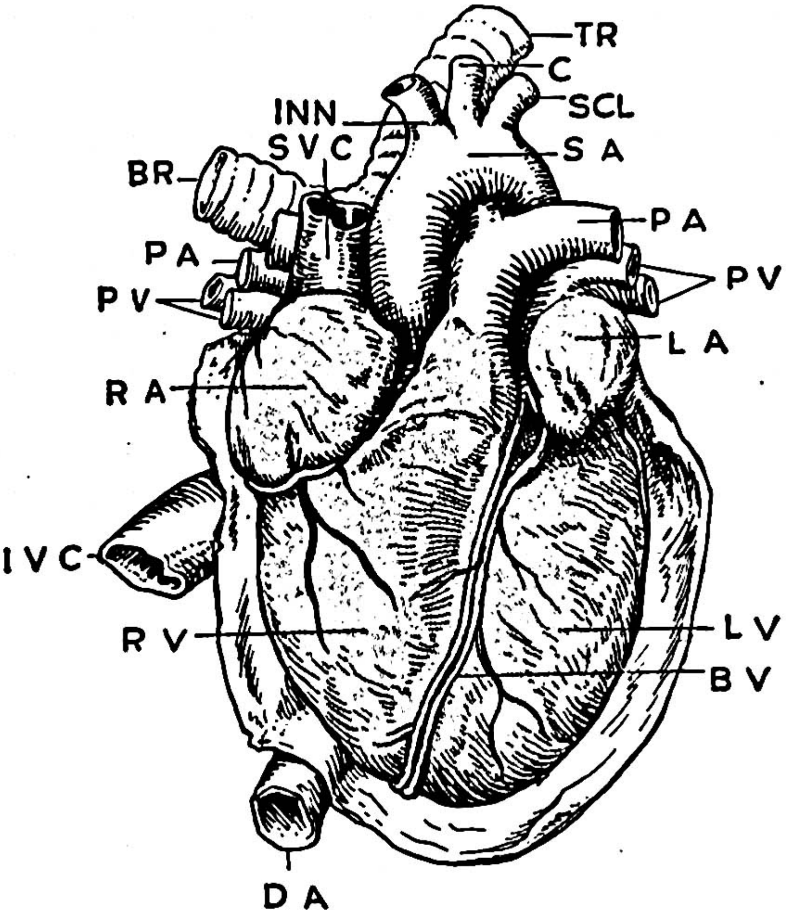
The Heart.

It is clear that the many-sided value of the blood depends upon its regular coursing through the whole body, and we have now to see how this is accomplished.

Until three centuries ago there was not a man in any civilisation who knew anything about this "circulation of the blood." The most learned physicians had the weirdest ideas about the function of the heart and the flow of the blood. Nowadays the essential facts are familiar. The heart, which one feels beating about the lower part of the breast-bone (though drawn a little to the left), is the central pumping-station. From it goes a great tube, or artery, which branches out—much as the trunk of a tree divides into branches, and finally into twigs—until its finest ramifications have carried the blood into the remotest tissues of the body, even into the teeth and bones. There the little twigs turn back, as it were, and become veins, and the veins from all parts join each other and at last bring the blood back to the heart.

In a sense it is as if the fresh-water circulation and the sewage circulation of a great city were managed from the same pumping-station. One set of pipes would convey water to every tap;

another set would bring back the foul water to the pump. The difference is that in the animal body the two sets of pipes join on to each other and form a continuous system. But, obviously, fresh and foul blood must not mix, and this has been secured by the evolution of a heart with the two halves completely separated from each other. We can trace the evolution of the heart by studying it in various types of lower vertebrates. In most reptiles the two halves are still imperfectly separated, and "mixed" blood (pure and impure, fresh and foul) goes to the greater part of the body. In the mammals and birds the separation is complete.



THE HUMAN HEART.

There are four chambers, two auricles or receiving chambers and two ventricles or driving chambers. The right auricle (R A) receives the impure blood from the body by two superior venæ cavæ (S V C) and one inferior vena cava (I V C).

The blood is passed into the right ventricle (R V), whence it is driven to the lungs through the pulmonary arteries (P A). From the lungs the purified blood returns by the pulmonary veins (P V) to the left auricle (L A).

From the left auricle it passes to the left ventricle (L V), whence it is driven up the systemic arch (S A) to the body. The systemic arch first gives off a right innominate artery (I N N, dividing into right subclavian and right carotid, to arm and head respectively). It then gives off a left carotid (C) and a left subclavian (S C L), to head and arm respectively. It is continued dorsally backwards to form the dorsal aorta (D A), the great artery distributing pure blood to the whole posterior body.

T R is the windpipe or trachea; B R, a bronchial tube carrying air to the lungs; B V, a blood-vessel on the wall of the heart itself.

The heart is a thick muscular pouch—with walls about half an inch at their thickest part in man—which has to drive the blood to the tissues on the one hand, and to the lungs for purification on the other. That is why it has separate halves. Each half, moreover, has a little chamber for receiving the blood (an auricle) and a larger chamber for pumping it (a ventricle), and valves are cunningly contrived at each opening so that the blood can flow only in one direction when the pump works.

So remarkable is the mechanism of the heart, that we do not yet know what regulates its "beat." There seems to be some mechanism in the heart itself for regulating it. Seventy-two times in every minute, in a healthy and resting man, the chambers draw their walls together and pump out the blood. There are tens of thousands of muscular fibres built so wonderfully into the walls that the chambers can close in from every side, like a man closing his fist, and give the blood a start that will carry it all round the body and back to the starting-point.

It is, of course, a mistake to say that the heart never rests. It rests, and recovers, between each beat. But its function is remarkable. As we said, it beats seventy-two to the minute when a man is resting. But let there be some sudden call for action, and, almost before you get from your chair, the great pump beats faster, as if it knew that the distant muscles and brain had now work to do and must have more blood. When we are sitting still, it throws five pints of blood (a little more than a third of all the blood in the body) into the arteries every minute. During a quick walk the heart pumps seventeen pints a minute; and the man who runs upstairs is asking his heart to pump thirty-seven pints a minute! During even less violent exercise than this, all the blood in the body (about fourteen pints) passes twice through the left ventricle of the heart and all round the body in a single minute.

From the left ventricle, the chief pump, the blood passes into a thick broad tube called the aorta. The elastic walls of this tube expand as the blood rushes in, and then slowly close again, driving the blood onward. In this way, and by the general resistance of the tubes (the arteries), the jerky discharge from the heart is converted into a steady flow after a time. The arteries branch out in every direction, and as they approach the tissues they have to feed they break into myriads of very fine tubelets, often not more than $\frac{1}{3000}$ of an inch in thickness. The wall of the blood-vessel has now to be so thin that the nourishing matter in the blood can flow through it to the tissues, and the waste matter from the tissues can get back into the blood. Even this is a far more complicated matter than is generally supposed. The cells in each tissue of the body must somehow select their own food and oxygen, and even the union of oxygen with carbon in the working muscle does not take place as we find it in ordinary combustion.

At the point where the artery subdivides into the finest tubelets (the capillaries), there is a wonderful apparatus, a sort of "stopcock," for regulating the supply of blood. Muscular fibres are coiled round the artery, and, as the artery enlarges or contracts, the supply of blood to that particular tissue is increased or lessened. When you sit down to a meal, for instance, the stopcocks are opened

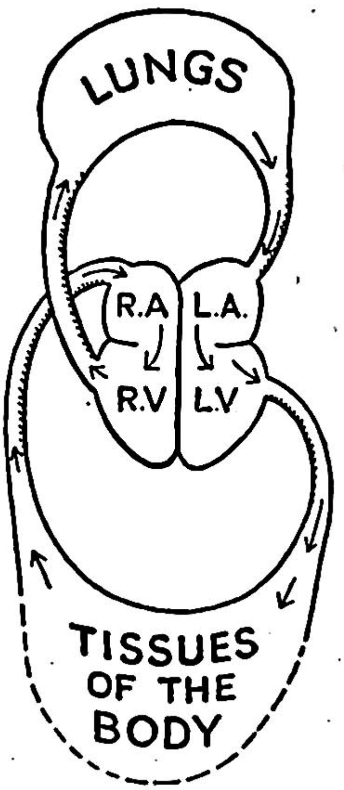


DIAGRAM OF THE CIRCULATION OF THE BLOOD THROUGH THE BODY.

Seventy-two times a minute the heart beats; that is to say, its muscular walls contract. Each half of the heart consists of two chambers: the auricle, which receives blood from the big veins, and the ventricle, which receives blood from the auricle and pumps it into the big arteries. Between the right and left sides of the heart there is no direct communication. Aerated blood is collected from the capillaries of the lungs and conveyed by the pulmonary veins to the left auricle, whence it passes to the left ventricle. Thence it is pumped into the great artery, the aorta, whose branches distribute it to every part of the body. Having given up much of its oxygen and nourishment to the tissues needing them, the blood is collected and conveyed by veins to the right auricle. From there it passes to the right ventricle, which forces it through the pulmonary arteries to the lungs, where it is aerated and again travels to the left side of the heart, ready to be again circulated. It will be noted that arteries are blood-vessels leaving the heart, while veins are blood-vessels returning to the heart. The arteries carry pure blood, except in the case of the pulmonary arteries to the lungs. The veins carry impure blood, except in the case of the pulmonary veins from the lungs.

A Wonderful Apparatus.

full to your digestive organs and partially closed against your muscles and brain. When you stand up and move about the room various muscles have to work, and the cocks are duly turned on to them. When your muscles need all the blood they can get, your brain and digestive organs get less. When you stand erect for some time, the regulative system has to see that blood does not accumulate in your legs at the expense of your head; but if you overdo it—if you stand long in a close crowd or a stuffy room—even this admirable system breaks down, and your brain, which is particularly sensitive about oxygen, runs short of blood. You "faint."

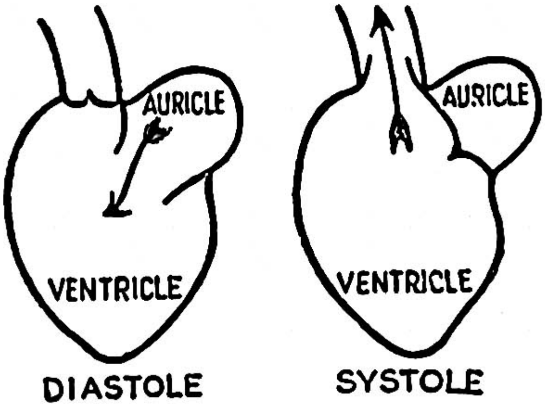


DIAGRAM ILLUSTRATING THE VALVES OF THE HEART.

During the period of contraction (systole) of either of the ventricles the valves which guard the opening of the big artery are open, whilst the valves at the gateway between auricle and ventricle are closed, thus preventing blood from being forced back into the auricle. During the period of relaxation (diastole) of the ventricle, the valves of the artery are closed and those between auricle and ventricle are open, allowing blood to flow freely from auricle to ventricle, but preventing back-flow from the artery.

Both auricles contract at the same time. Then both ventricles contract simultaneously. Then there is a short pause. Each complete cycle, including the pause, is a "beat"; and in a healthy adult the heart beats about seventy-two times in a minute.

Here again science has only made a great discovery to be confronted with a mystery. We know that there are nerves from the muscles of the arteries to the spinal cord, and that the stopcock we have spoken of is regulated by a reflex nervous message from the cord; but how these unconscious elements of the human mechanism work so perfectly together we do not know. When we remember how densely ignorant of all these things men were only a few generations ago, we may be sure that much will be discovered by our children and grandchildren.

Every year, indeed, brings new discoveries of a remarkable kind. We have already noticed that certain chemicals called "hormones," of which we shall speak more fully immediately, are produced in various structures (ductless glands) of the body, and "posted" in the blood, as it were, for a distant organ. One of these "hormones" comes into play in connection with the blood. When a man is setting about some prolonged and strenuous exercise, nerve-messages go to stimulate certain glands near the kidneys called the adrenal or suprarenal glands. They supply one of these chemicals (*adrenalin*) to the blood, and it passes round the circulating system until it reaches the small arteries. It closes the cocks and shuts down the supply to organs which are not at the time required to be active, and thus ensures a fuller supply to those organs which are called into strenuous exercise.

