Physiology for Everyone

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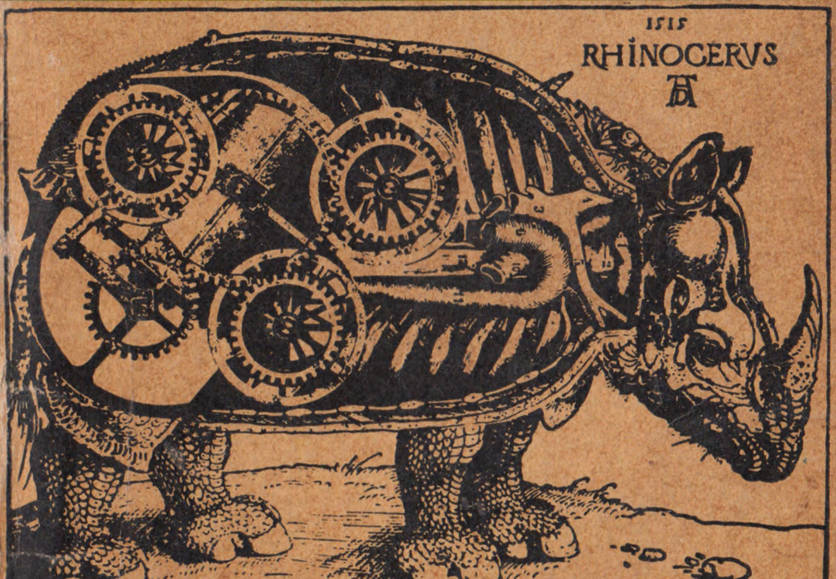

B.F. Sergeev

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Б. Сергеев

ЗАНИМАТЕЛЬНАЯ ФИЗИОЛОГИЯ

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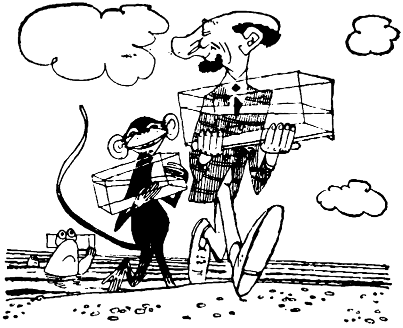
Water—A Personal Ocean

THE SUBSTANCE TO WHICH OUR PLANET OWES ITS EXISTENCE

When an astronomer on Earth points his telescope at one of the neighbouring planets, he always wonders whether there is water and oxygen there. His interest is quite natural, for, if they exist on the planet in any quantity, life there might be expected to resemble our own to some extent. It is water that brought our Earth into existence, developed it to its present state, and created life. Above all else, water is the most wonderful substance on the Earth and the more we learn about it, the more we marvel at it.

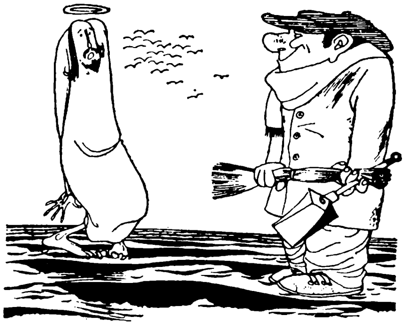
Very few people have ever meditated upon the remarkable properties of water. This is not surprising for we find water everywhere. It is a common phenomenon on our planet: three quarters of the Earth's surface is under water. About one fifth of the land is covered by solidified water (ice and snow); a good half of the land is always shrouded in clouds of water vapour and tiny drops of water; where there are no clouds, water vapour is always present in the air. Water is so common on our planet that it constitutes as much as seventy one per cent of the human body. And common things are never



regarded as wonderful. Its very commonplaceness, however, is extraordinary. No other substance is more abundant on the Earth and none occurs in three states at the same time: solid, liquid and gaseous.

Water has conditioned the Earth's climate. But for water, our planet would have cooled long ago and all life would have disappeared. The heat capacity of water is unusually high. When warmed, it absorbs a great deal of heat, and on cooling, it loses it. Oceans, seas and all other expanses of water on our planet, as well as atmospheric vapour, act as accumulators of heat: in warm weather they absorb heat, and when it is cold they give it off, thus warming the air and all the surrounding atmosphere.

The coldness of space would long ago have penetrated to the Earth, but for the warm coat of the atmosphere which surrounds our planet. In this coat the water vapour acts like a layer of cotton wool. Over deserts where water vapour is scarce the coat is full of holes. Thus unprotected, the Earth is fiercely heated by the Sun in the daytime and cools off completely at night. For this reason fluctuations in temperature in the desert are so great.



Nevertheless, the Earth would freeze in the long run, if it were not for another of water's remarkable properties. It is common knowledge that almost all substances contract on cooling, but water expands. If it contracted, ice would be heavier than water and would sink. All the water would gradually turn into ice and the Earth would be left with a very light mantle of gaseous atmosphere containing no water vapour.

Yet another extraordinary feature of water is that its latent heat of melting and that of vaporization are extremely high. For this reason it is possible to live in hot climates. Only by evaporating water (that is giving off a large amount of heat) can animals and man maintain their body temperature several degrees below that of the ambient atmosphere.

The role of water in nature is unique because life would be impossible without it. Life originated in primeval seas from the substances dissolved in them. Ever since, chemical reactions have been occurring in every cell of all animals and plants between the dissolved substances.

Perhaps the least known among the remarkable properties of water is its ability to form an extremely strong surface film which results from the very strong mutual attraction of the molecules in the uppermost layers. Its surface tension is sufficiently strong to support things which would appear unable to float. If a steel needle or a safety razor blade are placed carefully on the surface of water so as not to damage this film they will not sink.

The life of many insects is connected with this surface film. Water skaters, for example, live only on the water surface without ever submerging or coming onto dry land. They are unable to dive or swim and can only glide, with their legs set widely apart, on the smooth surface, similar to a skier gliding over snow. They touch the water only with the very tips of their legs which have a thick coat of hair. The surface film sags under their weight but remains intact.

Mosquito larvae, water beetles, and various snails attach themselves to this film from below. Snails not only hold onto the film, but can creep along it in much the same way as they do on the surface of any solid object.

Scientists long ago noticed that the purer the water, the greater the effort required to break its surface film. Molecules of the substances dissolved in water (mainly gases) wedge themselves between the molecules of water, thereby weakening the surface film. Even purified water does not completely possess this remarkable strength, for molecules of certain admixtures will always remain. To break a column two and a half centimetres in diameter requires a force of about nine hundred kilograms which is the approximate strength of some grades of steel. Nor is this the limit. Scientists have estimated that to break a similar column of absolutely pure water would require a force of up to ninety five tons. If there were a lake of pure water on the Earth, it would be possible to walk and even to skate on its surface as if it were solid ice.

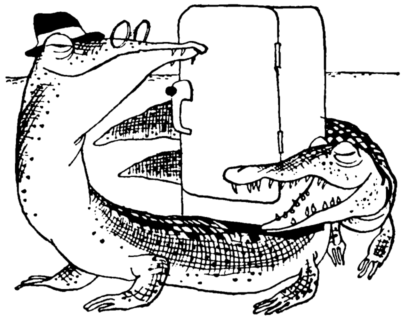
Do you know why almost all bodies expand when heated? This is not difficult to understand. The molecules of the substance begin to move more rapidly. They do not have sufficient room to do so and start jostling against one another. Consequently, the substance expands. Why does water behave differently?

A molecule of water is known to consist of one atom of oxygen and two atoms of hydrogen. These atoms are arranged in a triangle with the oxygen at one corner and the protons, the nuclei of the hydrogen atoms, at the other two, the orbits of their isolated electrons being greatly extended in opposite directions.

When the temperature of water is lowered and the thermal movements of the molecules become less intensive, the electromagnetic properties of the water molecules prove to be stronger than these movements. Individual molecules begin to unite as if holding out their hands to one another: two protons each attract one electron from the neighbouring molecules, while their own electrons are captured by the protons of their neighbours. Each molecule of water thus becomes linked with four others, forming a very beautiful crystal lattice with sufficiently large holes to take one molecule of water.

On the other hand, when the temperature is raised, the thermal movements of the molecules intensify, the bonds between them distort and break, and the ice melts. The molecules that have broken away fall into the holes and the volume of the water decreases.

How do the molecules behave in liquid water? Only comparatively recently did scientists begin to think about this. In general, water is a half-forgotten problem for physics and biology. It is no wonder that the very first investigations puzzled scientists. It turns out that the



water obtained from melted ice preserves the structure of the latter for a long time. But not all the water displays this property: floating in the melted water are countless minute islands of water which retain the structure of ice. Scientists called them 'icicles'. These icicles do not 'melt', even when the water is heated to thirty degrees Centigrade; only when the temperature is further raised does their number decrease; they begin to melt fairly rapidly when the temperature is more than forty degrees; they also disappear with time, whatever the temperature.

And how do the organisms react to these invisible icicles? In tackling this problem, scientists had to revise a great many facts that had long been known, but which were nebulous and never taken very seriously. For example, why does the number of micro-organisms vigorously increase in a zone where ice is melting? Why is it that the eggs and pupae of many insects which live in temperate latitudes cannot develop without low temperatures? Or why do young animals and birds fed on water from melted ice or snow grow more quickly and are less prone to illness? Perhaps it is not accidental that many animals give birth to their young in early spring and that birds from far away Africa and India migrate to the north to hatch their young.

All these seemingly isolated puzzles now have something in common: cold, ice, water from melted ice.

Scientists do not like to stop half-way. They had to find out what the water in living organisms was like. It was believed that it simply filled the spaces between large molecules, but this idea proved wrong. It has been found that the membranes of most cells in organisms and giant living molecules, in comparison to which molecules of water are infinitesimal, attract the latter and arrange them on their surface in a strictly defined order to form an ice-like crystal lattice. The larger the molecule the thicker is its 'ice' envelope. The protoplasm of the cells and the intercellular fluid contain vast numbers of icebergs. The organism 'freezes' a considerable part of the water it contains. The reason for the favourable effect of cold water from melted snow is that 'ice' is vital to the organism, the water becoming 'live' when frozen.

'Live' water has another important property. It has been shown that as far as structure is concerned, most of the molecules of proteins, fats and carbohydrates fit the structure of ice and can easily enter the hollows of the latter's crystalline network. Therefore, they are not damaged when water freezes.

The reaction of water towards the molecules whose form does not fit the structure of ice is quite different: on freezing, it breaks the large molecules and drives away the small ones. The ice in the Arctic Ocean is fresh-water ice because water rids itself of all salts when it freezes.

The molecules in a living organism can, for various reasons, change their form to some extent. Obviously, if the process develops considerably, such a molecule can no longer form a crust of 'ice' on its surface. The da-

maged molecule can be repaired with the help of tiny icicles. By 'freezing onto' curved molecules the icicles straighten them out, giving them their usual configuration.

One of the reasons why an organism ages is probably because it accumulates a large number of damaged molecules. If this assumption were correct, it would be possible to rejuvenate an organism by providing it with an adequate number of icicles. For this purpose the temperature of the organism has to be lowered so that individual icicles begin to form (experiments conducted on animals had a prolonged rejuvenating effect), or the organism has to be provided with ready-made icicles. Hence the favourable effect of water from melted snow.

From this point of view even the drinking of unboiled water instead of boiled is beneficial for the organism. High temperatures cause the water's crystal lattice to break up completely and the molecules form other bonds. In order to freeze boiled water these bonds first have to be ruptured, which is not easy. If you put relatively pure, freshly boiled water outside in the frost, it will not freeze at zero Centigrade, but, contrary to what text-books say, this water will only freeze when its temperature drops to seven below zero. The same is true of an organism. For the living molecules in the tea we drink to build 'icebergs' around themselves they must first break the bonds formed between the water molecules during boiling.

Water which does not freeze at a below zero temperature is known as overcooled. An excess of overcooled water in an organism facilitates the accumulation of the harmful products of metabolism. For on 'freezing' the water is purified by expelling harmful admixtures from its lattice. This is another disadvantage of drinking boiled water.

This is, of course, not the only important feature of 'live' water. 'Icebergs' are believed to perfom a very important function in the work of the muscles. It is well known that the energy required for muscles to contract is provided by the breakdown of adenosine triphosphoric acid, but what actually occurs remains a mystery. A study of the state of water in the organism has shed new light on muscle contraction. The working section of a muscle is the protein myosin whose chain is, similar to a string of beads, made up of a great number of protomyosins. The bonds between them are not only sufficiently strong to hold them together but are also able to contract the chain of protomyosins into a more compact formation. The force holding them in the extended state is obviously the crystal lattice of water, that is the ice armour formed around the molecule of myosin. If the armour is quickly broken, the chain of protomyosins released contracts, thus huddling together in a denser mass. It is the breaking of the 'ice' envelope and not the actual contraction that uses the energy obtained from the adenosine triphosphoric acid. The ice-like envelope is later restored by a molecule of myosin; 'ice' again extends the chain of protomyosins and the muscle relaxes.

Rupture of the ice envelope is instantaneous. If a free proton happens to be close to the iceberg one of the water molecules will take it up. But, as there can be only two in a molecule, it will at once give one of its own protons to a neighbouring molecule. The latter will accept the new proton, passing on one of its own to its neighbour, and so on. This reaction, like an electric current, immediately affects the whole row of water molecules and the iceberg begins to melt. (The molecules are kept together as a result of the bonds formed by the protons, which rupture when the protons are transferred to other molecules.)

DEAD WATER

Among the dramatic events of World War II three especially mysterious ones remained unknown or did not attract particular attention.

The first event took place in France. On May 16, 1940, when Nazi troops were marching on Paris, two French scientists from the Joliot-Curie laboratory were making their way to the south of France. They had with them several sealed containers in which there were 185 kilograms of—water. In Bordeaux the containers were loaded onto the British ship *Brampark.* A raft was built on the deck and all the containers of water were secured to it. Had the vessel been destroyed by enemy submarines the containers would not have been lost. The voyage, however, was successful and the load was brought safely to Great Britain.

The second mysterious event took place in Denmark, then occupied by German troops. On a rather stormy night Niels Bohr, a well-known physicist, escaped to Sweden in a small boat. The most precious thing in his luggage was a beer bottle, which he cherished dearly.

The beer bottle, however, was only a camouflage: it was filled with—pure water.

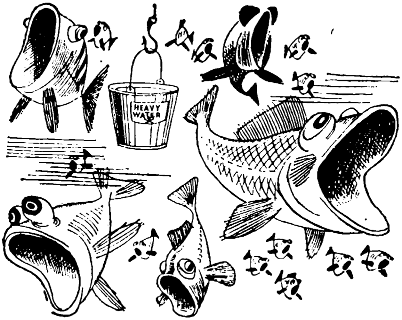
No less mysterious was an event that occurred in Norway. In 1942 the small Norwegian town of Rjukan was raided by British paratroopers. The object of this enigmatic operation long remained a secret. Only after the war did it become known that this risky operation had been undertaken with the purpose of destroying a small plant and a store of four hundred litres of water kept there.

The real reason for all these incomprehensible events was, in fact, heavy water.

Heavy water was discovered not long ago. Some forty years ago the American scientist Urey found that, besides ordinary hydrogen, there exists heavy hydrogen, whose atoms are twice as heavy as those of ordinary hydrogen. Scientists were so perplexed that they gave the new hydrogen the name of deuterium, as if it were not hydrogen at all but a completely different substance.

As is known, a water molecule comprises two atoms of hydrogen and one of oxygen. When atoms of heavy hydrogen are present heavy water is formed. It was more recently discovered that an even heavier hydrogen exists, called tritium, and that there are two kinds of heavy oxygen. Molecules of water are made up of various combinations of the atoms of these substances. Thus, any water is a mixture of eighteen various compounds, seventeen of which are varieties of heavy water.

The proportion of heavy water in ordinary water is negligible. Molecules containing the heaviest oxygen occur at the rate of one thousand per million, and those containing deuterium, two hundred per million. Heavy water, which was first obtained in a pure form just before the war, was essential in the creation of the atomic bomb. For this reason, the Allies took measures to prevent it from falling into the hands of the Nazis.



What is heavy water like?

The water studied best is that containing deuterium. It cannot be distinguished from ordinary water by its colour, smell or taste, but it is not good for living organisms. In this way popular legends about live and dead water arose. Heavy water proved to be dead in the real sense of the word, for it cannot sustain life.

Plant seeds placed in heavy water fail to germinate. Fish and single-celled organisms and microbes die after a short time. Mice and rats which are given heavy water to drink do not live long. If the heavy water they are given is diluted they survive, but suffer from terrible thirst. Heavy water always brings about death. It has even been suggested that an accumulation of heavy water in an organism is responsible for ageing, but there is still no convincing evidence to support this.

Is the small admixture of heavy water that is always present in ordinary water harmful to us? Obviously, it is not. In fact, small amounts of heavy water are beneficial for man, as it intensifies certain vital processes, whereas, large quantities retard them. Heavy water is not lethal for living beings, but any marked retardation of vitally important processes is fatal.

HOW MUCH DO WE WEIGH?

Do you know how much you weigh? Do not think this question very simple, even if you have weighed yourself quite recently. Have you any idea how your weight varies during the day, by the evening, or even in ten minutes?

The weight of a man's body is constantly fluctuating. Apart from quite obvious causes such as meals, when our weight increases spasmodically, there are others that bring about constant, slow, quite unnoticeable variations. The first to detect them was Sanctorius* over 300 years ago. He constructed huge scales and spent hours, observing how his own weight changed. The results of this experiment were so surprising that large numbers of visitors gathered in his laboratory to see the eminent scientist lose weight in their presence. The changes were appreciable: overnight Sanctorius would lose as much as a kilogram.

One can lose weight for various reasons. Loss of carbon dioxide alone accounts for a reduction of 75 to 85 grams over a period of twenty four hours. This is only a trifle compared with the loss of water via the lungs which amounts to 150 to 500 grams in twenty four hours, the quantity lost by perspiration being still greater. A man is constantly perspiring, although perspiration does not run from his body in large drops.

From the openings in the numerous sweat glands scattered over the surface of the skin minute drops of sweat are exuded which can be seen only through a microscope. If the air is dry they evaporate before new ones are discharged from the glandules, and the skin remains dry. In cold weather between 250 and 1,700

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* Santorio Santorio (1561-1636), an Italian physician, professor of medicine at Padua and colleague of Galileo.

grams of water are evaporated through the skin. A man doing hard physical work in dry hot weather exudes as much as ten to fifteen litres of sweat over a period of twenty four hours, and sometimes as much as four litres an hour. Even in this case, however, the skin may also remain dry. According to moderate estimations, people living in the southern regions secrete between 70 and 150 tons of sweat in the course of a seventy-year lifetime. This is enough to fill three large railway tank wagons.

What function is performed by sweat? Why does the organism give it off in such large quantities? It is the mechanism by which a man's organism protects itself against overheating. Evaporation uses large amounts of heat, six hundred calories per litre of sweat. If all this heat is given off by a man's body, its temperature will fall by approximately ten degrees. Unfortunately, our body expends only a small proportion of its heat on evaporation and, therefore, sweating cannot ensure cooling of the body, but can only protect it against overheating. Normal body temperature, about 37°C (in the arm-pit), is only maintained due to the evaporation of water from the lungs and skin, even when the temperature of the ambient air is as high as 40 or 50°C.

Sweating is not always beneficial. When humidity is high, sweat evaporates very slowly. It collects in large drops and flows over the body surface bringing no relief, as there is no cooling without evaporation. For this reason heat is easier to tolerate in dry deserts than in damp tropical forests.

Is it harmful to sweat a lot? Loss of three to five litres of water, whatever the cause, brings about intolerable thirst but this is not fatal if it is compensated sufficiently quickly. There was a well-known case in France in 1821 when a man doomed himself to death by stubbornly refusing to drink anything. The struggle

between life and death continued for seventeen days. The man could have been saved had he been given sufficient to drink, even as late as the fifteenth day of his amazing fast.

Where does the water contained in sweat come from? Where does man store the liquid he has drunk? Sweat glands draw water from the blood. As long as sweating is not excessive, the blood does not become thicker and no decrease occurs in its volume. But as soon as the water content of the blood begins to drop, the same amount of water flows into the blood vessels from the stores. (The chief sites of water storage are the subcutaneous tissue, muscles and other organs.) Conversely, the water consumed by man is absorbed by the blood from the intestines; the corresponding amount of water is immediately transported to the stores.

The amount of water which can be stored in the body is limited, especially in the case of birds and flying insects. It is scarcely enough to ensure the vital functions of the organism for a day or two, even in cool weather. But there must always be a reserve of water in the organism. The most original method for storing water has been invented by bees. A bee family, consisting of one thousand adult insects and a great number of larvae, cannot exist without water. What happens to the young when a long spell of weather unfit for flying occurs? The bees have found a way out. If you open a hive you can see large worker bees hanging motionlessly on the combs. They are living reservoirs of water. The bee water-carriers pour the excess water into the crops of the worker bees till they become too heavy to fly or crawl. After a day or two of weather unfit for flying their abdomens return to size and the reservoirs become empty.

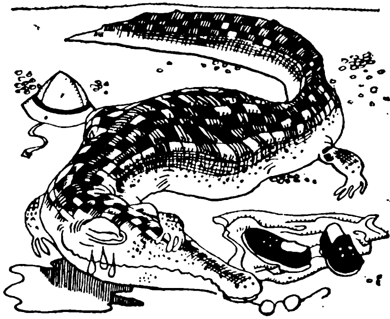
CROCODILE TEARS

The waves of the gentle, warm sea lap lazily against the shore and among tree-covered rocks, at the water's edge, where deer graze all day long. They come there to enjoy the cool breeze and the shade of the spreading oaks and pines. The sea splashes at the feet of the handsome antlered creatures but it is unlikely to hold any attraction for them. When the deer become thirsty, they clamber high up into the mountains in search of tiny holes filled with turbid and not very fresh water left over from the springs which dry up almost completely in summer.

Neither deer nor any other animals will ever go to the sea when thirsty. The winding shore of the continent, thousands of miles long, is surrounded by oceans. Yet, nowhere will you see animal tracks along it, for no animal on earth will ever quench its thirst from the sea.

People who are shipwrecked perish from thirst amidst the boundless expanses of salty sea water. Sea water is unfit for drinking since too many salts are dissolved in it: thirty five grams in one litre, including twenty seven grams of common salt.

Why is sea water unsuitable for drinking?



An adult needs up to three litres of water a day, including the water contained in food. If one were to drink sea water, the organism would receive a hundred grams of salt daily. If these salts were to penetrate the blood all at the same time the consequences would be unfortunate. The blood usually eliminates an excess of salts, once normal requirements have been filled. The main purifiers of the blood are the kidneys. An adult discharges a litre and a half of urine (i.e. half of the daily intake of water) a day and gets rid of sodium, potassium, calcium and other harmful substances. Unfortunately, the concentration of these salts in sea water is much higher than in urine. Therefore, to rid the organism of the salts absorbed with sea water a much larger quantity of water would have to be drunk.

How can sea fish and animals live? Where do they find fresh water?

The fact is that they do find it. The salt content in the blood and tissue fluids of fish and other vertebrates is very low. Thus, marine predators obtain a considerable amount of good drinking water with their food. These liquids are quite good for man as well, and the first to notice this was the French physician A. Bombard, who undertook an extremely daring experiment to prove that the ocean has everything that man needs for survival, and that people who have been shipwrecked can escape death if they are able to make use of the gifts of the ocean. For this purpose he set out to cross the Atlantic Ocean in a small rubber boat, eating nothing but fish and the tiniest invertebrates he managed to catch from his boat, and drinking, instead of water, the liquid he pressed out from the bodies of fish. It took him sixty five days to cross the ocean from Europe to America and, although this diet greatly undermined his health, he succeeded in proving that man can live from the ocean.

One is prompted to ask where fish obtain their fresh water. It has been found that fish are equipped with a wonderful distilling apparatus, different from the kidneys. The kidneys of fish are so small and underdeveloped that they hardly play any part at all in discharging salts from the organism. The distilling device is located in the gills. Special cells trap the salts contained in the blood and remove them from the organism in a highly concentrated form together with the mucus.