When the blood has passed through the tissues—given up its nutriment and received the waste carbonic acid gas and the soluble nitrogenous waste—the blood turns back towards the heart. It passes into a new set of fine tubelets or capillaries, and these unite in the veins. The veins have thinner walls than the arteries, as there is now less pressure, but they have a remarkable series of valves along their course. The blood cannot flow back—cannot go wrong. You can actually trace one or two of the valves on the veins of your arms if you try to force the blood back to your fingers. Little knots stand up here and there. So the blood courses steadily back and is poured into the opposite side of the heart to that from which it started. It enters the right auricle, and passes on into the right ventricle; and the next beat of the heart sends it to the lungs, where it gives up its carbonic acid and gets a fresh supply of oxygen.

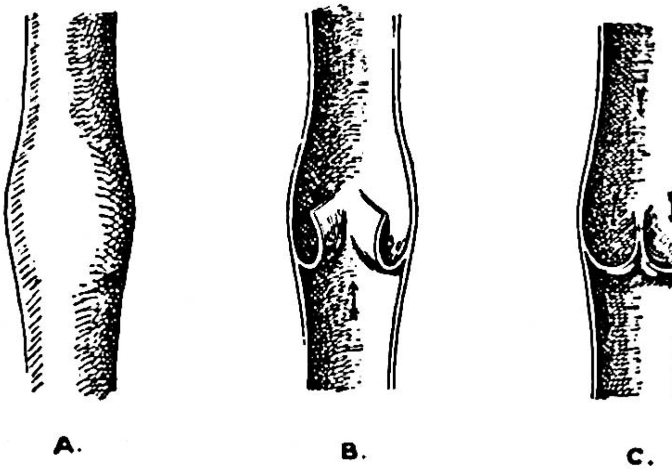
§ 7

How and Why we Breathe.

The blood has many functions. It takes fluid food to the organs and, in its red corpuscles, it carries oxygen. It has also to bring away from the organs the waste products of their activity, the carbonic acid (carbon dioxide), which is got rid of in the lungs, and the soluble nitrogenous waste, which is got rid of by the kidneys. The work that is done in the various organs—such as the muscles, nerves, and glands—may be roughly compared to the work done in a simple steam-engine. Fuel must be supplied; then oxygen (the essential element of air) must be supplied to unite chemically with the fuel and convert the energy which is locked up in it into heat and active work. The stomach supplies the fuel. The lungs, like the blacksmith's bellows, supply the draught of oxygen. If we do not forget that in the animal body the chemical action is far more subtle and indirect than in the furnace, this may be taken as a useful simple view of what goes on.

Let us follow the draught of air into the lungs and the blood. We saw that, for the food to become available to the tissues, the blood-vessels have to become finer and finer until at last their walls are so thin that the nutritive material can pass through them. It is the same with the air-passages through which we breathe. The air enters by the nostrils; we will suppose, at least, that the reader is sensible enough to breathe always through the nostrils, and teach his children to do the same. In the nose there is a warming chamber, richly supplied with blood (and the supply automatically increases in cold weather), and there is a sort of sieve or filter (the hairs in the nostrils) for "screening" foreign bodies from the air. Dry air is also moistened in the nostrils. There is a mucous membrane in it which is most useful if you treat it reasonably; but if you treat it unreasonably—if you pack yourself with others into a moist, stuffy, unventilated railway-carriage or small room—it will get gorged with blood and "boggy," and offer a good field for certain microbes, and—you will have a "cold in the head."

Behind the root of the tongue the air-way crosses the food-way and enters the windpipe or trachea. At this point there is the customary "door," automatically opening and shutting; and behind this delicate folding-door are the "vocal chords" which we use for speech. The windpipe divides at its base into the two bronchial tubes, one for each lung, and there are ingenious arrangements for dealing with dust or microbes that have got past the sentinels in the nose. There is a coat of mucus to intercept them (as a flypaper does flies), and there are countless microscopic lashes or cilia which bend and straighten rhythmically, beating towards the entrance, and thus gradually push out the intruder. If certain kinds of dangerous microbes settle on them, the glands pour out large quantities of mucus, and your lungs automatically blow it out at times—you have a "cold" and a "cough."



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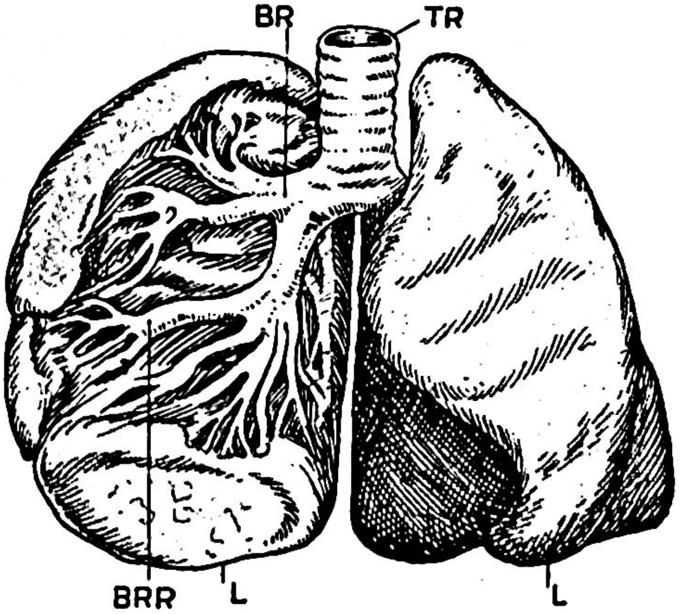
A, a swelling on a vein, indicating the presence of a valve within it. B, the vein laid open, showing the valves partly open: blood flowing in the direction of the arrow will have free passage between the valves. C, showing the valves shut: blood forced backwards in the direction of the arrows will find the valves closed against it.

In the lungs themselves the bronchial tubes branch out into numbers of fine tubes as the arteries do, and each tube ends in a score or more of little air-chambers. There are about six millions of these minute chambers (each about $\frac{1}{10}$ of an inch long) in the two lungs, and they are formed so as to give as much surface as possible. If we could open them all out and piece them together, we should have a total surface a hundred times larger than our skin. This is the wonderful contrivance evolved for bringing a large body of air into almost direct contact with the blood fifteen times a minute or more. In a deep breath we can take in a whole gallon of air, and even a normal breath takes in two quarts.

Nerve Messages.

But who attends to the working of this wonderful bellows while we are sleeping or are concerned with other matters? It is, of course, another of those automatic mechanisms which have been formed in the animal body during millions of years of trial and sifting. The lowest part of the brain, a part called the *medulla oblongata*, includes a nerve-centre which is sensitive to the carbonic acid in the blood and, stimulated by this, sends automatic messages to the muscles of the ribs and the midriff, or diaphragm. At each intake of breath twelve pairs of muscles work harmoniously in expanding the chest, and then other muscles pull the "bag" together again and expel the air. But how can the air extract the carbonic acid from the blood in so short a space? All such difficulties are provided for in the body-machine. You breathe out only a fifth of the air in your lungs every time. The little air-chambers automatically close if, by a strong effort, you try to empty your lungs. The exchange of gases is going on all the time. If, on the other hand, the muscles are working hard, and need more oxygen, the increased carbonic acid in the blood stimulates the medulla, and nerve-messages from it rain upon the lung-muscles until you "pant for breath."



THE WINDPIPE AND LUNGS OF MAN. (From a specimen.)

TR, the trachea or windpipe, supported by gristly rings. It divides into two bronchi (BR) entering the lungs (L). There they break up into finer and finer bronchial tubes or bronchioles (BRR), ending in little dilatations which are divided into chambers called "air-cells." On the walls of these the interchange of gases takes place. To the left side, as diagrams go, the lung is seen intact; to the right, partly dissected.

A man or woman engaged on sedentary work gets into a way of using the lungs to only about a tenth of their capacity. You understand the pale scholar and the anæmic girl in the cash-box. They provide too little oxygen, and the blood will not provide red corpuscles which are not needed. If such people will go for a good swinging walk, in air that is rich in oxygen, the blood will stream through their medulla, the nerve-centre at the base of the brain, and the lungs will open out.

The real "breathing" is, of course, deep inside the body. The little air-chambers have walls almost as thin as soap-bubbles, and a rich supply of similarly thin blood-vessels (capillaries) outside them. Through these thin walls the red corpuscles somehow extract the oxygen from the air, and the blood also gives off the carbonic acid. Then the blood streams back to the left chamber of the heart to be pumped through the body in the way we have described. When this blood finds itself in the thin-walled capillaries amongst the organs of the body, the red corpuscles yield their oxygen, and the blood returns to the heart with a new load of carbonic acid.

We have seen that this union of oxygen and food in the tissues may roughly be compared to what goes on in a steam-engine. It enables the organs to work—to do the work we describe here—and it produces heat. And in connection with this heat we employ, all our lives, wonderful mechanisms which even modern science has only partially mastered.

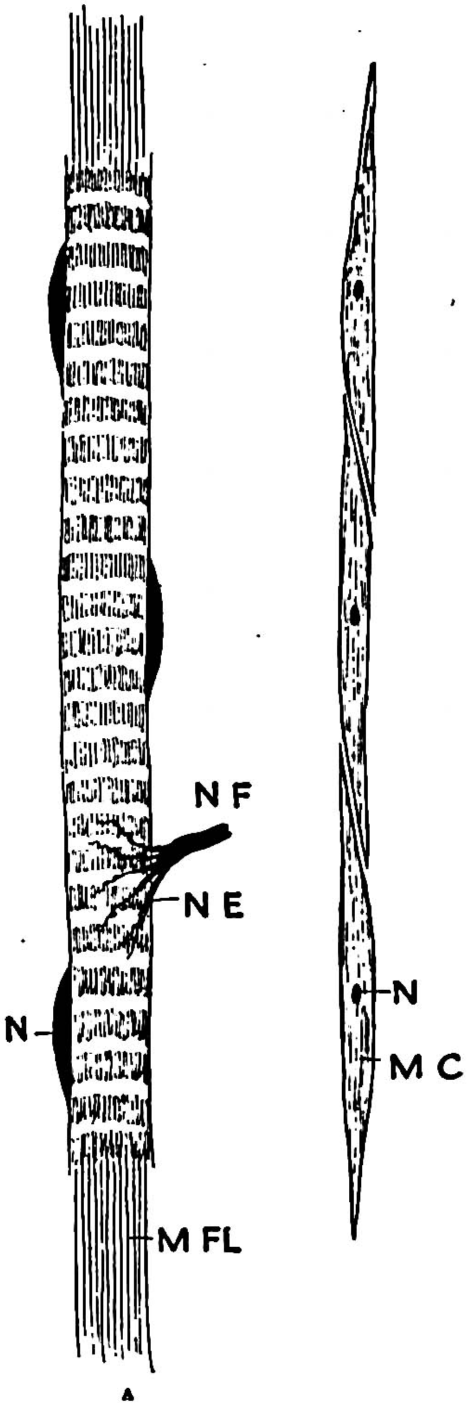
The blood must be kept at a temperature of (in a normal human body) about 98·4° F. When the air sinks very low in temperature, we shiver, or stamp our feet, or rub our hands. The shiver is an automatic warning to take exercise, to increase the combustion in the muscles. When, on the other hand, the outside temperature rises too high, we get the stopcocks of our arteries, which are tightened on a cold day, now opened wide, to let the blood's heat escape by the skin. If this does not suffice, automatic messages go from the nerve-centres to the millions of sweat-glands in the skin, and we "sweat." To raise the temperature of the watery fluid so much heat has had to be extracted from the blood. If the air is dry as well as warm, this mechanism is generally sufficient, but if we are in a "moist heat"—everybody knows how much worse it is than dry heat—the evaporation through the skin is checked, and the temperature of the blood rises until it may be too much for our brain. Even cold moist weather is trying. Our vitality is lowered in meeting it, and the cold-microbes get their chances to invade the body.

A wonderful mechanism surely! But there seem to be unintended effects at times of these ingenious devices. Take the "crimson flood" on a girl's cheek at some ugly word, or some word of praise, or some consciousness of guilt. The stopcocks to the capillaries in her cheeks are opened wide, but we can hardly suppose that some nervous reaction was evolved for that purpose. Sudden paleness is more intelligible. The cheek blanches in the face of danger, because the stream of blood has been directed to the brain and muscles that may have to meet the situation, and such temporarily useless organs as the cheek have the supply cut off.

§ 8

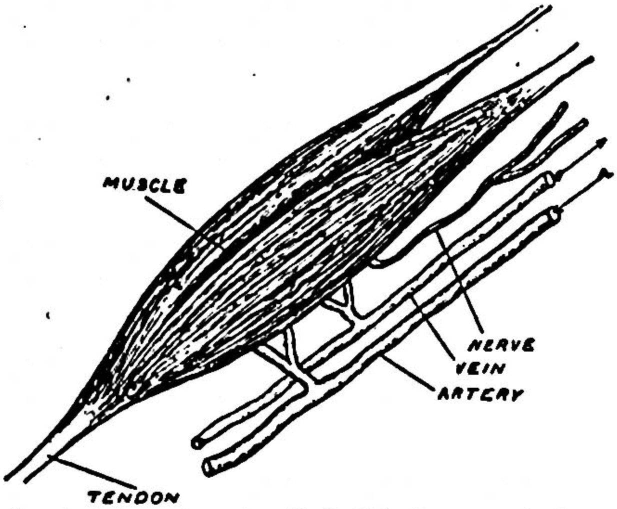
The Large Machines of the Body.

We may seem so far only to have concerned ourselves with organs which exist for the sake of other organs. That, in point of fact, is the nature of every organ in the "organism"; and indeed, it would be at least equally correct to say that bones and muscles, which one naturally thinks of as forming the greater part of the body, exist very largely for the purposes of digestion and respiration. Nutrition and reproduction are the oldest functions, the original functions, of the animal body. The elaborate skeleton, with its masses of muscle, has evolved to protect and minister to these fundamental activities.



A. A striped or striated muscle-fibre, quickly contracting, showing alternate dark and light bands. It is built up of very delicate fibrils (M FL). It is stimulated by a nerve-fibre (N F), which divides into an end-plate (N E) on the contractile substance. A striped muscle-fibre is due to the great elongation of a cell, with multiplication of nuclei (N), or to a fusion of elongated cells.

B Three smooth or unstriped muscle-cells (M C), elongated spindles, dovetailed into one another, each with a nucleus (N). There may be longitudinal fibrillation. Smooth muscle-cells are slowly contracting. They occur in such situations as the wall of the food-canal, the wall of the bladder, the wall of the arteries; and abundantly in sluggish animals, such as sea-squirts.



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A DRAWING OF THE BICEPS OF THE UPPER PART OF THE RIGHT ARM, SHOWING ITS TENDON, ITS BLOOD-VESSELS, AND ITS NERVE.

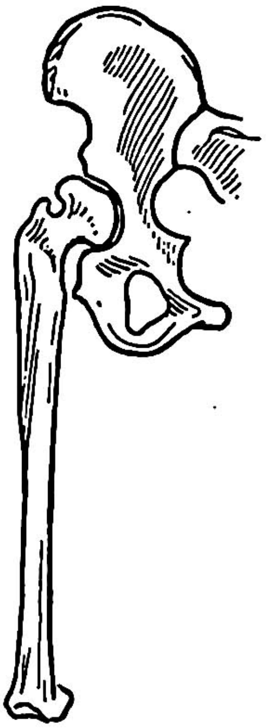
A tendon or sinew fastens a muscle to a bone; the artery brings oxygen and food-material for the muscle; the vein carries away carbon dioxide and waste; the nerve conveys the stimulus which provokes the muscle to contract. The biceps lies along the upper arm or humerus; its upper end is connected by two tendons with the shoulder-blade or scapula; its lower end is connected by a tendon with the radius, one of the bones of the lower arm; when the biceps contracts, becoming shorter and broader, as we can feel it doing, it raises the lower arm nearer the upper arm.

Of the distribution of the two hundred bones and two hundred and sixty pairs of muscles which form the great bulk of the body little can be said here. A catalogue of the bones would be a list of unfamiliar terms; and a catalogue of the muscles would be almost an essay in Greek. It is in the development and minute structure of bone that modern physiology is chiefly interested. As is now generally known, the body begins its existence as a single cell—a microscopic speck of living matter surrounded by a membrane—and the development of the body is due to the repeated and rapid multiplication of this cell (the fertilised ovum or egg-cell), until countless millions are formed. It is a "cell-state": a commonwealth of millions of living, active units bound together into a harmoniously working organism.

As this "protoplasm"—the jelly-like matter which composes cells—is soft, the beginner may wonder how it can build up such structures as teeth and bones. To understand this, as far as we do understand it at present, we have to remember that, as the cells of the body multiply from the original egg-cell, they also separate into different classes. We get muscle-cells, nerve-cells, bone-cells, gland-cells, and so on; and they differ remarkably in structure from each other.

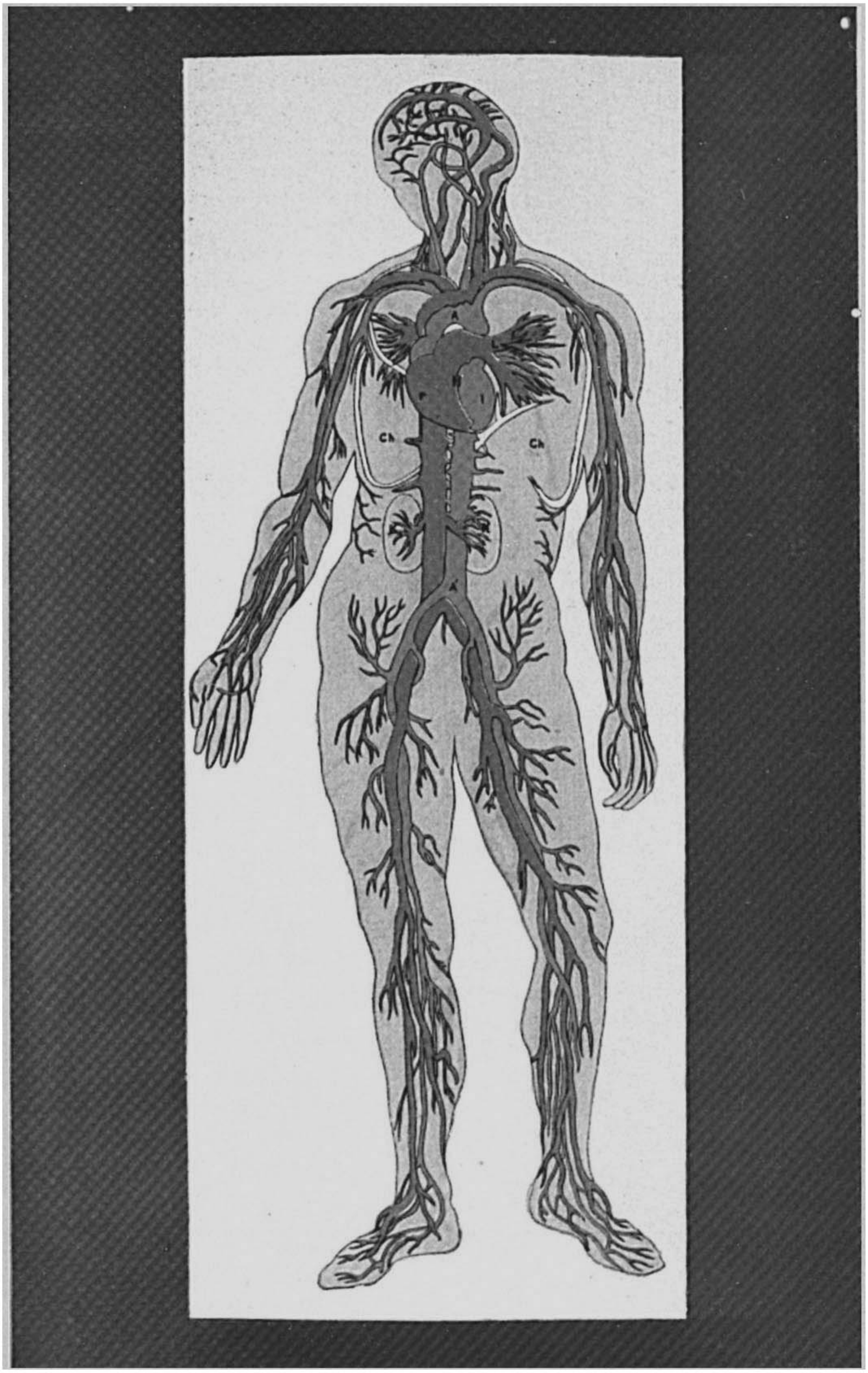
One contingent of these cells consists of the "bone-builders," and long before birth they begin to construct the supporting framework of the body. It is, of course, not bone at first. Frames of cartilage preceded bony frames in the course of racial evolution, and a cartilage-frame goes before bone in the development of the individual body. When the time comes, the bone-builders extract the lime-salts which have got into the blood with the digested food, and they use these in building up the bones. Sir Arthur Keith tells us that there are two million of these bone-builder cells at work in the thigh of a new-born baby, and that the number rises later to a hundred and fifty millions. They make the bones solid, then they change the interior into the light but strong texture with which everybody is familiar.

How is it that we feel no creaking, no jarring, or friction, of the two hundred and thirty joints by which our bones play upon one another? Here is another ingenious contrivance. A layer of cartilage remains over the end of each bone. It is dense, very elastic, and always well lubricated by one of the many remarkable



THE HIP-JOINT.

The thigh bone or femur is shown with its rounded head fitted into the socket (acetabulum) of the hip-girdle, which, in turn, is fixed to the sacral region of the backbone This hip-joint is a good example of a "ball and socket" joint with a deep cup; the shoulder-joint is on the same principle, but with a shallow cup. The head of the thigh-bone plays in the cup furnished by the hip-girdle and has considerable freedom of movement, but much less than the arm, which plays in a shallow cup.



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DISTRIBUTION OF THE MAIN BLOOD-VESSELS OF THE HUMAN BODY

The Arteries are shown in red, the Veins in blue. H, the heart ; *l*, left side, *r*, right side. Arising from the left ventricle of the heart is the main artery, the dorsal aorta (A). The letter is put at some distance from the heart, near where the vessel gives off the branches (in red) for the head and arms (carotid and subclavian arteries), and at the point where it arches backwards and downwards to pass through the chest and abdomen, till at A' it gives off branches for the legs. The veins are represented running alongside of the arteries. Beside the dorsal aorta runs the great vein—the inferior vena cava—going to the right auricle. At K is represented the position of the kidneys and their renal vessels. L represents the pulmonary veins of the lung, the only veins with pure blood in them. J, jugular vein, coming down the neck. Ch, outlines of the chest.

automatic lubricating systems of the body. The cartilage cells themselves in this case are converted into lubricating fluid when they die!

The muscular system which moves the bones is the red flesh with which we are familiar in the butcher's shop. Everybody who has carved a joint, and knows the importance of cutting "against the grain," is aware that one of these large muscles of the ribs or limbs of a cow consists of muscular fibres packed closely in bundles. There are 600,000 fibres in a single muscle of man's arm, the biceps. Each fibre is composed of many fibrils, the seat of that power of contractility which we very little understand. The body-machine is still full of problems and mysteries for us. Three hundred years ago the courageous anatomists of the later Middle Ages began to make out the structure of the organs. Later came a generation which dissected the organs into tissues. Later still, as the microscope improved, the tissues were dissected into cells, and the whole life of the organism was resolved into the co-operative life of millions of these units. But we now know that the secrets of the life of the cell lie partly in the molecules which compose the cells, and these are beyond the range of the most powerful microscope. We must wait and be grateful for what we know. Science never rests. On the very day on which I am writing this page the press announces the discovery of a new microscope, which takes us at a bound deeper into the mysteries of living nature!