Sea birds also find difficulty in obtaining fresh water. The stormy petrel and the albatross, residents of the open ocean, live far from the sea shore. They come to the land once a year to have their young. Cormorants, guillemots and various sea-gulls never drink fresh water, in spite of the fact that they live close to the shore. It was formerly believed that they were content with the tissue fluid of their prey, but it has been proved that they willingly drink sea water and some of them even cannot do without it. Long ago it was observed in various zoos that these birds do not survive in captivity. Zoologists were puzzled for delicate tiny hummingbirds endure captivity, parrots, ostriches, eagles and owls easily survive in cages, but gulls perish after only a short time. The final conclusion was that these beautiful sea birds cannot live in cramped cages because they miss the broad expanses of the ocean. But it was not their longing for the sea nor the cramped cages that killed the birds. It was simply that they could not obtain sufficient salts. When salt was added to their food, gulls continued to live happily.

Sea birds and reptiles possess wonderful distilling equipment. This is not kidneys, but a nasal or, according to the latest terminology, salt gland. In birds it is to be found on the upper edge of the eye socket, its excretory duct discharging into the nasal cavity. The concentration of sodium in the fluid secreted by the gland is five times that of the blood and two or three times greater than that in sea water. The fluid discharged from the nostrils hangs from the end of the beak in the form of large transparent drops which the bird shakes off now and then. Ten or twelve minutes after a sea bird is given very salty food drops begin to fall from its nose, thus giving the impression that the bird is suffering from a bad cold.

In such sea reptiles as turtles, snakes and lizards, unlike birds, the excretory duct of the salt gland opens into the corner of the eye, the secretion flowing from the eye. People noticed long ago that crocodiles could weep large transparent tears. Having devoured its prey the crocodile, allegedly, mourns over it. For this reason the term 'crocodile tears' came to be used to describe the worst hypocrisy. This mystery was only recently explained as the way the crocodile's organism rids itself of the excess of salts absorbed with water and food.

The green turtle wanders about the warm seas and oceans all the year round. Only once a year, under the cover of night, and at a special time in the year, does the female come onto the sandy beach to bury its eggs. On its way back to the sea the turtle weeps bitterly, letting large salty tears fall onto the dry sand. Is it upset at leaving behind the place where some time ago it was hatched from an egg? Or is it weeping over its offspring left to the mercy of fate? This is certainly not the case. It is simply that its salt glands are doing their ordinary work of ridding the organism of salts. There is nothing unusual about it. Green turtles are known for their tearfulness, but in the water their tears are not noticeable. This is why it took man so long to solve the puzzle of the salt gland.

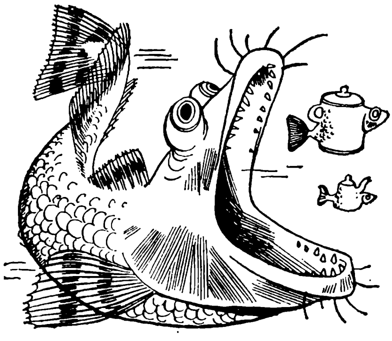
DO FISH DRINK?

Do fish drink? What do you think? I can see you smile ironically: as soon as a fish opens its mouth it is filled with water.

Whether fish like it or not, some water enters their stomach along with their food. Is it enough water for them? Are fish ever thirsty? Scientists found the answers to these questions long ago.

Fish inhabit all the waters of the Earth but each species can only live in its own natural conditions. Only a few kinds of fish can go from salt water to fresh water and back again without physical damage. Eels are unrivalled in this respect. They live half of their life in salt water and the other half in fresh water. What prevents fish from easily changing over from one kind of water to another? The skin, the membrane of the oral cavity, the gills and other parts of a fish's body, including the membranes of the individual cells of all organs and tissues, are permeable to water: they are readily percolated by water, but do not let in salts and many other substances.

Where does water percolate? Into a reservoir or from it? It does not depend at all on where it is mor abundant. The process of diffusion is controlled by tl osmotic pressure of solutions which is produced by th



substances dissolved in them. The higher their proportion, the greater is the osmotic pressure and the more intensively the solution absorbs water. In fresh water it is practically zero, whereas in the blood and tissue fluids of fish there is a great deal of salts and protein substances producing an osmotic pressure of six to ten atmospheres. It is by means of this force that the organs of fresh-water fish draw water into their bodies from the outside. If they were not provided with excretory devices removing surplus water from their organs the fish would swell up in no time and die. Consequently, fresh-water fish never need to drink water. They have enough trouble as it is, ridding themselves of the water which penetrates on all sides.

It is quite different in the case of the marine bony fishes. The salt content of sea water is much higher than that in the fish's tissues and the osmotic pressure of sea water is thirty-two atmospheres, whereas in the organism of such fish it is as low as ten to fifteen atmospheres. Therefore, the insatiable ocean is greedily sucking water from their bodies. It may seem paradoxical at first glance that the sea is able to dry up fish swimming in it. No wonder they are always thirsty.

Not all sea fish drink. The most ancient fish, sharks and rays, which most likely moved into the oceans before bony fishes (called teleosts) did, have adapted themselves to life in salt water in quite a different way. They have learned to retain urea in their blood. Urea is a rather harmful substance and is immediately expelled by other animals. For this purpose they had to cover their gills with a special membrane which does not allow urea to permeate. The osmotic pressure of the blood of sharks and rays is thus much higher than that of sea water and their bodies, much like those of fresh-water fish, also take in water from the ocean. They are, therefore, anxious to get rid of it.

This same principle was borrowed from sharks by the crab-eating frog which was recently discovered by scientist in south-east Asia. Of all the amphibians, it alone has adapted itself to life in salt water. The frogs, however, spawn in fresh water, but when their young are big enough they leave the fresh water and go to the sea where they feed on crabs. Like sharks, the frogs retain urea in their blood but they can do this at will: before going to the sea they accumulate a store of urea, any surplus being later expelled when they leave for fresh water. Thus, whatever their habitat, the frogs have no need to drink water.

CAN THE AIR BE SQUEEZED DRY?

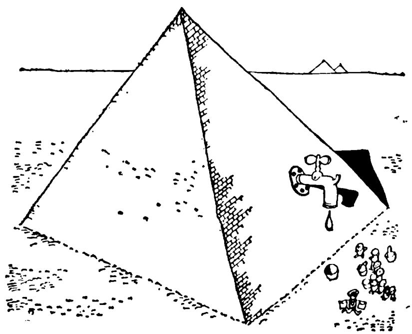
Long ago zoologists noticed that some desert animals who in their natural habitat had never seen a pool of water, even one the size of a spoon, drank plentifully and willingly when kept in captivity. How they can go without water when at large has long remained a mystery. Maybe the desert is not as dry as it seems at first sight? Or is it perhaps possible to procure water there?

Before we answer these questions, let us consider how people living in arid areas obtain water. Many holiday homes, sanatoria, and pioneer camps are located on the narrow strip of land along the south coast of the Crimea, between the mountains and the sea. When summer comes thousands of holiday-makers set out for the Crimea. Yet, none of them suspects how much trouble workers in the municipal services take, or how much effort is required, to provide a continuous supply of water, so that holiday-makers can take a bath regularly, wash, and cook their meals. As you know, there are no large rivers or lakes on the southern coast of the Crimea, and the local streams dry up early in summer.

In the Crimea they start storing water as soon as autumn comes, when it usually rains. The water is collected in surface tanks and huge underground reservoirs to be stored till summer. Nevertheless, water shortages often occurred, till a tunnel was cut through the mountains allowing a full-size river to run to the coast.

Only a few decades ago such undertakings were unthinkable. But in ancient times the inhabitants of the Crimea managed without them. They obtained water directly from the air. Dry as it is, the Crimean air is never without water vapour. The sea is not very far away after all. Archaeologists have explained how water was extracted from the air centuries ago.

In the eastern Crimea, not very far from the town of Feodosiya, the large estate of a mediaeval nobleman was discovered where there was a remarkable construction: a large paved area covered with stone pyramids. Within the pyramids were numerous tunnels and cavities. On entering the pyramids, the hot sea air precipitated to form drops of dew on the cold inner walls of the pyramids; the walls would become 'misted over', much like windows in cold weather. The minute drops of dew combined to produce larger ones which trickled down



the walls and through a special chute into an underground pool.

Thus, water can be obtained anywhere, hot and arid deserts included, although one cannot get much watei from dry air. And yet, even in arid deserts, drops ol dew form at night under piles of stones. Penetratinℊ deep into the sand, the air leaves the minutest amounts of moisture there. These are sometimes not so negligible either.

In the sands of the westernmost part of the Kara Kum desert water melons thrive and they need n(watering. Springs of fresh water are scarce there. To make up for it, the wind blowing from the Gulf of Kara-Bogaz-Gol brings moist air into the desert. At night, when it grows cool, the air leaves so much water behind that the sand sometimes had scarcely enough time t(absorb it, and water can be collected in vessels place(at the bottom of deep hollows.

Many desert inhabitants seem able to find the dew which has fallen at night in rock clefts and deep burrows and make use of it.

The kangaroo rat (or bettong) which lives in the dry Australian deserts can even extract water from the soil,

This peculiar little animal feeds on the seeds of various plants which are so dry that there is practically no water in them. The rat does not eat the seeds immediately after collecting them but carries them to its burrow in its remarkable cheek pouches. The hair of the rat grows not only on its face but also in its mouth, thereby preventing saliva from penetrating the cheek pouches. This ensures as sparing a use of moisture as possible. Absolutely dry seeds collected on the surface of the ground are stored in deep burrows. If even the tiniest amount of moisture is present in the soil, the seeds will begin to absorb it. The osmotic pressure of dry seeds is as much as four hundred to five hundred atmospheres and they draw in the water with the same force. The kangaroo rat does not eat the seeds until they have become enriched with water.

The peculiar spiny agamoid lizard, or moloch, which lives in the hot arid deserts of Australia, has proved even more inventive. Its entire body is covered with sharp protuberances and barbs. This monster has long been known, but for a long time scientists assumed that the lizard only used its barbs to protect itself against predators. Now, however, it is known that they serve another, no less important, purpose. The horny layer of the moloch's skin is permeated with innumerable pores which open on the outside into the furrows between the barbs. A drop of water which falls onto the lizard's skin will immediately soak into the pores, without penetrating its body, which it cannot do as there are no pores in the deeper layers. The pores are so arranged that the water has no alternative but to move in the skin towards the head. Here the capillary network comes to an end in two small porous pouches for collecting water which are situated in the corners of the moloch's mouth. If there is some water in the pouches, the moloch only has to move its jaws to pump out a drop of water from each pouch.

The moloch is quite happy without drinking. If it comes across a spring in the desert, it only needs to take a dip and its skin will take in more water than the lizard could drink, a store of water is being accumulated inside the skin.

Apart from this, the moloch's barbs are considerably colder than the skin. At night minute drops of dew form on them and are immediately absorbed by the skin. Thus the moloch takes in water directly from the air.

THE WATER MANUFACTORY

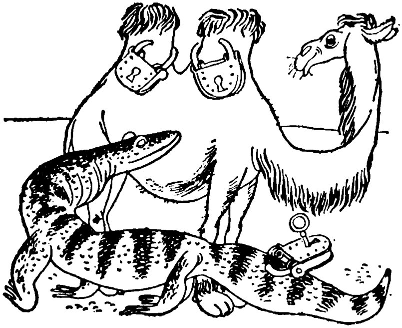
The midday sun beats down ruthlessly on vast areas of the desert and during the day the sand becomes so hot that, if one were to step on it barefoot, it would burn the skin. There is not a single living creature to be seen anywhere. This is not surprising for there is no water to be found for tens or even hundreds of miles around.

For all that, there is life in the desert. It can be observed at dawn, before the morning wind begins to move the sand. Wherever you look you see an intricate pattern of countless tracks. Here a slow-moving tortoise has dragged its shell. A little further off there are two rows of small dots and a deep furrow between them made by a tail: this is the track left by some small lizard. And the small groups of tracks lying some distance apart have been made by a swift-leaping jerboa. And those larger ones belong to a gazelle. It turns out that life in the desert has been in full swing at night and that in the morning all living creatures take shelter from the heat of the day.

How can animals live in such a barren region? How do they manage where there is such a shortage of water?

Many desert dwellers such as the antelope, suslik, gerbil, jerboa, and tortoise either never drink at all or can go without water for a long time. They use green plants instead. In spring and after rain the desert returns to life for a short time. Everything turns green and blossoms. But after the grass has become yellow and parched in the scorching sun, animals begin digging up the bulbs of tulips and other plants. These bulbs, protected by their leathery skins, contain a great deal of moisture. The beasts of prey do not suffer either, for they obtain their water by eating herbivorous animals. It is still no small wonder that most desert dwellers have provided themselves with their own water-producing plant and stores where they keep the raw materials for manufacturing water.