Meantime, science has shown us that the muscular system is an automatic living mechanism of the most wonderful kind. To every muscle the arteries bear their streams of food and oxygen, the muscle-cells select their diet, and the veins take away the waste-products. On every muscle there are also the fine endings of some nerve from (generally) the spinal cord, and at the proper moment a discharge along the nerve causes the whole mass of the cells or fibres in a muscle to contract simultaneously and lift the bone to which the muscle is attached. The nerve-impulse itself is slight. It is merely like a match set to the great energy stored up like powder in the muscle. But when we remember the number of muscles needed for a single harmonious action—we bring fifty-four into play at each step in walking, and there are about 300 muscles concerned when we walk—the delicacy of their adjustment, the precise degree of action needed in each, we cannot but marvel at the ceaseless regularity and correctness of this unconscious play of muscle and nerve and nerve-centre. We can say only that it is broadly and beautifully illuminated by the story of evolution—a slow advance during millions of years, during which every individual with a defect is sifted out and every improvement means longer survival in the struggle for life.

THE ELBOW-JOINT.

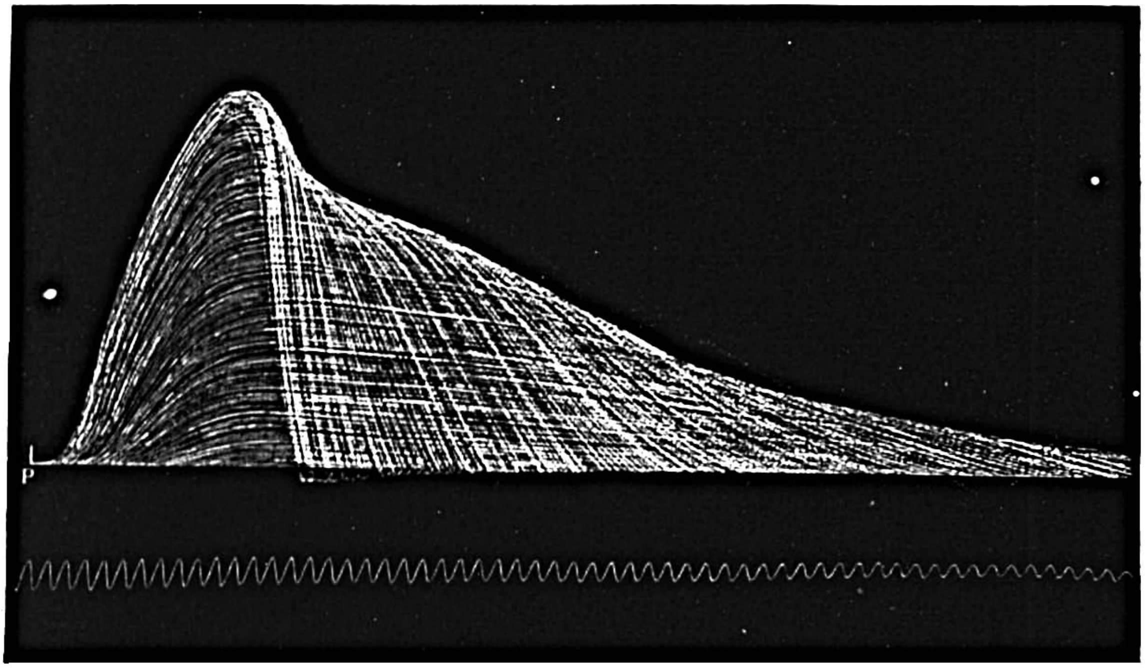
The elbow is a fine example of a simple hinge-joint. The lower end of the humerus works on the upper end of the ulna, which bears an elbow process or olecranon, which prevents the arm being bent back The biceps muscle, which is fixed above to the shoulder-blade, is inserted below on the radius, and bends the arm when it contracts. At the back of the elbow-joint is seen the triceps which straightens the arm when it contracts.

§ 9

THE NERVOUS SYSTEM AND THE BRAIN-CENTRE

The Nervous System.

Most wonderful of all structures in the body-machine, and most difficult to understand, is the telegraphic system—the nerve-threads or "wires" and the central stations in the brain, the spinal cord, and certain other clusters of nerve-cells. A unified cluster of nerve-cells is called a ganglion



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INFLUENCE OF FATIGUE ON THE CONTRACTION OF A MUSCLE.

The muscle is made to write a series of curves, P being the point of stimulation; the lower separate wavy line is the time-tracing, the waves indicating hundredths of a second. The point is this: For a time the contractions improve, becoming more and more vigorous, with higher and higher steep curves. But by and by the contractions get less and less vigorous; they take longer and longer; the curves get flatter and flatter. Finally the muscle ceases to contract at all.

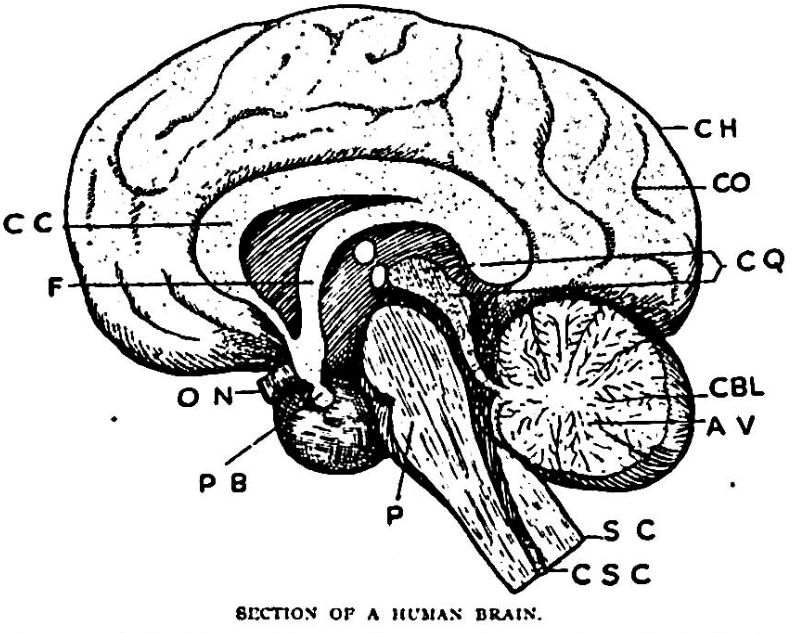
or nerve-centre. In the simplest forms of life there is no nerve, no muscle, no mouth or stomach. The microscopic unit is one single cell—a bit of jelly-like living matter enclosed in a more or less definite membrane. Each and every part of it digests food, contributes to the movement, and is sensitive to the surroundings. In the course of evolution there arose larger organisms with *bodies*, with millions of cells bound together in harmony, *showing division of labour*. Some cells specialise on nutrition, some on reproduction, some on locomotion, and so on. Some of these cells specialise on sensitiveness, and thus arise nerve-cells. Then some specialise on one particular kind of sensitiveness, and there appear patches or pits in the skin, one sensitive to light, another to smells, and so on. Further advance unites these various centres by nerve-fibres, and at last a central telegraph station, a long tract of nerve-matter, connects up the various sense-centres and the muscles and glands. When a backbone is evolved, the main tract of central nerve-stations is enclosed in it; and, as life advances, the upper part of this "spinal cord" swells into a brain and is protected by a skull.

This interesting story of the evolution of the brain and sense-organs deserves to be told at greater length, but this slight outline may serve at present for our understanding of the essential nature of the nervous system. There is, as we said previously, a postal system and a telegraphic system in the body. Certain organs discharge certain chemicals (hormones) into the blood, and the blood delivers them to distant organs which are thus set to work. Obviously, this postal system would be too slow for the purposes of ordinary life, and so the telegraphic system is richly developed. Suppose that in bathing you tread on a sharp stone. In a fraction of a second a nerve-thrill flashes from that part of your foot to a certain centre in the spinal cord, and a return thrill causes the muscles of the leg to contract, thereby jerking back the foot. In an animal far down in the scale like the octopus this nerve-message goes at about eighty inches a second; in the frog the speed has worked up to ninety feet a second; in man it reaches about four hundred feet a second.

In the case of man the nerve-message often goes on to ring a bell in the brain, as it were—to announce itself in consciousness—but the greater part of the body-machine is run, as we have seen, by automatic action, and we will first master this. We have spoken repeatedly of "reflex action." We mean by this nervous action without conscious effort. The message that goes to the brain or spine is automatically "reflected," along a different "wire," to the muscles or glands. When a piece of dust blows against your eyeball, one nerve sends some sort of thrill to a centre in the brain. Within a very small fraction of a second this message passes through a nerve-centre in the brain, and another thrill comes back to the muscles of the eyelids. Nearly the whole body is connected up, generally through the spinal cord, by an automatic nervous machinery of this kind. For the muscles of the head and face the nerve-centres are in the brain.

The nerve-cells (or neurons, as they are often called) have a cell-body and outgrowing fibres or "wires." Each cell has two or more fibres running out of it, and these in most cases end in brushes of still finer threads. The nerve-cells are, therefore, particularly suitable for communicating with each other. In the brain and spinal cord especially each cell runs into a little brush or tree of fine fibres, and they interlock with each other. In the nerves that carry messages or commands to the muscles and glands many long fibres are bound up into bundles by a sheath. Inside each fibre there is a mysterious central channel, the axis cylinder, probably of a liquid nature.

What the real nature of a nerve-thrill is we do not yet know. It is accompanied by electricity, but it is not itself an electric wave, for such a wave would travel more than a million times faster than the nerve-message does. The nerves are also peculiar in the fact that they never get tired (as long as they are well supplied with oxygen), and physiologists have not been able to discover any definite chemical change in them. Even the production of carbon dioxide is



SECTION OF A HUMAN BRAIN.

Nerves entering the brain F is a longitudinal bridge of fibres, called the fornix. It makes the roof of the optic thalami region, or third ventricle. Behind the fornix are seen two transverse commissures cut across. C Q, the corpora quadrigemina or optic lobes. C H, the fore-brain or cerebral hemispheres, showing internal indications of convolutions (C O).

CBL, the cerebellum, with an internal pattern (A V) called the arbor vitæ This is due to the folding of the nervous tissue into a number of lamellæ, which give off secondary plaits.

S C, the spinal cord. C S C, the cerebro-spinal canal continued down the centre of the spinal cord.

P, the pons Varolii, a bridge forming a sort of transverse floor to the cerebellum. Behind P is the "bulb" or medulla oblongata.

P B, the pituitary body, a nervous and glandular body growing down from the floor of the optic thalami region, or third ventricle. O N, the optic nerve.

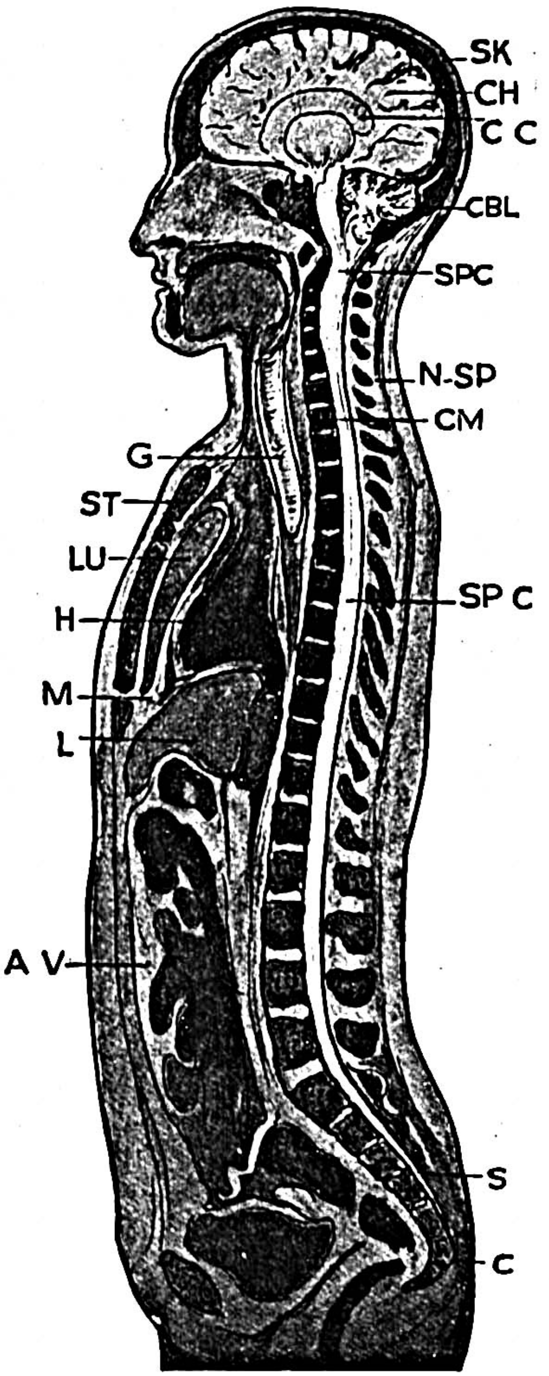
questionable. Sleeping or waking, the wires are always alive, yet physiologists have not found that any heat is produced in connection with their activity.

The Brain-centre.

It is otherwise with the masses of nerve-cells which make up the great brain-centres. Everybody knows that these grow tired, and must have a period of rest and recovery. Sleep is, however, still a puzzling phenomenon, and no theory of it can be regarded as satisfactory. All that physiologists are generally agreed upon is that the blood-supply to the brain is checked, and this lessening of the supply of oxygen (as to which the brain is particularly sensitive) lowers the vitality of the organs of consciousness. About the end of the first hour of sleep (which is the real "beauty-sleep") the brain-life is entirely suspended, and the blood is busy feeding the tired muscles. Some hours later more blood seems to return to the brain, and we get partial consciousness, uncontrolled by intellect, in the form of dreams. In a few individuals there may be, instead of a partial return of consciousness, an awakening of the power of automatic response to stimulations. They are apt to "walk in their sleep."

Our knowledge of the brain is now a special and formidable branch of science; it will be referred to later when we come to deal with Mental Science.

"In some way that we do not understand, our personality is more bound up with our nervous system than with the rest of our body. Our quickness or slowness, alertness or dullness, cheerfulness or gloominess, reliability or fickleness, good-will or selfishness, are wrapped up—in our ordinary life inextricably—with our very wonderful nervous system. Some people believe that our inmost self uses the nervous system as a musician uses a piano, and compare the disorder of mind illustrated in the delirium of fever, or the decay of mental vigour in the aged, to disturbances or wear and tear in the instrument. Others think that the inner life of consciousness—feeling, thinking, and willing—is one aspect of our mysterious living, and that the physico-chemical bustle that goes on in the nervous system is the other aspect of the same reality. The two aspects are inseparable, like the concave and the convex surfaces of a



VERTICAL SECTION THROUGH THE HEAD AND TRUNK OF THE HUMAN BODY.

SK, the skull; C H, the cerebral hemispheres of the brain; C C, the corpus callosum, a bridge of nerve-fibres binding the cerebral hemispheres together; CBL, the cerebellum. SP C, the spinal cord; N SP, neural spines of the vertebræ; C M, a centrum or body of a vertebra; S, the sacral vertebræ fused; C, the coccyx, a fusion of post-sacral vertebræ; A V, intestine and other abdominal viscera; L, the liver; M, the muscular midriff or diaphragm, separating the abdominal cavity from the chest cavity; H, the heart; LU, the lung; ST, the sternum or breastbone; G, the gullet or œsophagus. From a specimen.

dome; but no metaphor is of any use, the relation is quite unique.

"This is one of the oldest of riddles, and Tennyson made 'The Ancient Sage' say:

> 'Thou canst not prove that thou art body alone,
> Nor canst thou prove that thou art spirit alone,
> Nor canst thou prove that thou art both in one:
>
> For nothing worthy proving can be proven,
> Nor yet disproven.'

"Yet three things seem to us to be quite certain: (1) Our nervous system is a scientific actuality that can be measured and weighed; it is complex beyond our power of conception, if only because of the millions of living units which it includes; it is the seat of an extraordinary activity which baffles the imagination. No theoretical view can stand that is subversive of the fundamental reality of our nervous system. (2) Even more real, however, if there are degrees of reality, is our inner life of consciousness, our stream of thoughts and feelings, desires and purposes. It is our supreme reality, for it includes all others, and no theoretical view can stand that is subversive of this reality. (3) But the third certainty is that organism and personality, body and mind, nervous metabolism and consciousness, are in the experience of everyday life interdependent. If it is a relation, there is nothing to which we can compare it; if it is a unity, it is equally unique. We are mind-bodies or body-minds; sometimes we feel more of the one, sometimes more of the other."[1] That, however, as we have seen, will form the subject of a later chapter.

We may note here that it is a popular fallacy to suppose that all the contents of the skull are concerned with thought and feeling, or that a large head means a large capacity. The bulk of the matter in the cranium has nothing to do with thought. It is only a very thin rind or cortex of nervous matter, about a ninth of an inch thick on the average, covering the fore-part of the brain (from the top of the head to the base of the forehead) which is the organ of consciousness. But this precious cortex is an intricate structure made up of 9,200 million nerve-cells, and it is in man folded and creased so as to pack as much surface as possible within the limits of the human skull. Round this central area are the nerve-centres for controlling the muscles of the head, face, eyes, tongue, and the like; and the centres for receiving the reports of the eyes, nose, and ears are also in the brain. In a man who weighs 150 lb., the nerve-cells of the brain-cortex would weigh about $\frac{1}{1000}$ part of the total, but this small part controls the whole.

At the back of the head is the cerebellum, or "small brain": the chief centre for co-ordinating the movements of the muscles so as to produce harmonious action. If it has been injured in a bird or a dog, the animal can no longer stand up or maintain a balance of movement. All day long the cerebellum must be receiving countless messages from all parts of the body and directing our three hundred muscles to co-operate. It is entirely automatic, yet no central telegraph station in the world is so busy or so accurate. It also in some way maintains the tone of the muscles.

Below the cerebellum is the medulla, which, as we saw, is the organ for controlling the muscles of the chest that cause breathing. It has,

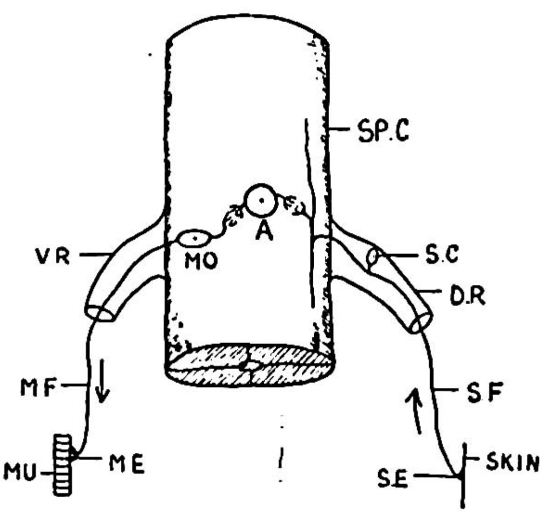


DIAGRAM ILLUSTRATING REFLEX ACTION IN MAN OR ANY BACKBONED ANIMAL.

From a sensory nerve-ending (S E) in the skin, a stimulus passes up a sensory nerve-fibre (S F) to a sensory nerve-cell (S C) in the spinal ganglion of a dorsal or afferent root (D R) of a spinal nerve. The fibre, continued from the sensory nerve-cell, divides in the spinal cord (SP C), and the message passes on to an associative, intermediate, or internuncial nerve-cell (A). Thence it is shunted to a motor nerve-cell (MO), from which a command passes down a motor nerve-fibre (M F), issuing by a ventral or efferent root (V R) of a spinal nerve. The motor nerve-fibre ends in a nerve-plate (M E) on a muscle-fibre (MU), which is stimulated to contract.

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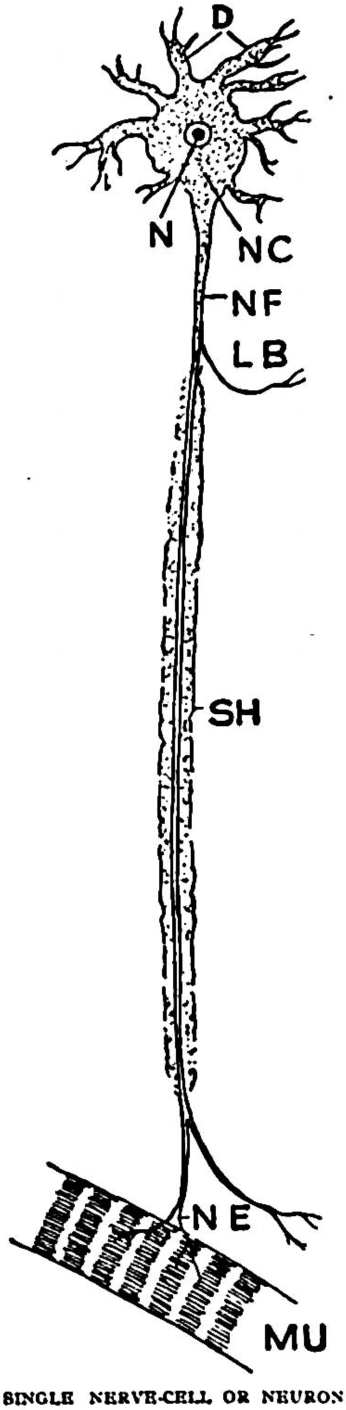
[1] Professor J. Arthur Thomson, *The Control of Life*.



A SINGLE NERVE-CELL OR NEURONE.
(After Stöhr.)

N is the nucleus of the cell; N C, the central cell-substance or cytoplasm. The nerve-cell communicates with others by means of fine protoplasmic branches or dendrites (D). It gives off a nerve-fibre (N F) to a muscle (MU). This fibre has as its essential part an axis cylinder or core, surrounded by a medullary sheath (SH) of a fatty material; and outside this there is a clear membrane called the neurilemma. It will be observed that the medullary sheath is not developed at the origin or at the end of the nerve-fibre. A lateral branch of the fibre is shown (L B) and the ending (N E) on the muscle.

however, much more work to do than this. It has some control of the heart and blood-vessels, and it influences movement in the alimentary canal from the salivary glands to the small intestine. We must remember that these hind-parts of the brain are the oldest. The cortex—the nervous matter connected with mental life—is a later acquisition.

And the oldest part of all is the long cord of nerve-cells which is enclosed in the spinal column. Along this are the various centres for working automatically the great muscles of the trunk and limbs and abdomen. Pairs of nerves leave it at intervals, and all day long these are receiving messages and issuing orders. It has an extraordinary power of automatic learning. Watch the baby learning to adjust its muscular actions to its desires or feelings, or a girl learning tennis or typing. In a short time the machinery will react promptly and perfectly to the stimulus. It is through the spinal cord that the brain can influence movements which are usually automatic.

We cannot discuss here how far the bodily features may serve as indices of mental character, whether the face, the eyes, the shape of the head, or the hands—an interesting chapter on the subject will be found in Sir Arthur Keith's little book, *The Human Body*. There is no correspondence, he tells us, between the functions of the various parts of the brain, so far as we yet know them, and the overlying parts of the head to which "phrenologists" have assigned definite functions. Some day we may be able to add to our knowledge of a man's character derived from observation of the expression of his face, his words and actions. "The day may come when by looking at the brain, or even at the skull which encloses it, we shall be able to tell the capabilities of a child or a man, but we have not yet reached that point." Neither is it true that the lines of the palm of the hand can be "read" as guides to the future: palmistry is childish make-believe.