Incidentally, all animals on our planet, as well as man, possess a means of producing water. When we are working the cells of our organism are 'burning' energy-giving carbohydrates and fats. Their complete 'combustion' results in the formation of two substances: carbon dioxide and water. Carbon dioxide is very harmful, and the body expels it without delay, leaving water for its own needs. One gram of carbohydrates gives 0.56 gram of water, and one gram of fats gives 1.07 grams. The



body of a full-grown adult produces 300 grams of water daily.

For man this is an insignificant quantity, but for some animals this is the only way to obtain water. Bustards, larks, gerbils, some species of mice and other rodents get along quite happily for a long time without water. Many of these hardly drink at all, feeding on dry grass stems and plant seeds which contain practically no moisture. The water they need comes from oxidation of the fats and carbohydrates in their food.

The best raw materials for water production are fats and carbohydrates because, besides water and CO_2, no harmful substances are formed as a result of their combustion. They are also very easy to store. All creatures living in dry steppes and deserts, such as snakes, lizards, antelopes, giraffes, zebras, lions and ostriches, are able to store large amounts of fat.

Animals have special places in which to store their fat. No fat is kept under the skin, otherwise the animal would die from overheating. For example, the camel stores fat in its humps which are not intended for mere adornment or to make the ride on its back more comfortable. The hump is loosely supported on the camel's back, and as the rest of its body surface has no fat, the camel is never hot.

Often the tail serves as a store. In this case, too, the store is a separate unit. In jerboas and gerbils the fat is accumulated at the base of the tail. The store of fat in the tails of the gigantic lizards known as monitors is very large, and in fat-tailed sheep it is even bigger. These sheep have two large protuberances on each side of their tails. The store of fat may vary: in camels it is sometimes as much as 110 to 120 kilograms, and in fat-tailed sheep ten or eleven kilograms.

If an animal finds itself without water, it immediately starts producing its own water, using the store of fat for the purpose. The camel can go without water for 45 days, working quite normally and eating nothing but its usual amount of dry hay for the first fifteen days.

This method of producing water is very convenient: oxidation of the fat is accompanied by the formation of large amounts of energy, which are used up by the organism, thus enabling it to do without food. However, many desert animals experience more acute thirst when in captivity than when in their natural environment, as production of water is greatly reduced under these conditions. When at large they have to hunt every day. This involves much running about and they expend a great deal of energy in order to eat their fill. As is known, the fats and carbohydrates required by the muscles are turned into water in the long run.

Not only desert animals live on chemically produced water. When the organism has no other means of replenishing its store of water, oxidation of fats is the only source. It is, therefore, not surprising that there is so much fat in birds' eggs. Fat is a source of energy which at the same time yields a considerable amount of water.

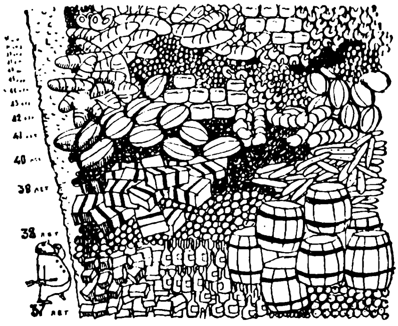
Certainly, life in the desert has not only become possible because its inhabitants have developed the ability to produce water chemically, obtain it from the air, and find it in minute quantities in the sand and stones, but also because they have learned to hide themselves from the heat of the sun during the daytime, found ways of preventing the evaporation of water from the organism, and, what is even more important, they have learned to use water with the strictest economy. But for all these measures, life in the desert would be impossible.

Construction Materials

LUCULLUS' FEATS

In 74-64 B.C. the Roman legions headed by Lucius Licinius Lucullus completely defeated the troops of the Pontician King, Mithridates VI (the Great), and then those of his relative, the Armenian King, Tigranes II. The great State of Mithridates disintegrated. Lucullus, however, became widely-known not only for his feats of arms and his genius as a military leader, but mainly for the luxury and gluttony in which he indulged.

The Romans enjoyed eating and liked to be extravagant. Their lively feasts lasted for hours and hours, even days. During this time they consumed large quantities of exquisite food. The feasters used to recline on cushions and listen to music and songs while savouring various viands, followed by a great deal of wine. Even the Romans' well-trained stomachs were unable to digest such large amounts of food. This, however, was not imposed upon them. Having eaten their fill, the feasters would put two fingers in their mouths to cause vomiting, and would then return to their meal. People like Lucullus still exist nowadays. If one adds up all one eats and drinks within a lifetime, one can think of oneself as



Lucullus, since this will amount to huge quantities of different foodstuffs, the transportation of which would require several railway containers.

Requirements in food differ. Smaller animals need larger amounts of food, relatively speaking. For example, a mole needs as much food every day as he weighs, and very often three times as much.

One should not think that to eat large amounts is good. An experiment was conducted by the scientific workers in Professor Nikitin's biochemical laboratory in Kharkov. One group of rats was fed on extremely varied and good food, but was given so little that the young animals could not grow, nor did they gain a single gram in weight. Another group was given the same food but in unlimited quantities. Strange as it may seem, the rats on the starvation diet lived longer than those who ate their fill.

Many animals need to eat very frequently. A mole will die after fourteen to seventeen hours of starvation, whereas ticks can live without food for several years. Some animals only eat once during their lives. There are also animals who stop eating as soon as they become full-grown. May-flies *(Ephemeras)* belong to this group.

Man also derives some benefit from short spells of starvation. Medicine even cures some diseases by making the patient starve. Starvation certainly seems to be beneficial in certain cases. Modern physicians disagree on this point, but they are unanimous in acknowledging the fact that starvation, when not prescribed by experienced physicians, may cause considerable harm to a patient.

In general, the reason why we need to consume this large amount of food during our lifetime is clear. It is primarily intended to provide construction materials. No matter how strange it may seem on the face of it, we continue to build up and rebuild our organism till well into old age. Throughout his life man's hair and nails are growing; the erythrocytes, the red blood corpuscles, live for only two or three months; then they die and are replaced by new ones. The cells of the skin epithelium live for an even shorter period, not more than seven days.

The molecules of each cell in the body are continuously being replenished. Some molecules are completely destroyed and new ones are synthesized in their place, whilst others are partially rebuilt. Some of the construction materials become waste matter and can no longer be used. For this reason all organisms continually need a supply of new construction materials. Trouble immediately begins if a deficiency occurs. Lack of copper or iron will result in anaemia. Even bones, which seem so firm, are continuously being built up. If the food consumed over a long time contains no calcium, bones which have sufficient calcium will start to give it up to supply the organism's other needs and they themselves become soft and pliable.

The other purpose of food is to provide the organism with energy resources. The building of new molecules is in itself a process which calls for a certain amount of energy. Then there are the muscles and all the other organs of our body, most of which never stop functioning, not even for a single minute. Even when one is asleep the heart goes on working, as do the breathing muscles, the liver, kidneys, gastro-intestinal tract, and endocrine glands. Even the brain goes on expending energy on quite a large scale, although this is the one we notice least.

Energy losses can be quite easily restored. Used as 'fuel' are fats, carbohydrates and, to a certain extent, proteins which 'burn' in the organism to form carbon dioxide and water. The organism actually consumes only one kind of fuel—glucose. Fats and proteins are first converted to glucose, before they become a power-supplying material.

It is easier to provide the organism with fuel than to supply it with all the necessary construction materials. Man's body consists mainly of carbon, nitrogen, oxygen and hydrogen, with small, sometimes negligible, amounts of other chemical elements.

Gabriel Bertrand, a French chemist, calculated that the body of a man weighing about 100 kilograms contains:

oxygen	63 kg	sodium	260 g
carbon	19 kg	potassium	220 g
hydrogen	9 kg	chlorine	180 g
nitrogen	5 kg	magnesium	40 g
calcium	1 kg	iron	3 g
phosphorus	700 g	iodine	0.03 g
sulphur	640 g		

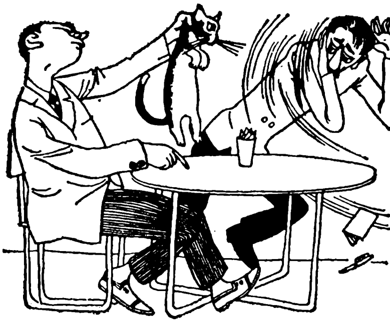
Fluorine, bromine, manganese and copper are present in even lesser amounts. It is quite possible that all the other elements, even those which are not very active chemically, such as gold, can be found in the organism but we still do not understand the part they play.

Normally, with a well-balanced diet, the organism receives adequate amounts of all the necessary elements through the food and water consumed. When, however, any one element is lacking various diseases, sometimes very serious, may occur. When soil lacks iodine it is necessary to add it to the household salt. The water of the river Neva is considered to be the purest and the best drinking water in the world, but this purity is its main shortcoming. One of Leningrad water-works has begun to add fluorine to the drinking water, since absence of fluorine frequently causes tooth trouble. What is more, Swedish scientists discovered that people who systematically use soft water are much more liable to develop cardiovascular diseases.

Some difficulties in supplying chemical elements to the organism arise because most substances composing the tissues and organs cannot be synthesized directly from elements. For instance, proteins are built up of different combinations of twenty-two amino acids, of which only ten can be synthesized by the organism, while the remaining twelve must be obtained ready-made. Besides, even when we ourselves produce the amino acids, the nitrogen necessary for the purpose must be supplied in the form of organic compounds. The same is true of glucose which cannot be synthesized directly from carbon and hydrogen in the organisms of animals, and this is why ready-made hydrocarbons are used to produce it.

Of the many substances which are absolutely essential to the organism, even in small amounts, mention must be made of vitamins. They are indispensible to life.

The choice of food is very important. Bees are an excellent example. A queen-bee which feeds on so-called royal jelly from its first days till the end of its life lives for two or three years. The worker bees receive this miraculous food for only the first few days of their



lives and are given coarser food from the third day on. As a result they do not become completely fertile females and live only two or three weeks.

The composition of food may influence not only physical but also mental development. According to popular belief, in Italy the districts growing white apricots give the world many more geniuses than all the other regions of the globe. Such suppositions are not completely unfounded. At any rate many psychopharmacologists do not think it absolutely absurd to search for a substance which might produce geniuses, stimulate the brain and facilitate educational training and other mental processes. At some future time this search will probably bear fruit.

Man is an omnivorous creature. Apart from sheer habit, nothing prevents him from adapting to any kind of food. There are few omnivorous creatures in the animal world, for the majority of creatures eat a certain kind of food. Some feed on strange things—wood, wool, feathers, squama (fish scale), or wax—which, on the face of it, do not seem to be very good to eat.

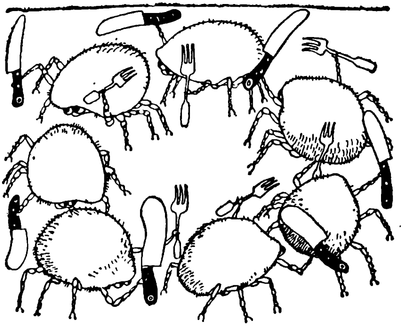
Animals of the same species may sometimes differ widely in their tastes. In a family of mosquitoes the females are blood-suckers because they need protein to produce offsprings while the males are content with plant food.

Taste frequently changes with age. The evolution of feeding habits is particularly striking in African honey-guides. Those amusing little birds do not make their own nests but abandon their eggs to other families just as our cuckoos do. The foster-parents feed the future honey-guide with insects, as they do their own offspring. But, when the little nestling grows up and becomes independent, it begins to search for destroyed bee nests and feed choicely on beeswax.

How and why it develops a passion for wax is difficult to say, since its foster-parents do not teach it, but the honey-guide begins feeding exclusively at the expense of bees and looks for undamaged nests as well. However, it is not strong enough to cope with a bee community on its own and resorts to the help of stronger robbers (honey-badgers at the worst), its loud chirping notifying the local inhabitants and certain animals of its find.

Of the strange eating habits in the world cannibalism is the most repulsive. This word is taken from Spanish and means 'eating human flesh'. It is also used to denote animals which feed on their own kind.