§ 10

THE ORGANS OF SENSE

Another section of this work tells how our wonderful sense-organs were slowly evolved, and it is enough here to observe that they

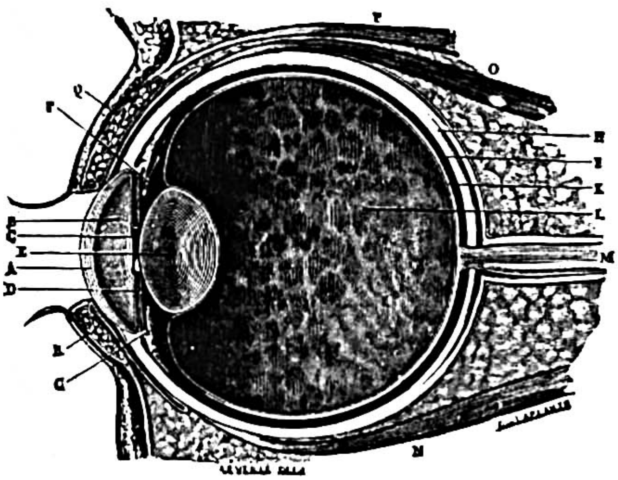
The Organs of Sense.

began as simple sensitive patches in the skin which, in the course of millions of years, have grown into elaborate organs. They are the sentinels of the commonwealth of cells. For ages theirs was the vital function of locating food and announcing danger. Now, in man, they are the chief channels of those glimpses of nature which the mind unites in the marvellous structure of modern science.

The skin, to begin with, is crowded with little organs of sense. Nerves from the great centres branch out in every direction, and the fine twigs at last end in sensitive bulbs underneath the skin. The most numerous of these are for the purpose of announcing "pain." We speak of pain as something in the body-machine which we could very well spare, but a little reflection will soon tell us that it is a most benevolent institution. It announces some danger which, if it were not thus indicated by the ringing of the bell in the brain, would not be noticed, and might become fatal. Other little bulbs, especially numerous on the palm-side of the fingers, minister to the sense of touch. Others feel cold, and a different set experience heat. By careful testing, the reader can find for himself that these sensations are localised in different areas on his arm. There are other nerve-endings again for the sense of pressure.

Other sensitive bulbs, which line part of the mouth, are the receiving organs for the sense of taste. Little oval bodies stand up like a close regiment of diminutive soldiers on the upper surface of the tongue. Each of the internal cells of these "taste-buds" ends in a hair-like process, and these processes touch the nerves which convey their particular stimulation to the brain. Probably different flavours are perceived by different nerves. The tip of the tongue is richer in the little bulbs that appreciate sweet things, while the back part is richer in the means of recognising bitterness.

Substances must be in a liquid form to announce themselves to taste. For the sense of smell, on the other hand, they have to be broken up into very fine particles like a gas. Nerves from the olfactory centres in the brain branch out in the membrane which lines the upper part of the nasal cavities, and this membrane includes numerous sensory nerve-cells which act as sentinels against dangers which announce themselves in the air. An odorous body is one which gives off minute particles of its matter into the air. The sense of smell was once of the gravest importance in the animal economy, and even in men it is so highly developed that they can detect a speck of musk diluted in eight million times as much air. A very strong offensive substance like mercaptan can be "sensed" even if there is only one grain to twenty-five billion times as much air. In man, however, the sense of smell is degenerating, and many individuals have it very feebly.



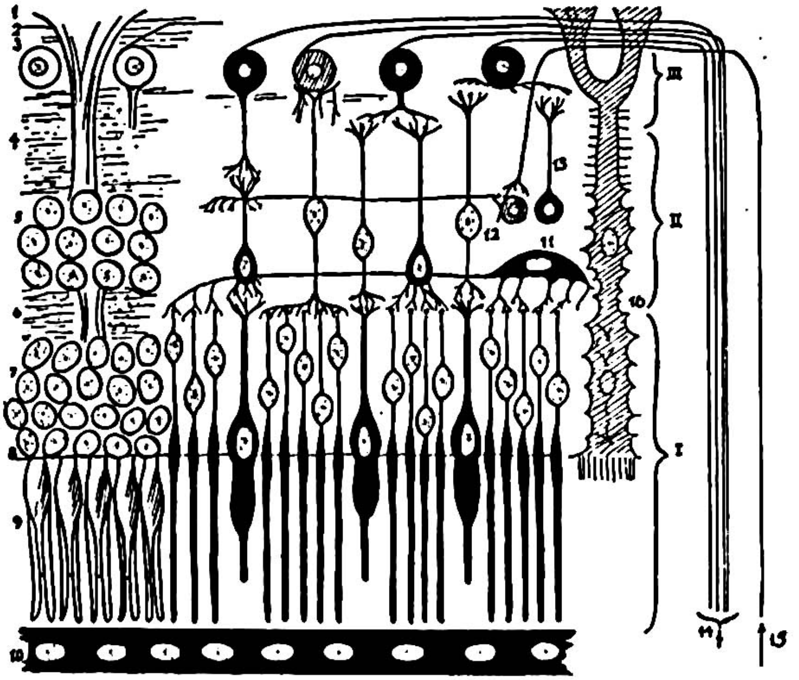
From "The Household Physician," by permission of Blackie & Son, Ltd.

REPRESENTATION OF A VERTICAL CUT THROUGH THE EYEBALL IN ITS SOCKET.

In the figure, muscles (P, O, N) of the eyeball are shown. A is the cornea; it closes the front of the anterior chamber (B), which is filled with aqueous humour and the back wall of which is formed by the curtain of the iris (D). In the middle of the back wall is the opening of the pupil (C), through which is seen the lens (E). Behind the lens is the posterior chamber (L), filled with vitreous humour. Entering the eye from behind is the optic nerve (M), which is distributed to the retina (K). The posterior wall of the eye shows from within outwards the image-forming retina, the dark choroid with blood-vessels (I), and the firm protective sclerotic (H).

The Sense of Vision.

Most important of all the senses is that of vision, for nearly all the ideas of things in the mind of an ordinary person are visual images. The essential part of the mechanism of this sense is the eyeball and the nerve which goes from this to the sight-centre in the brain. The eye is a camera of a most remarkable description. It is a roundish ball made of dense and



DIAGRAMMATIC CROSS-SECTION THROUGH THE RETINA OR PERCIPIENT LAYER AT THE BACK OF THE EYE. (After Hesse.)

The figure gives some idea of the intricacy of this layer, which is not thicker than the paper of this book.

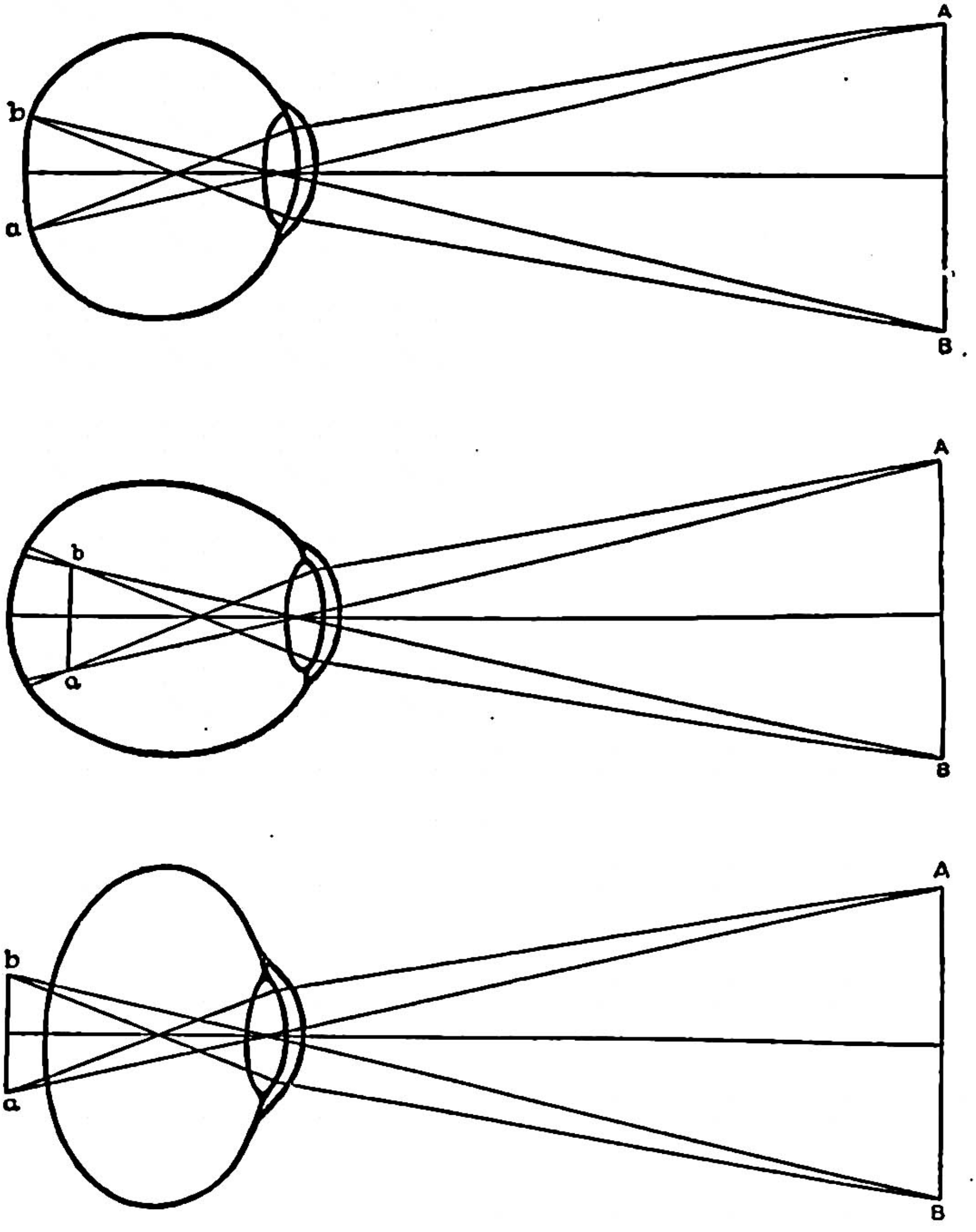
1. Inner or anterior limiting membrane, next the vitreous humour in the cavity of the eye. 2. A branch of the optic nerve dividing up. 3. A layer of ganglion cells. 4. An inner layer of nerve-fibres. 5. A layer of bipolar cells (so-called "inner granular layer"). 6. An outer layer of nerve-fibres. 7. Layer of visual cells (so-called "outer granular layer"). 8. Outer or posterior limiting membrane. 9. The rods (longer and thinner) and the cones (shorter and broader). 10. Pigment layer of the retina. 11. Tangential cells. 12. Bipolar cells. 13. An amacrine cell. 14. Centripetal fibres of the optic nerve. 15. Centrifugal fibres of the optic nerve. 16. Muller's supporting cells. I, II, III, the three areas of nerve-cells in the retina.

It is not in the least within the scope of this work to explain the minute structure of the retina; the figure has been introduced to give some impression of the complexity of the vital architecture. The essential fact is that the rods and cones somehow convert the pulses of the luminiferous ether into stimulations of the fibres of the optic nerve.

strong fibrous tissue, opaque for five-sixths of its surface, but transparent in the one-sixth which bulges out in front, as the cornea. To the interior of the cornea, separated from it by a watery fluid, there is a delicate curtain which hangs over the transparent "window" in front and forms the variously coloured iris.

This curtain is a wonderful arrangement for adapting the eye to the intensity of light which falls on it. Fibres of muscle are so ingeniously distributed in it that it can almost close the opening in a strong light, or open it wide when the light is fainter. The "iris diaphragm" with which the photographer regulates the entrance of light into his camera is merely a poor imitation of it. Moreover, it contains pigment cells, which may be crowded when the light is strong or fewer in number when the eye wants as much light as possible. So we get the black eyes (eyes rich in pigment, to mitigate the light) of the southerner, the blue eyes (with little pigment) of the dweller in the darker northern lands, and every intermediate shade and combination of them.