An interesting kind of cannibalism can be observed among avian ticks, which are carriers of spirochaetosis, an extremely dangerous disease for birds. When they attach themselves to a bird the larvae of these mites, the nymphae, and the adult insects do not always penetrate into its body. If there are a lot of them a few always prove to be cannibals; these try to find a female tick or a nymph that is already sucking blood and attach themselves to it. Sometimes another cannibal attaches itself to the first one, then a third cannibal and so on, making a queue of up to five, all sucking the bird's blood or



victim's haemolymph from one another. The victim, incidentally, does not react to this onslaught at all. The chain of parasites feeding upon one another does not break apart until all of them have satisfied their hunger. The mites attacked by their fellows remain alive and continue to develop normally.

Speaking of exotic tastes, one should not forget the coprophagous animals which do a great deal of good (*kopros* is the Greek for dung, *phagos* means one who devours).

Many animals only resort to eating excrements for a short time. For instance, some of the dog family will eat the faeces of their offspring while they are very young. This is, no doubt, for the sake of hygiene, to ensure cleanliness in the den.

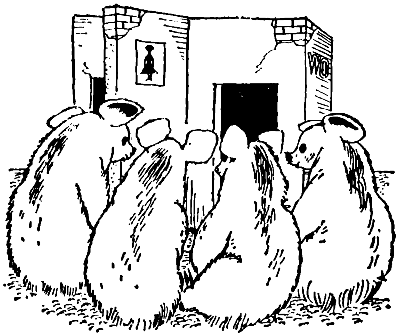
The dung-eating habit of the larva of the honeycomb moth which usually feeds on beeswax is extremely interesting. But, if voracious creatures have already succeeded in destroying a bee nest completely and devouring all the wax, the larvae have to eat their own excrements which have accumulated by that time in excess. The surprising thing is that the new excrements also prove edible. More than one generation of honeycomb moth can thus grow up feeding on their own excrements, and eating them up again. This peculiar cycle may sometimes last for seven or eight years.

The explanation for this everlasting replenishment of energy resources is simple. Beeswax is a substance which is extremely hard to digest. Even in the intestines of the honeycomb moth, which is adapted to feeding exclusively on beeswax, it is never digested completely. This explains the efficacy of the repeated processing of excrements.

Our Earth is also inhabited by large numbers of permanently coprophagous creatures. Some beetles, mites and worms feed solely on dung. Among them are some which will eat only cow, horse or hare dung. Of special interest are dung beetles, which dig small burrows beneath dung heaps and fill them up with food supplies for future larvae.

The sacred scarabs are puzzling in that they roll the dung up into balls which are many times larger than they themselves. It was not without reason that the ancient Egyptians thought these beetles to be sacred and worshipped their graven images. Every Apis, a sacred bull which lived in the temple of Memphis, had an image of this natural sanitary worker painted on its body.

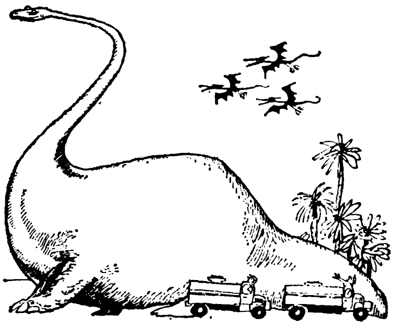
Red wood ants normally live exclusively on the excrements of aphides which contain sugar and other nutrients. The ants not only gather the excrements, they also protect the aphides against their enemies, breed them and tend them. In the autumn the ants search for the winter eggs of the aphides and hide them in their anthills. When spring comes and it gets warm, these toilers drag the young aphides out onto the grass and pasture them. Every evening they carry them 'home' until the nights grow warm enough for them to stay outdoors. Some ants breed aphides that live on roots and



build for them miniature sheds of earth. In one year a single anthill collects about one hundred kilograms of aphides' excrements.

Some animals are coprophagous only in their infancy. The Australian eucalyptus forests are inhabited by charming little animals which look like cuddly Teddy bears. They are koalas, reared in their mothers' pouch which, unlike that of a kangaroo, opens to the rear. To begin with, the young feed on their mother's milk and then eat her excrements which consist of a pepton-rich pulp of digested eucalyptus leaves. Since the pouches open to the rear, the young can easily obtain their food during flight (koalas live at the tops of tall trees and never come down to the ground).

And what about us, humans? You may imagine that it is our natural aesthetic feelings that guard us against feeding on such strange things. Far from it. Don't forget honey. This tasty and widely-used food is of a rather non-aesthetic origin. The raw material is flower nectar which is first processed in the craws of the foraging bees where cane sugar is partially converted into fruit and grape sugar and then discharged into the honeycomb cells. This is how honey is obtained from flowers.



Even less aesthetic is the origin of honeydew which is collected in vast amounts in Germany. This is simply the same excrement of the aphides as the wood ant eats, but, nonetheless, the people of that country consider it to be a great delicacy.

But, ignoring the somewhat exotic tastes of coprophagous creatures, one must admit that they are very useful. They not only make our planet cleaner, but retain valuable organic compounds within a natural cycle, and this is even more important.

It seems that in the past there were fewer coprophagous animals on the globe than now. At any rate they evidently did not cope with their duties. About seven to eight million years ago Europe was inhabited by ichthyosauruses, gigantic predatory reptiles. They were so big, there were so many of them, and their reign lasted so long that in some parts of the Earth the ichthyosauruses left rather conspicuous traces of their existence in the form of huge dung heaps.

They say that time exerts an ennobling effect on all things. This is true to a certain extent. Common pine resin which has lain underground for a few million years turns into stone and becomes noble amber. Over thousands of years the dung of the ichthyosauruses has turned to stone which has enhanced it in that its unpleasant smell disappeared. The largest accumulations of coprolite (fossilized excreta) have been found in England, not far from York, and in Western Germany where they have long been mined and used to advantage. When finely crushed, coprolite has proved to be a very good fertilizer.

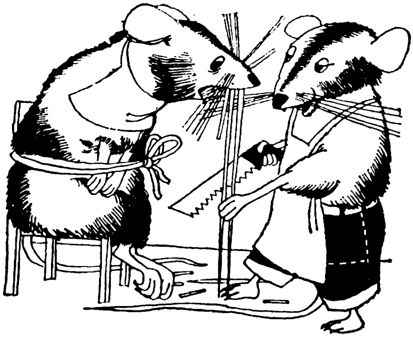
Strange as it may seem, this is not the only use for coprolites. Owing to the fact that they contain much cemented sepia (the ink sacs of fossilized molluscs), fish scales and undigested bones, the polished surface of coprolite has a beautiful pattern. This explains why fossilized ichthyosaurus dung is used for making various small articles, brooches, beads, and other adornments for women.

Indeed, history sometimes works in a very curious way and the whims of women's fashion are limitless.

TEETH WHICH 'CRAWL'

When asked to name the most important organs in the body, few people remember the teeth, but these, nonetheless, perform a very important function. The teeth frequently help to kill the prey, hold it and then break it up for food. This is why wild animals which have lost their teeth are doomed to death. Even man, who has learnt to make false teeth and is in no way limited as to his choice of food, is not indifferent to the loss of his natural teeth.

Teeth are equally important both to predatory and herbivorous animals. The well-known Indian hunter Jim Corbett describes several instances when the loss of but a single canine tooth made a tiger attack domestic animals and even humans, as he was no longer able



to cope with the large hoofed animals on which he usually fed.

Rodents probably give their teeth more work than any other animal. Even the sharpest teeth cast from the hardest metal would be worn down by such work. The only solution is for the teeth to keep growing. In fact, the front teeth of rodents grow continuously and so quickly that if the animal were deprived of hard food and the teeth stopped wearing down, they would grow to an incredible size and incapacitate their owner. The incisor teeth of rats grow three centimetres a month. If they did not wear them down every tooth would reach seventy to one hundred centimetres by old age.

The elephant's expectancy of life depends on the condition of its teeth. In a free state it feeds on vegetable matter some of which may be rather hard and has to be crushed by its powerful molars. An elephant has only two pairs of working teeth: one pair is in the upper jaw, the other in the lower. In addition, each jaw has five pairs of rudimentary teeth. As the teeth wear out, they fall out and new ones grow in their place until the sixth pair, which is the last, has worn out. The

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elephant's nutrition gradually deteriorates and this results in its death.

Teeth are also extremely important to predatory fish. Sharks have jaws whose inside surface is studded with teeth. These are arranged in regular rows with the tips pointing backwards, thus allowing the shark to hold its prey securely. Of course, the teeth at the very front have to work the hardest and they wear out the most rapidly. Sharks, too, would have a bad time, if their front teeth were not replaced by new ones. The fact is that the front teeth are in motion throughout the shark's life. Bent over like attacking soldiers, row after row, they slowly but steadily move towards the edge of the jaw. The front rows of old worn-out teeth gradually 'crawl' out and, after having taken a glance at the outside world, fall out, only to be replaced by the next ones. Having worked their share, and become well worn-out, these teeth, in their turn, release themselves and those behind move up to replace them. This process continues, until the shark dies. Some extinct fossilized sharks had teeth which had not fallen out and, although they were quite old, they had the front part of their snout studded with teeth. This ability to constantly renew its teeth means that a shark is able to fight right up to old age.

When the teeth are used solely to crush food they may be located in some place other than the mouth. In some cases it may even prove advantageous to move them from the 'preparatory' shop to some adjacent department. Fish of the carp family have a toothless mouth but you would be well advised not to put your finger into the throat of such a fish for it is there that they have their teeth and the initial processing of food is carried out.

Some predatory fish and turtles have their teeth in their gullet. These are not so much teeth as very sharp and sometimes rather large spikes which are necessary to prevent the prey, which is still alive, from getting away. A spike-studded gullet is very much like the skin of a hedgehog or spiny anteater. All the spikes point towards the stomach and the food can thus only move in that direction. There is no way back from the stomach.

Those creatures which have no teeth of their own have to resort to substitutes. Food eaten by birds is crushed by little stones in their stomachs: the grains are taken into a thick-walled muscular stomach of considerable strength and crushed between the little stones as though between millstones.

Small stones are often to be found in the stomachs of birds. You may find them if you are preparing a chicken for the oven. But this phenomenon is still a puzzle in many respects. What makes birds swallow stones? They do not do it because they are hungry. How do birds know when the stones in their stomachs have worn out and need replacing? What makes them pick up only sufficiently strong stones? As yet, we cannot answer these questions.

Not only birds are fond of swallowing stones. Stones weighing 350 to 500 grams are often found in the stomachs of whales, walruses and seals. From time to time they belch out these stones and this is why there is often a lot of stones from the sea bottom deposited in places where these fin-footed animals spend a good deal of their time when on land. One might think that they have decided to establish a geological museum on the sea-shore.

Scientists do not as yet know why sea mammals load their digestive tract with such unusual objects. The reason may be that the stones help, as they do in birds' stomachs, to crush such hard parts of their food as mollusc shells and the chitinous shells of arthropods. Another reason may be that these are used in the struggle with intestinal parasites which are a particular nuisance to fin-footed animals.

Animals are especially apt to swallow stones when they have gone for a long time without food. Hence, the suggestion has been made that swallowing stones prevents the stomach from atrophy (the shrinking of an organ or tissue with resultant cessation of functioning). Thus, swallowing stones keeps the stomach busy, when it would otherwise have nothing to do.

However, it is quite probable that some sea mammals indulge in stone eating for reasons other than that of digestion. Some scientists believe that stones become indispensible when the mammals feed particularly well and get fat. As a result, their mean specific gravity drops and they find it more and more difficult to submerge in water. Sea-faring animals may also swallow stones so as to take aboard some ballast and increase their weight. Calculations prove that the amount of ballast is quite large: some seals had as much as eleven kilograms of stones in their stomachs.

In far from all cases are the teeth the best possible tools, and Nature has not hesitated to substitute more perfect technical means for them. Many species of the prosobranchiate snails feed on molluscs which are rather large and enclosed in a hard shell. To make a hole in the shell with a radula would take weeks or even months, and the radula would wear out. Therefore, these snails use a specific saliva instead of teeth, which is a four-percent solution of sulphuric acid. Nor is this very strange, for, if the glandular cells of man's stomach secrete hydrochloric acid, why should snails not make use of sulphuric acid.

The acid secreted by the snails is so strong that it hisses and effervesces when it falls on marble. It dissolves the mollusc shells quite easily. When attacking their prey, the snails apply their saliva to the shell and loosen a small section of it. The preying snail then bores a hole with its radula, inserts its proboscis and is then able to enjoy eating the defenceless victim.

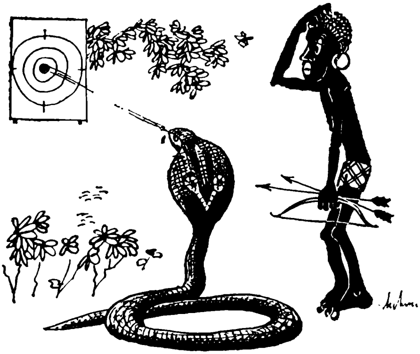
It is not always enough to crush food for it to pass easily into the gullet. This is why the 'preparatory shop' contains the large and small salivary glands for both the mechanical and chemical processing of food. Saliva performs many important functions, but the most important seems to be to wet each lump of food which otherwise would not pass into the alimentary tract. Any one who has had a chance to observe the European pond tortoises will have easily been convinced of the importance of saliva. The pond tortoises have no salivary glands. They eat their prey in water, amply washing down each mouthful. But on land they are helpless, since completely dry food sticks in their throats.

The saliva of most animals contains substances (enzymes) which are the first to act chemically on the food being taken in. Nature has subsequently developed these properties, making saliva somewhat poisonous. This is necessary as numerous micro-organisms, most of them harmful to the organism, may lodge in the moist lining of the mouth and the remains of food stuck between the teeth.

Usually, if Nature undertakes experiments with poisons, it does not stop half-way, but creates something capable of inspiring real horror, as, for example, poisonous snakes, whose bite may be fatal for man.

Now, from where does snake venom come? The venom is merely the snake's saliva secreted by somewhat modified salivary glands opening into a groove inside the tooth. The venom is only secreted when the snake bites, pressing against a little sac at the base of the tooth. During the bite all the venom is injected into the wound.

Some snakes have proved very ingenious in developing their lethal weapon. Cobras (the rose and zebra type)



and other African snakes have perfected their technique of biting and are very good at spitting their venom. Their poisonous fangs differ somewhat from those of their fellow snakes. The groove along which the venom is ejected does not open out at the very tip of the tooth, but some distance from it, widening into a sort of funnel (evidently to facilitate ejection). For this reason, if the bite is not deep, the poison may not reach the wound, but disperses in fine drops over a wide area. As in a shot-gun the strike area is the larger, the greater the distance between the snake and the target.

Snakes are experts at spitting venom and have a range of up to four metres. This range is achieved by combining the pressure in the venom sac with the inertia of movement, achieved by jerking the head forward, simultaneously ejecting the venom. If the venom gets into the eyes, the mucous membrane of the nose or the mouth of small animals they will die. Such a long-range weapon is more efficient than in other poisonous snakes.

Not only snakes have poisonous saliva. In the Pacific, near the Islands of Fiji, New-Guinea and Samoa there live gastropod molluscs with beautiful, cone-like shells as much as fifteen centimetres in length. However, one should not touch these cones. The crafty mollusc is sure to bite you with the sharp teeth of its radula. The poison of these creatures, especially that of the larger ones, is fatal to man.

A THOUSAND-YEAR-OLD MYSTERY SOLVED

Even primitive people knew that the food eaten by man and animals is digested in their stomachs. When skinning their game they were sure to peep into their stomachs and even nowadays almost no housewife can resist the temptation of learning what the pike had for dinner and whether the chicken's stomach contains anything of interest besides small stones and sand. When hunters cut up their prey they found in their intestines neither meat, nor grass or seeds, but a porridge-like mass, as though the food had been cooked there.

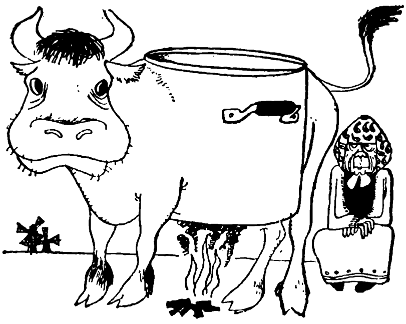
It took man a long time to find out what really occurs. The food is not changed under the influence of heat: the temperature in the stomachs of even the 'hottest' warm-blooded animals is no higher than 38-43°C and this is not sufficient to cook food. Digestion takes place with the aid of gastric juices containing special enzymes.

The alimentary canal of man and animals is a complex chemical laboratory. The food consumed is ground, mixed with various digestive juices and moves gradually from one part to another. In each part the food is held long enough for it to be processed and is saturated with special substances. These substances are absorbed during the digestive process, that is, during the breakdown of complex chemical substances into simple ones (proteins into amino acids, fats into glycerol and fatty acids, carbohydrates into monosaccharides). What cannot be digested and used by the organism is disposed of.

It was not easy to study the process of digestion. It was as late as the turn of the last century that the Russian scientist Ivan Petrovich Pavlov completed a detailed study of the main digestive glands. They turned out to be numerous and, what is more, it was discovered that for each type of food they produce a special composition of gastric juices. Academician Pavlov was awarded the Nobel prize, the highest international award, for these investigations. Thus, the basic mystery surrounding the process of digestion seemed to have been unveiled. However, the discovery was not yet complete. Nobody could reproduce the entire process of digestion in the laboratory by pouring into a test tube the necessary gastric juices in the correct sequence, and thus imitating the process observed in living organisms under natural conditions. The food was also digested in the test tube, but the process was all too slow, much slower than in the alimentary tract.

Recently, Soviet scientists have succeeded in uncovering this mystery. An astonishing thing is that the food which comes into contact with the intestinal wall is digested much more quickly than the main mass of food. This is similar to what happens when food is fried in a pan: the food in immediate contact with the pan cooks much more quickly. This is quite understandable, for this food is much hotter than the rest. But the intestinal wall is not at all hot, so why then does it accelerate digestion?

The first thing was to find out whether the intestinal wall really accelerated digestion. With this in view, the following experiment was carried out. A piece of intestine from a freshly-killed animal was placed in one of two test tubes containing equal amounts of a mixture of starch and an amylase (a starch-splitting enzyme). Splitting of the starch proceeded much more rapidly around the piece of intestine which proved that the in-



testinal wall did accelerate digestion. But how does this happen?

Another experiment was carried out. A piece of intestine was placed for some time in a test tube containing a starch solution. The idea was that if the intestine contained digestion-accelerating substances they would be secreted into the test tube. The intestine was then removed and some amylase added to the starch. Digestion proceeded slowly, just as in the original experiments.

Perhaps the piece of intestine did not have enough time to secrete the substance it was supposed to have. Yet another experiment was carried out. An extract was obtained from the intestine of a slaughtered animal. The extract should, no doubt, have contained the required substance. However, when the extract was added to the test tube containing the starch and amylase it did not accelerate the rate of digestion. This meant that the intestinal wall did not contain substances accelerating the process of digestion. What then triggered off the process?

The puzzle was solved unexpectedly. It was the very construction of the intestinal wall that facilitated the process of digestion. The surface of the epithelial cells lining the intestine carries ultra-microscopic shoots. Each cell carries as many as three thousand shoots and this makes the surface area of the intestine very extensive, enabling it to adsorb, i.e. precipitate and retain a great many enzymes. These enzymes act as catalysts accelerating chemical reactions. The enzymes interact chemically with the reagents, but as soon as the reaction is complete they regain their previous chemical composition. This explains why even small amounts of catalysts markedly accelerate the rate of chemical reactions.

It is only natural that digestion is more energetic on the inner surface of the intestinal wall where the concentration of enzymes is much greater. The total amount of enzymes may not be large; they can be used again and again. What is important is their extremely high concentration and this is why even moderate amounts of enzymes ensure a high rate of digestion.

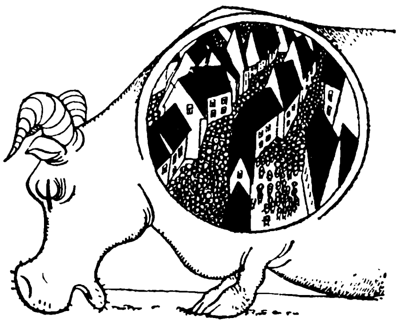
Food is digested in two stages. The first stage involves the bolus (where the concentration of enzymes is low) as it moves along the alimentary tract. At this stage, the food is subjected to primary treatment, the food lumps are first broken down into smaller ones and these in turn become separate molecules. The main process of digestion (the breakdown of molecules) occurs at the second stage, when digestion takes place in the intestine near the intestinal wall. This type of digestion, called parietal digestion, is very good for the organism. The first advantage, which has already been mentioned, is that it is possible to attain a very high rate of digestion with only small amounts of enzymes. The other advantage is that the digestive enzymes can be used sparingly. The enzymes that are adsorbed on the intestinal wall are preserved and continue to serve the organism for a long time, while those from the bolus are eliminated together with the remains of the undigested food and are thus lost. The third and final advantage is that the completely digested food, which is ready to be absorbed by the blood, is just where absorption takes place, i.e. close to the intestine wall. This greatly accelerates and improves absorption.

This discovery allowed another mystery to be solved. Physicians have long been aware that sometimes some of the glands in man's digestive system almost stop functioning as a result of illness. The sick person does not notice this since it does not affect his digestion. How the food was digested remained a puzzle. Now it has been discovered that the negligible amounts of enzymes secreted by a faulty gland are adsorbed by the intestinal wall, accumulated and retained, thus ensuring the normal digestion of food.

WHAT DO COWS EAT?

This question may seem surprising. Not only those who are not at all familiar with agriculture but even little children know quite well that cows feed on grass. However, one should not be in a hurry to give this answer, since ruminants, including cows, cannot be considered as really grass-eating animals.

We know that plants contain a great deal of cellulose which is used as a building material in cell walls. In order to use the cellulose as a nutrient and to obtain the very valuable substances contained in the cells, an enzyme is needed to split it. Strange as it may at first seem, the glands in the cow's digestive system do not produce such an enzyme. In general, no animals, not even wood fretter, wood carpenter or other wood-boring insects, which feed almost exclusively on wood, i.e. on nothing else but cellulose, have such an enzyme. Animals which have adapted themselves to coarse vegetable food digest it with the help of myriads of micro-organisms invading their alimentary tracts.



Such a colony of microbes has been best studied in cows. These microbes are to be found in a special section of the stomach known as the rumen (first stomach). Each cubic centimetre of the contents of the rumen contains from 15 to 20 thousand million micro-organisms. It is these organisms that feed on the grass which enters the cow's stomach. They eat up almost all their free food, thereby gaining weight and greatly multiplying. The cellulose contained in the grass is used for the production of the starch- and glycogen-like substances making up the body of the microbe, while the vegetable proteins are converted into microbial protein.

The fate of the rapidly growing colony of micro-organisms is simple: they are readily digested in the subsequent sections of the stomach and intestines, while the glucose, amino acids, fatty acids and certain other substances produced by them are absorbed by the blood without any treatment. The micro-organisms are thus the main source of basic nutrients. For this reason the cow should not be considered a grass-eating, it is, in fact, a microbe-eating animal.

It should, of course, occur to us that, since we feed not the cow itself but the microbes in its rumen, merely supplying the microbe factory with new building material, it should be possible to substitute synthetic fodder for natural. This is by no means idle speculation.

The bottleneck in the production of meat, milk, etc. is the fact that farms have an inadequate supply of protein-rich fodder. The animal organism cannot produce protein from inorganic substances and to get as much protein as they need farm animals eat plants, which are capable of synthesizing it from various inorganic nitrogen-containing substances. Vegetable foodstuffs, however, with the exception of pea and bean plants, are poor in proteins. This is very unfortunate because much more fodder is required to obtain one ton of meat, if the fodder is poor in protein. Besides, if the protein content of the fodder is low, the organism will use it up completely, whilst the remaining nutrients contained in it will be only partially assimilated. Thus, in order to achieve a sufficient gain in weight vast amounts of fodder are required, of which some are wasted. Consequently, scientists have long been seeking protein substitutes and now we have such substances, one of them being urea or carbamide. Urea is not a substance completely foreign to the organism. When proteins are split in the ordinary way, a very toxic substance, ammonia, is formed which is inactivated by the liver and secreted from the organism as urea.