Behind the circular window, the pupil, is the crystalline lens, which, unlike any lens that man can make, can be altered by fine muscles so as to focus itself for any distance. Other muscles and tendons are attached to the outside of the eyeball, and they automatically turn it in the direction we want. Some men of science have found many defects in the eye, and there are defects: but when one thinks of the unconscious agencies that have built up this wonderful camera, and work it automatically every moment of our waking lives, one is not disposed to cavil.



These three diagrams show the situation of the image in a normal eye, in the myopic or short-sighted eye, and in the hypermetropic or long-sighted eye. In the normal eye, the image a b is clearly produced on the retina at the back. In the short-sighted eye, the eyeball is too long and consequently the retina—or receptive tissue—is behind the clear image. In the long-sighted eye, the eyeball is too short and consequently the clear image is beyond or behind the retina.

But the most wonderful part of it is the "sensitive plate" at the back of the eyeball. A semi-transparent membrane, which we call the retina, lines three-fourths of the interior of the eyeball (which is filled with fluid), and it is particularly developed at one spot, the real seat of distinct vision. On this "yellow spot" in each eye the rays of light form an inverted image of the object at which we are looking. The stereoscope enables us to understand how the images of the two eyes are blended, and how they enable us to see nature more perfectly.

Vision, as might be expected is still very imperfectly understood. The retina is a very complex layer of delicate nerve-cells, in which certain parts that are known as "rods" and "cones" seem to be the essential elements. There seems to be chemical action, though whether there are three distinct chemicals for the three primary colours, or one chemical that breaks into separate colours, or what happens, we do not know. It is generally suspected that colour-vision is connected with one or more fine chemicals which may be lacking in "colour-blind" people. However that may be, the nerve-layer closes up at the back of the eye and, as the optic nerve, conveys the images of things in some way to the conscious centre. What precisely travels along the nerve we cannot say, but to imagine that an image or picture is conveyed is to imitate children who think that words travel along a telegraph wire.

The Sense of Hearing.

The organ of hearing is not less remarkable than the eye. We have already seen that the external ear is, to use the cautious words of Professor Starling, probably of no use whatever. In cases where it has been cut off the sense of hearing was not affected at all. But it was useful and mobile in an earlier ancestor of man. From it, in any case, a narrow channel about an inch long, protected against adventurous insects by wax secreted by its glands, conducts the waves of sound to the real ear.

At the outer end of this passage the sound-waves beat upon a sensitive drum, the tympanum, a membrane of a most ingenious construction. This membrane must not have a period of vibration of its own. It must respond readily and immediately to every sort of wave that impinges on it. It is therefore so constructed that each part of it has a different period of vibration, and it is further "damped" by a little bone pressing against it on the other side. The pressure of air on the outside of the drum, which must alter with changes of pressure outside, is regulated by a channel (the Eustachian tube) running to it from the roof of the mouth.

Three little bones (the hammer, anvil, and stirrup) convey the vibrations of the drum to another drum, which is stretched across the entrance to the real ear inside the skull. As the waves of sound impinge on the tympanum and set it vibrating, the three little bones work together and repeat the vibrations on the second drum, the "oval window." Beyond this is a coiled shell which contains the real organ of hearing—a large number of hair-cells (the "organs of Corti") interlacing with the fine fibres of the auditory nerve. The vibration of the "oval window" agitates the fluid inside this organ, and the hair-cells communicate this movement to the nerves, which then convey it to the brain. Once more we have a mechanism full of ingenuity in every part, and brief descriptions of this kind are almost unjust to the various organs of our body; but to-day we should require a large volume to give an account of our knowledge of the brain and sense-organs alone. We have referred to the three small bones of the ear by which the waves of sound are conveyed to the inner ear. "The history of these bones is strange. The hammer was at an early stage of the evolution of mammals a part of the lower jaw; the anvil was the bone on the base of the skull, with which it articulated. When mastication and molar teeth were evolved in the ancestry of mammals, a new joint was formed in the lower jaw, and these two bones—the hammer and the anvil—were taken into the service of the ear."[1]

§ II

THE DISCOVERY OF HORMONES

Remarkable Discoveries about the Glands.

A physiologist would class the different parts of the body as bones, muscles, nerves, and glands, and we have in conclusion to say something about the last. We have already spoken of the myriads of tiny tubular glands which line the alimentary canal. Another mass of tubular glands make up the essential part of the kidneys. They really form a filter of a remarkable pattern. Arteries bring the blood to the kidney tubules, which are stimulated to action by the blood. Each—by vital action, not a mere physical process—takes out of the blood the fluid nitrogenous waste substances and a certain amount of water, and the tiny ducts connected with the tubules run together and carry the waste or urine to the bladder.

But the main interest to-day is in what scientific men call the "ductless" glands: glands

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[1] Sir Arthur Keith, *The Human Body.*

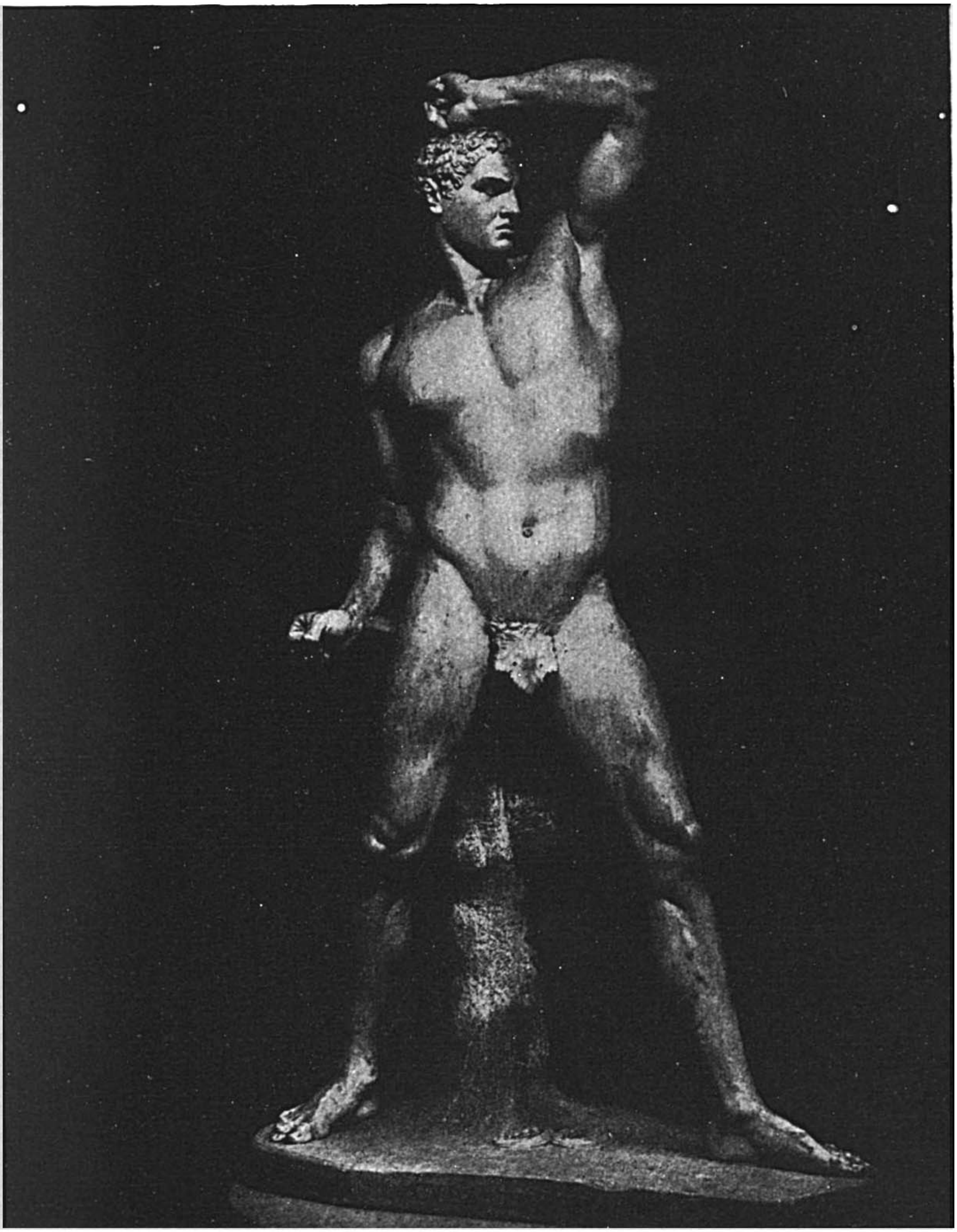

Photo: Anderson.

STATUE SHOWING HUMAN MUSCLES.

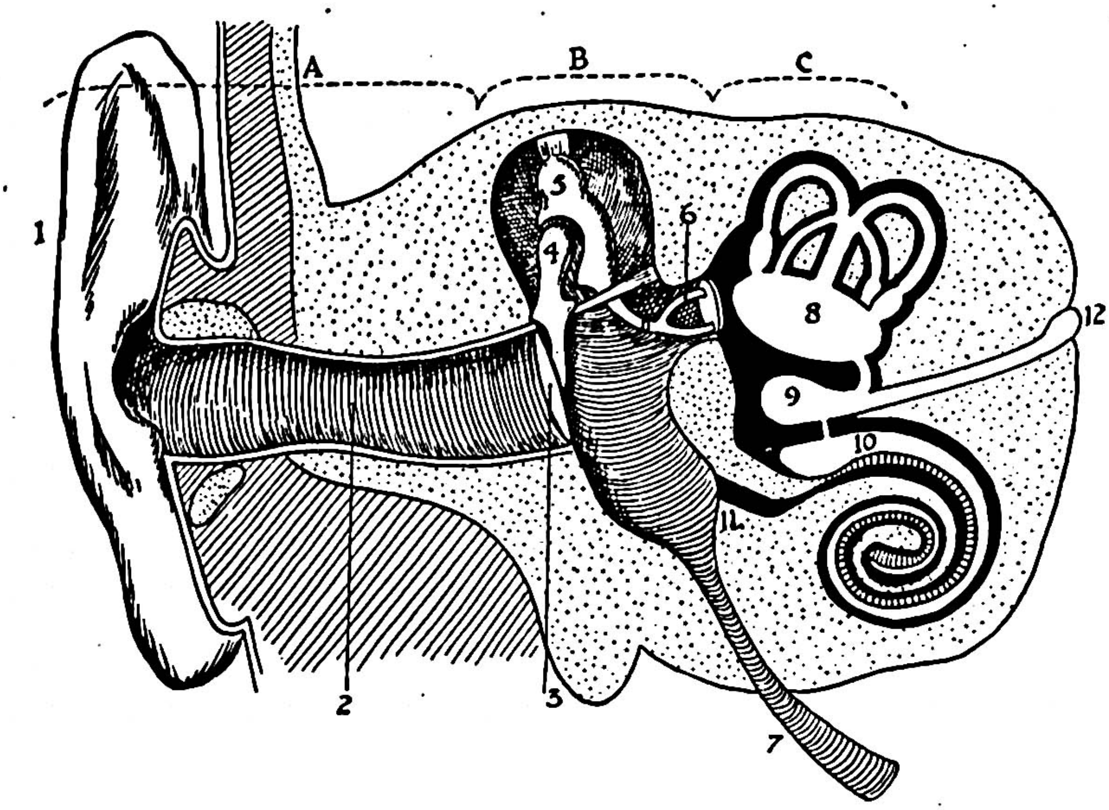

DIAGRAM OF THE HUMAN EAR. (After Hesse and Weber.)

A, the outer ear-passage; B, the middle ear; C, the bone (periotic) enclosing the inner ear.