Soviet farmers have been using carbamide for feeding cattle since 1959. In the cow's rumen carbamide is hydrolysed into ammonia from which, in turn, microbial protein is synthesized. The rumen is vast in size, sometimes reaching a capacity of 100 litres, and allows huge amounts of protein to be produced. One ton of carbamide produces an extra 8 to 10 thousand litres of milk, 1.8 to 2.1 tons of meat or 120 kilograms of wool.

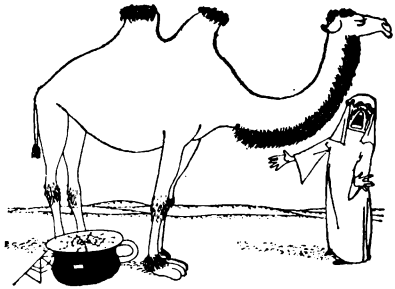
Caution should be taken when using carbamide as feed for cattle. An excess may lead to the micro-organisms not having sufficient time to use up all the ammonia which has formed, and it may result in poisoning. Carbamide cannot be given separately without other fodder, since in order to synthesize proteins the micro-organisms in the rumen need a certain amount of energy. This energy is obtained from the cellulose, starch and sugars. Besides, protein synthesis also requires vitamins A and D, sulphur, phosphorus, cobalt, and other minerals.

The use of urea as a feed additive did not come all of a sudden. Nature is frequently ahead of man in its 'guesses'. Animals which live in very severe and barren areas constantly experience acute shortages of water and food, so they have learnt to utilize the waste products of protein metabolism. The kidneys of a starving camel secrete almost no urea. It remains in the organism and enters the stomach, the microbe-producing factory, where protein is synthesized from it.

Urea cannot be used extensively in animal farming because it is very toxic. It can only be given under the strictest control, otherwise mass poisoning of cattle may result. Safer protein substitutes must obviously be found.

The causes of poisoning in animals fed with urea have already been detected. It is known that the rumen contains an enzyme, urease, which quickly hydrolyses the urea there. The ammonia so formed depresses the microbes, and they suspend feeding, while the ammonia which accumulated in large quantities enters the blood and so poisons the animal. So as to save cows from poisoning, it is necessary to prevent the urease from hydrolysing or to intensify the activity of the micro-organisms.

Recently, Soviet scientists have tested two protein substitutes, urea phosphate and urea glucosyl. They



believe that the introduction of phosphorus into the urea molecule should hinder the action of the urease and render the ammonia formed harmless. The introduction of a carbohydrate into the urea molecule (urea glucosyl) is expected to provide nutrition for the 'cow microbes', i. e. provide the energy to synthesize real proteins from the urea. The two substances have proved much safer than urea, and their use has yielded very good results.

There are other methods of using protein substitutes. Micro-organisms can be grown on farms and then used for feeding cattle. This is more expensive, complicated and less effective, but it is quite safe and will improve the nutrition of ruminants and other farm animals. Professor L. D. Petrov succeeded in trebling the protein content of a medium over forty eight hours by allowing the micro-organisms to develop on a carbamide-enriched potato. Such feed, rich in protein substances, can be successfully used for pigs.

So, a peculiar feature of the digestion in ruminants has prompted scientists to think of the possibility to enrich, through the microbial synthesis, the natural fodder of animals with proteins. We can, therefore, hope that in the near future much of the fodder for farm animals will be produced not in fields, but in factories.

Single-celled organisms have no special pans to cook food for themselves. The ingested food enters a vacuole, a kind of a provisional pan which disappears as soon as the process of digestion is over.

The process is different in more complicated organisms. The many-celled organisms which were the first to appear on our globe, the polyps and jellyfish, were nothing more than living pans. The similarity is not so much external as internal. In their appearance they remind one of a tobacco pouch, a little sac consisting of two layers of cells with an orifice for the intake of food and the excretion of all that is indigestible.

When the food is in the pan, special cells secrete specific substances under the action of which the food begins to be cooked and disintegrates into small particles. Then they are seized by the cells of the inner wall and the process of cooking is completed. Of course, not every cell is lucky enough to capture a tasty morsel, but the lucky ones are not selfish, and are willing to share it with their hungry neighbours. Besides, the cells in these animals are not permanently joined together. They are constantly floating and changing places with each other. Those which have had enough and stored up some nutrients are supposed to be forced aside by the hungry ones.

Things became more involved with the advent of more highly organized living beings. The way of digesting food had already been acquired and did not cause any trouble. The real difficulty was the delivery of nutrients to each and every cell of the body. At first, this function was taken up by the digestive system. In other words, the intestines tried to reach every cell in the body.

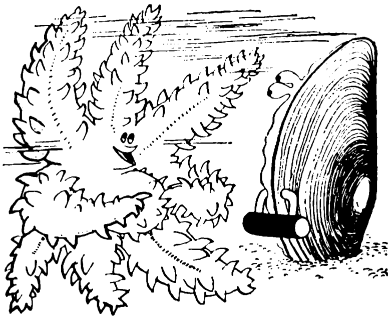
Thus, the Turbellaria came into existence. Their vast intestine, resembling a spreading tree, served as the base around which the body developed, feeding all the cells of the body. Of course, a supply system occupying nearly four fifths of the body was cumbersome; so the method was later rejected by Nature, and the functions of digestion and supply were strictly differentiated.

Nature is full of contrasts. While it was attempting to employ vast digestive organs, it was also trying to get along without them. Indeed, what were they for? Would it not have been simpler to moisten the food with enzymes, then wait for it to be digested, and finally absorb the prepared nutrients?

The Turbellaria class we have just spoken about also includes tiny animals without intestines. Their only organ of digestion is a gullet where gastric juices are poured onto the prey and the half-digested food is absorbed. The gullet rests against digestive parenchymatous cells which have no walls and are not separated from each other. Here the food particles, as if in a large amoeba, are finally digested. Owing to the very small size of these animals the remaining cells can exist.

The idea of moving the 'kitchen' with all its dirty utensils and waste products outside proved a very good one and many animals make good use of this peculiar method. The tiny insect larvae inhabiting the tissues of animals or plants most frequently resorted to this. Their jaws are too weak to work their way through living tissues. This is largely aided by the secretion of gastric juices which soften the surrounding cells. The larva eats a ready-cooked dinner while gradually moving forward.

The same method is used by adult insects who drive a sharp stiletto into the leaves or some other part of the plants, spraying them with digestive enzymes which destroy the cellular structures and engender the hydro-



lysis of starch and polysaccharides into monosaccharides. This well-cooked jam is then eaten with relish. If the insects prefer a meat diet, they drive their stilettoes into their own brothers or other creatures and inject a drop of enzymes under the skin.

To arrange for the kitchen to be outside proved convenient for large animals too. Starfish live in all the oceans of the world. These beautiful and rather sluggish animals are real beasts of prey, their favourite food being oysters. The starfish actually devastate oyster banks. It has long been a mystery how an awkward starfish can open a tightly closed oyster shell. The habits of the starfish have recently been studied. It turned out that they never try to force open the mollusc's shell. It acts in a much simpler way. It turns its stomach inside out and waits for the moment when the oyster opens its shell slightly. A tiny opening, one millimetre wide, is enough for the stomach to pry its way into the mollusc's home. Now nothing can stop the starfish from digesting the prey in its own abode. When the mollusc has been killed, its shell opens by itself, making it easy to scrape clean the crude of the shell.

Some modern animals prefer not to cook for themselves but to find some suitable 'canteen' or 'cheap restaurant' and have their meals there. The animals in question are helminths which are intestinal parasitic worms. These deleterious, repulsive creatures have not taken the pains to provide themselves with any digestive organs. To be more exact, what they did was to get rid of them, since their ancestors no doubt possessed some such devices.

The intestinal parasites prefer to have everything served to them ready prepared and they manage perfectly. In the intestines of man or animals they ingest through their skin the food digested and prepared by the host for himself.

However, it may not have been easy to adapt oneself to such a life. In order to live in the intestines, they had to become accustomed to being without oxygen and to provide themselves with a firm cuticle (an outer layer) which reliably protects them from the host's gastric juices but allows them to absorb the food digested by the host.

One could hardly call the intestinal parasites complete lazybones, since they are compelled to do some absorbing. There are far worse lazybones. One such was described in a funny Ukrainian anecdote.

A lazybones was invited to take on a job.

'What kind of work will I have to do?' he asked.

'Nothing hard,' he was told. 'You will just have to dip the noodles into sour cream and swallow them, dip them into sour cream and swallow them.'

'No,' replied the lazybones after some consideration. 'First dip and then swallow,' and he refused the job point blank.

Lazybones like this are to be found in the depths of the ocean: one of them is the male angler fish which lives in the darkness of the middle depths of the ocean.

For a long time scientists classed the males and females as being from different species because they did not resemble each other. The males are much smaller than the females and do not have the famous 'rod', a long filament on the head. When they grow up they begin dreaming of a girl friend and set out to look for her. Having become love-sick over their would-be mate they loose their appetite, at least there seems to be no other conceivable reason why they do not eat. They eat nothing, and, if they fail to find their partner before they run out of subcutaneous fat, they starve to death.

It is not easy to find a girl friend since angler fish are scarce and live on their own. Only a few netted females had their males with them. Thus it is understandable that when a male does find a partner he sticks close to her. As soon as he sees a female he wastes no time, and sinks his teeth into some soft spot in her body and does not let go but keeps hanging onto his wife. Little by little, they become one, and incompatibility of tissues somehow does not seem to interfere with the process. Meanwhile, the male's sensory organs waste away, as well as almost all his other internal organs, including the digestive system, only his testicles go on functioning intensely. All necessities, such as oxygen and nutrients, the parasitic male gets from the blood of the female. This lazybones does not even need to absorb food, nor is he engaged in any dipping or swallowing as the one in the anecdote. The only thing he has to do is distribute the food uniformly throughout his body.

External digestion frequently leads to curious things. If animals with well-developed digestive organs resort to this method, the question naturally arises as to what happens to the pans that have become unnecessary. Nature does not like excesses. Unnecessary organs die off or master a new function. This is what happened to the digestive tract in the larvae of Mermithidae worms, tiny, parasitic eelworms.

The first man to pay attention to the strange features of the digestion of Mermithidae worms was the German scientist Hans Meissner. He noticed that their larva had a very narrow oesophagus, the walls of which were completely without muscles. The tiny nematodes feed on liquid food, but it is hardly possible that such a weak oesophagus could suck it in. One of Meissner's colleagues suggested that the food is drawn into the oesophagus by special capillary forces which make it float straight into the mouth and all the worms have to do is to keep their mouth open.

But Meissner was at variance with physics and did not believe in capillary forces. He never gave up his microscope and was rewarded in the long run when he detected quite by chance that the larva's oesophagus had a blind end and was not connected to the intestine, the latter having no inlet or outlet (nematode worms have no stomach, the intestine being directly adjacent to the oesophagus). No matter how hard he tried, he failed to explain how nematode worms feed.

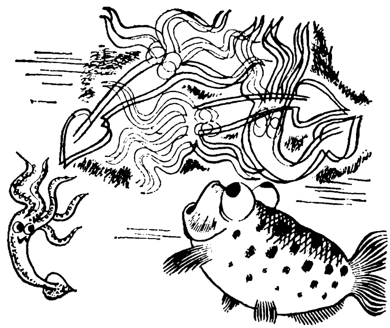
Only recently, scientists have succeeded in solving the puzzle. The digestion of nematode worms is of an external type. No food can get inside their oesophagus. On the contrary, the tissues surrounding it produce gastric juices which gradually percolate into the oesophagus and thence pass to the outside. To these are added enzymes which come from the worm's body along special ducts in its cuticle (outer shell). The gastric juices digest the tissues of the host creature in which the larva lives and the ready-prepared meal is absorbed directly through the cuticle and taken all over the body by the blood.

Why then do the larvae need an intestine? The food which enters the blood proves to be only partially used for growth and other purposes, the excess not passing from the intestine to the blood, as you find in all self-respecting animals, but vice versa, from the blood to the intestines.

The intestine of nematode worms is not empty. Its orifice is filled with special cells where food is accumulated in the form of protein and fat granules. The larva's intestine is thus used as a food store. Adult worms stop eating and use the stored material for sexual products and as a source of energy. Nematode worms could not reproduce if they did not have an adequate store of food.