1. The ear-trumpet or pinna, practically fixed in man and unimportant. In many mammals it helps to locate the sound. 2. The outer ear-passage with the drum or tympanum (3) running across its inner end. The drum vibrates when sound-waves strike it. 4, 5, 6. The ear-ossicles, hammer (malleus), anvil (incus), and stirrup (stapes), which by their movements transmit the vibrations from the drum to the inner ear. The "window" in the bony wall of the inner ear on which it abuts is called the fenestra ovalis. 7. The Eustachian tube, leading down to the back of the mouth; by it air can enter indirectly into the middle ear. 8. The larger chamber of the inner ear, called the utriculus, with three semicircular canals arising from it. They have to do with balancing and the like. 9. The smaller chamber or sacculus connected with the coiled cochlea, the essential organ of hearing (10), containing the organ of Corti. There is also shown the endolymphatic duct (12). 11. Another "window" in the periotic bone, the fenestra rotunda. The dark-coloured cavity is called the perilymph-space; it contains a fluid called perilymph; it is separated from the internal cavity of the ear by a membrane, within which there is endolymph. The dotted tissue is bone.

which extract substances from the blood but do not pour their secretion into special channels. We have already mentioned a most interesting example in the suprarenal glands: two little bodies near the kidneys, each about the size of a segment of a small orange, which pour into the blood a "chemical messenger" (or hormone) for regulating the supply of blood to the various organs.

It is one of the most remarkable discoveries of recent years, that there are numbers of little glands entirely devoted to the manufacture of hormones. "If all the glands of internal secretion were rolled together they would form a parcel small enough to go into a waistcoat pocket, yet such a small mass can influence the working and growth of the whole body." In his interesting book, which we have already mentioned, Sir Arthur Keith, referring to the dispatch of secretion to the stomach, uses the following suggestive words: The secretin, or hormone, which acts as a missive "is posted in the nearest letter-boxes or capillaries in the duodenal wall and is carried away in the general blood circulation, which serves for all kinds of postal traffic. In a postal system where there are no sorters and which must be conducted by an automatic mechanism, letters or missives cannot be addressed in the usual way. Their destination is indicated, not by their inscription, but by their shape. The molecules of secretin may be regarded as ultra-microscopic Yale keys sent out to search for the locks of letter-boxes which they can fit and enter." They circulate round the body until they find their destination. "What is still more wonderful in this system is that the letter-boxes, or we may call them locks, have a positive attraction for the key missives which are destined for them." It was Professor Starling who named these messengers Hormones.

The thyroid glands—two little lobes on either side of the windpipe—are bodies of this nature which have attracted a good deal of popular attention of late years. The secretion formed is discharged straight into the blood stream, and for that reason they are called ductless glands or glands of internal secretion. They will be discussed at greater length in a later section of this work. Here it is enough to say that the chemical stuff, or "hormone," which they secrete increases the vitality of the tissues; it makes the tissues "greedy for oxygen," and the work goes on more briskly. Hence it is that decay or imperfect development of the thyroid glands leads to that state of bodily and mental feebleness which is called "cretinism," while the extract from the glands can be used for the purpose of "rejuvenation." This small organ, the thyroid gland, is necessary to the health and normal development of both body and mind, and this knowledge has been put to practical application in some cases with astounding results.

Near the thyroid glands are four small bodies—the "parathyroids." The function of these is not yet clear, but there is serious nervous trouble if they are removed. Then there is a "thymus gland," which seems in some way to prevent the sex-organs from developing too early. It is situated in front of the breast-bone, and must act by "postal service." The internal sex-organs themselves post a good many of these "hormones" in the blood. Everybody knows the striking difference between a normal and a castrated animal. The development of secondary sexual characteristics, such as antlers, seems to be largely stimulated by chemical messengers of this kind. One of the most interesting illustrations is in connection with the milk in the mother's breasts. How does the mammal mother come to have this rich development of her milk-glands just at the moment when it is needed? It has been discovered that, as soon as she becomes pregnant, the ovaries begin to discharge a hormone into her blood, which finds its way to the breasts and stimulates them. Probably the embryo itself also produces hormones which pass into the mother's blood, and serve a useful purpose up to the time of birth.

Finally, there is a remarkable and long neglected little body in the head, the "pituitary body," which is a rich laboratory of hormones. It controls the growth of tissues by stimulating them. When it is removed from an animal, the body becomes feeble and undersized. On the other hand, some rather unfortunate people have their pituitary body overgrown, or over-active, and they develop unpleasantly large faces, hands, and feet, or become "giants."

Such, as far as one can tell it in so brief a space, is the tale of the wonderful mechanisms in the body. Even the skin, which binds and protects this marvellous system of parts, is a remarkable organ when one has time to study it thoroughly. On the tender eyelids of a young child it is as thin as tissue paper, yet on the palms of some "horny-handed son of toil" it will produce protecting cells until it becomes an eighth of an inch thick. It is, moreover, rich in sweat-glands (which, as we saw, are most important for regulating the temperature of the body), lubricating or sebaceous glands, corpuscles for the sense of touch, and little pits in which take root the hairs which were once of great service to the body. Every internal surface also has its lining, or skin: tough where toughness is required, but so fine in the right places that gases and fluids can pass through it for breathing and nutritive purposes. "The proper study of mankind is man," said a great poet; and we may surely add that we know no more interesting study in the universe.

§ 12

Before we leave the subject of this article a further word should be said.

Mind and Body.

The comparison of the body to an engine is very useful, but it is more than a little apt to lead us astray. For the body is living, and in higher animals, at least, there is a "mind" that counts. No one has succeeded in making clear the relation between mind and body, if there be a relation, but what we are sure of is that there are two aspects, two sides to the shield, the mental and the bodily. Just as a dome has its inner concave and its outer convex curve, inseparable from one another, two aspects of the same thing, so the living creature is a feeling, remembering, willing, and sometimes thinking being, just as really and truly as it is a feeding, moving, storing, and energy-transforming system. On the one side there is "mind," probably present even when it is not apparent to the observer; on the other side there is the routine of chemical processes which we call metabolism. Sometimes the living creature is more of a body-mind, sometimes more of a mind-body. We cannot solve the riddle: the mental or subjective and the bodily or objective activity are bound together in one. What we are quite sure of is that the ideal for the organism is a healthy body at the service of a healthy mind. Let us take an illustration of the influence of mind on body.

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SECTION OF HUMAN SKIN.

1. To the outside with ridges is the horny layer of the epidermis (*stratum corneum*).

2. Then comes the second layer of the epidermis, the Malpighian layer (*stratum malpighi*); and traversing this is seen the coiled duct of a sweat gland.

3. Third comes the under-skin or dermis, the seat of many glands and blood-vessels. Its surface is raised in hillocks or papillæ. Into these there run blood-vessels and nerves.

Emotions and Digestion.

The famous physiologist of Petrograd, Professor Ivan Petrovich Pavlov, was the first to demonstrate the influence of the emotions on the health of the system. Everyone knows that a good circulation and a good digestion make for cheerfulness, but the converse is also true. "A merry heart is the life of the flesh." The researches of Pavlov, Cannon, Carlson, and Crile have made it quite clear that pleasant emotions favour the secretion of the digestive juices, the rhythmic movements of the food-canal which work the nutriment downwards, and even the absorption of what has been made soluble and diffusible. On the other hand unpleasant emotions, such as envy, and mental disturbances, such as worry, hinder digestion and the smooth working of the nutritive process.

The Cult of Joy.

When the hungry man sees the well-laid table his mouth waters, but everyone knows that a memory or an anticipation will also serve to move at least the first link in the digestive chain. Professor Dearborn writes: "It is now well known that no sense-experience is too remote from the innervations of digestion to be taken into its associations, and serve as a stimulus of digestive movements and secretions." As was said of old time, "He that is of a merry heart has a continuous feast." When our joyous index is high, our digestion is good. As Dr. Saleeby has put it, freedom from care has nutritive value. It does not seem far-fetched to wonder if the joyousness of singing birds may not react on their remarkably well-developed capacities. We speak smilingly of our friend's "eupeptic" cheerfulness, but our smile is a little apt to become a materialism. We have to inquire whether our friend is not "eupeptic" because of his psychical success in the great task of happiness. The truth is that the mental and the bodily harmonies are the bass and treble of one tune.

The influence of mind on body finds a good illustration in the stimulation of the adrenal glands by strong emotion. Anger, which may be righteous, affects the production of adrenalin by the core of the adrenal glands, situated near the kidneys. The slight increase in this powerful "chemical messenger" or hormone, which the blood sweeps away, has numerous effects through the body. It constricts the smaller blood-vessels, and there is less blood in the peripheral and more in the deeper parts. It raises the blood-pressure, excites and freshens the muscles, adds to the sugar-content of the blood, increases the coagulability of the blood and so on. In short, the whole body is prepared for a fight, and all under the influence of what was to begin with a psychical event.

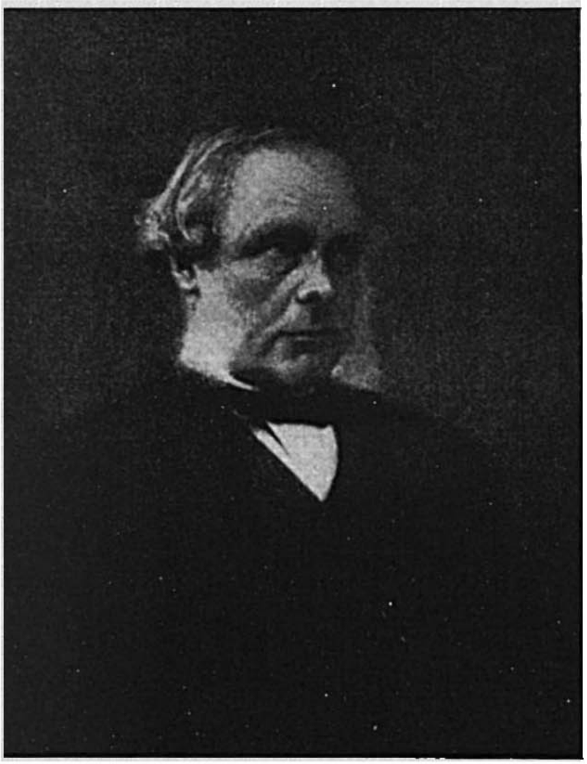

Photo: Rischgits Collection.

LORD LISTER.

Joseph Lister (1827–1912), famous as the introducer of antiseptic methods into surgery. Following Pasteur, who showed that wounds went wrong with gangrene and the like because microbes or germs got in, Lister used a dressing, such as carbolic acid, which killed the microbes. Lister was Professor of Surgery in Glasgow, Edinburgh, and King's College, London.

"Good news, psychical if anything is, may set in motion a series of vital processes, complex beyond the ken of the wisest. What is true of digestion is true also of the circulation. Wordsworth was a better physiologist than he knew when he spoke of his heart leaping up at the sight of the rainbow and filling with pleasure at the recollection of the daffodils dancing by the lake-side. There are facts which point to the conclusion that a gladsome mind increases the efficiency of the nervous system. Good tidings will invigorate the flagging energies of a band of explorers; an unexpected visit will change a wearied homesick child, as if by magic, into a dancing gladsome elf; a religious joy enables men and women to transcend the limits of our frail humanity."[1]

Healthy-mindedness.

There is reason, then, to believe that emotion has its physical accompaniment in tensions and movements throughout the body, and in changes in the secretion of glands. There is a physiological reverberation of joy. But there must be more than this. The nervous system has a notable *integrative* or unifying function; it makes for the harmony of the bodily life. This function

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[1] Thomson, *The Control of Life*, 1921.

it may discharge the better if the psychical side is finding its due development. Thus it is well known that æsthetic emotion—delight in the beautiful—is very markedly a body-and-mind reaction, affecting the whole creature as a unity. It is practically certain that many people fail in health because they starve their higher senses and minds.

We venture to go further, under the conviction that physiology and psychology must join hands—as is suggested, indeed, by the name of the new science of psychobiology. The physiological ideal is bodily health; its essential correlate is healthy-mindedness. No doubt the invalid may have a vigorously healthy mind and the athlete a mind diseased, but, on the average, the two aspects of health must develop together. Hence the importance of mental dieting, mental gymnastics, mental rest, mental play, mental stores; though these must be sought as ends in themselves, not as aids to digestion!

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