Not infrequently higher animals also use their pans in a manner contrary to what they were intended for. All mammals have digestive systems beginning in the oral cavity, passing via the oesophagus to the stomach, after which a long series of saucepans follows: a duodenum, jejunum, ileum, caecum, colon, S-shaped intestine and a rectum. In man's body they measure up to 8.5 metres, while in that of the herbivorous animals they are much longer. Some 50 to 70 centimetres of the pipe can be cut out anywhere along its length with no detrimental effect to digestion, the exception being the first 25 to 30 centimetres which comprise the duodenum; under no circumstances should this be touched. Animals whose duodenum has been removed usually die shortly after the operation and those who survive the first few difficult days die within the first three months. A sharp decrease occurs in the body temperature, sometimes as much as four degrees. They lose their appetite and gradually grow thinner, losing by the end of the second or third month up to 60 per cent of their weight, and then die.

Scientists have not yet discovered the reason for this. Two suggestions have been made to explain the phenomenon: either the elimination of the duodenum



upsets their digestion, or else the duodenum, besides digestion, performs other functions essential to the body. Observations testify to the latter. If the duodenum is not removed completely, but three or four centimetres are left, the animal will not die. This means that it is not the operational trauma which leads to the animal's death but the absence of a duodenum. It is possible to exclude the duodenum from the process of digestion completely without removing it from the body by bypassing the food. Such animals live quite well, which proves that the duodenum performs some other functions. The duodenum is alleged to be an endocrine gland secreting some very important substances into the blood, which are as yet unknown to us.

Of no less interest is the defensive function of the liver in nudibranchiate molluscs. This is a very large organ that consists of numerous lobules with interconnected ducts opening into the stomach. The glandular ducts of the liver run through the whole body of the molluscs, entering the tentacle-shaped protuberances on their backs, at the tops of which they open to the outside. It is there that the numerous stinging capsules, the mollusc's formidable weapons, are found at these points in the epithelium of the small ducts. The most interesting thing is that the stinging capsules do not belong to the molluscs themselves but are 'borrowed' from the hydrozoan polyps on which the molluscs feed. The stinging capsules are not digested in the mollusc's alimentary tract but enter the liver. The capsules are thus able to shoot poisonous harpoons as soon as anything touches their host, the mollusc. The victim's weapon, therefore, actually becomes the property of the victor.

A very peculiar defensive function is performed by the intestines of cephalopods. Right near their anus squids and cuttlefish have the opening of an ink sac. This ink sac is actually a large pear-shaped gland excreting an ink-black liquid, a few drops of which are sufficient to make the water turbid. The mollusc thus confuses its enemy with a 'smoke screen', while it disappears into the depths of the sea.

Many molluscs are capable of excreting their ink in such a way that it does not dissolve but is suspended in the water like a large blob similar in shape to its creator. The cunning mollusc palms off its double onto its persecutor.

This chapter should finish here, had scientists not come across another wonderful creature dwelling in the depths of the ocean. Pogonophorae have been discovered and studied only recently due to the efforts of the outstanding zoologist, A. V. Ivanov, from Leningrad, USSR. They resemble long, thin worms with a turban of tentacles at the head end, ranging from one to 220 in number. Sometimes these are bound up in the form of a tube or coil. Pogonophorae live in long tubes which they build themselves and are as happy there as in little burrows. They are fairly developed creatures, having both a nervous system and an enclosed system of blood circulation, but no digestive organs. Nobody knows how they get along without them, but A. V. Ivanov has made an interesting suggestion. He maintains that the pogonophora makes use of external digestion. Having caught a suitable object, the animal hides together with its prey in its tube and then, having entangled its victim in a dense mesh of tentacles, the little predator makes an improvised stomach into which the cells at the base of the tentacles secrete the digestive enzymes, while the tentacles themselves suck in the digested food.

It is difficult to tell how close this suggestion is to reality. One thing is certain: the digestion of the pogonophora is yet another of Nature's wonderful inventions.

THE FOOD INDUSTRY

It is the second half of August. It is still warm but one can feel the approach of autumn for the days are growing shorter and the morning mists denser. The signs of autumn are all around: the hay has long been stacked in the meadows, and the leaves on the birch-trees are turning to a golden colour. It is harvest-time. The shops are full of vegetables, all kinds of fruit, and early grapes.

It is especially beautiful in the forest at this time of the year. The sunny forest glades and spots shaded by centuries-old fir-trees are full of the fragrance of ripe berries, while the hollows smell of mushrooms. On Fridays and Saturdays thousands of town-dwellers with their buckets and baskets head for the suburban trains, and on Mondays housewives make jam, bottle fruit, and pickle and dry mushrooms, filling the air with pleasant aromas.

This time of the year finds the wild animals busy harvesting too. Many of them would not be able to live through the long winter without stored food. This is why they have become so good at stocking up. No sooner does it get dark and the roar of the tractor engine dies away than they cautiously leave their burrows; mice, field voles, hamsters, all fill their underground storage bins with the best grain. When winter comes, every hamster will have in its burrow three or four kilograms of neatly stored grain. When it is cold and the fields are covered with snow these little rogues will not have to come out into the open. They will be warm, well-fed and quite safe.

The forest dwellers do not lag behind the field animals. On the edge of a forest glade one can see mushrooms hanging in rows from the thick branches of a little dead fir-tree. What kind of mushroom gatherer is this and why does he dry his mushrooms in the forest? Why, this is none other than the mischievous red squirrel! Running about the forest, it puts a ripe nut or acorn in the hollow trunk of a tree or hangs a small mushroom on a branch, thinking that it will all come in handy for the winter. The little chipmunk is fond of storing cedar cones, but its young are seldom lucky enough to enjoy such reserves. Everyone likes those tasty little seeds, but it is extremely difficult to pick them out of the cone. The lumbering bear, master of the taiga, prefers to dig up the chipmunk's pantry and have its breakfast without any fuss. And should the owner of the pantry appear on the scene the bear will finish it off too!

In the meadows of the Altai mountains there are some wonderful types of grass and, when winter comes, small stacks of hay are to be found there. Take a close look at those little haystacks and you will see that the hay in them is stacked very carefully. They are not made from all the kinds of grass growing in the meadow but only from the more succulent and nourishing kinds. The owner of the stack is a small rodent known as a hay-creeper. With the coming of autumn

these small animals start their hay-making. They cut down the best stems and spread them over the meadow to dry, and then make little stacks of them. In this way they are sure to have the best hay for winter.

Bees start stock-piling in early spring. As soon as the sun warms the soil and the early flowers form a brightly coloured carpet, the bees fly out to collect nectar to make honey. But it is not easy for a great deal of raw material is needed, to say nothing of the skill of the cooks, otherwise nothing will come of it.

The nectar collected from flowers contains forty to sixty per cent water. The bees' task is to 'boil the water off' until not more than twenty per cent remains. A healthy, strong family of bees is capable of collecting 150-250 kilograms of honey in a season which means that 180-350 litres of water have to be evaporated. This is easy if there is a spell of warm weather. But when it gets colder the bees crowd together on the honeycombs and keep them warm with their own bodies.

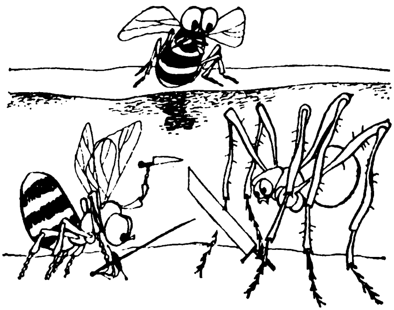
When the honey is completely ready, it is transferred to a special comb and sealed with wax. Here it will be stored till the bees need it. If the honey has been well made it will never ferment or become sugary.

As yet scientists have no clear idea why honey keeps for years. Normally, what spoils any foodstuffs, including jam and canned foods, are micro-organisms, which are eliminated by prolonged boiling. What is more, food containers are sealed in such a way as to keep micro-organisms out. But bees preserve their honey without resorting to boiling. Honey itself is known to contain substances which destroy micro-organisms. Ancient peoples made use of this property in folk medicine for they knew that honey was good for healing wounds.

Another difficult task is to keep plunderers away from the honey and it is no wonder that bees keep a keen eye on their treasure. The guards at the entrance of the hive never doze off, and at the slightest danger a swarm of defenders will fly out to meet the enemy without a care for their own lives. The smell of a freshly torn off sting is the signal for battle. This excites the bees and they attack whatever creature happens to be near the hive at the moment of alarm. Even the lumbering bear, master of the woods, will retreat under their joint onslaught.

No force seems to exist which can stand in the way of bees. But the temptation to partake of the honey is so great that some desperate creatures do try their luck. Plunderers watch for an opportunity day and night, in warm and bad weather, and resort both to force and cunning. The smallest insects are the worst: they defy all obstacles.

Man combats insects using chemicals. Moths are frightened away by the smell of naphthalene and insects are killed by DDT, various chlorine- and phosphorus-containing compounds and other insecticides. But bees had invented a chemical antidote many thousands of years before man did. Nature has plenty of poisonous plants and the bees know such plants very well and



even collect nectar from some of them. The poisonous nectar can even kill the bees themselves (though they are not very sensitive to it), but the honey contains poisonous additives only in such low concentrations that it is not dangerous for them. However, the plunderers eating the poisoned honey are doomed to death. A timely disinsection will keep the honey in the bee family.

Beasts of prey have far more trouble in storing food for themselves. Red-backed shrikes, which are only slightly larger than sparrows, string beetles, little lizards and frogs up on prickly bushes and dry them in the sun. No one knows whether they do so because food is plentiful or whether they store food for a rainy day. Home-made pemmican is not very tasty but very few animals are really capable of preserving meat.

Ichneumon flies have an original method of storing food. To be more precise, they are anxious not for themselves but for their offspring. The little larvae like to have live food, but their mothers are not too happy about nursing their children themselves. They prefer to provide their offspring with food and shelter, and avoid personal contact.

It is not too difficult to build a home for the children. It suffices to make a deep burrow, the entrance to which is later sealed up by the mother. How to keep the food fresh when there is no refrigerator in the burrow presents a greater problem. As soon as the thoughtful mother finds a suitable catterpillar, spider, beetle or its larvae, she attacks. Resistance is of no avail, for, once astride her prey, the fly puts her sting into it. The ichneumon then carries the lifeless prey into the burrow, lays one or more eggs on its corpse, seals up the burrow and... says good-bye to her little ones, leaving them to fend for themselves.

The prey remains in the burrow until a larva hatches out from an egg. It will not spoil because the victim is actually a preserved 'fresh' food. When attacking their prey, the ichneumon does not strike anywhere but carefully selects a definite spot. The sting pierces the victim's body and reaches the ganglia of the nervous system. There it injects a drop of poison, causing paralysis. Some ichneumons only 'preserve' spiders, and they even prey on tarantulas. When attacking such a formidable enemy, in order to protect both itself and its offspring, the fly (only the female is sufficiently brave) first pins the spider down and then inserts its sting where it can paralyse the nerve ganglia responsible for the control of the poisonous tentacles. The victor can now take its time stinging the spider in the chest and so cause general paralysis.

Many ichneumons will not risk attacking a tarantula themselves, but wait for their fellows to do this dangerous work for them. Then, while the victor is looking for a suitable burrow, they steal the ready-made food or lay their own egg on it.

The food supply is ample, as the mother lays her eggs in such a way that the larvae first eat those parts of the prey without which it is able to go on living. The prey still remains alive even when half or even three quarters of its body has been consumed.

The food is well preserved. Indeed it is better and more nutritious than our canned food.

No less original is the preserved food used by the larvae of some gall midges. The relationship between the parents and the children is a vivid example of the selflessness of the parents, for the mother gives herself up as food for her children.

Those insects live in the following manner. In spring the larvae hatch out from the eggs. They never live to become adults, but still manage to give birth to an offspring. The larvae do not lay eggs, but remain in the mother's body and develop there. When from eight to thirteen baby daughters have hatched, they gradually eat up their own mother from inside. When they finish, they leave her hollow skin. They cannot be said to be ungrateful and cruel, since their bodies, too, will accommodate a dozen 'loving' daughters and the mothers will, in turn, sacrifice themselves for their daughters' sake. Only the autumn generation of mother larvae will avoid being devoured by the jaws of their daughters. This generation will safely turn to pupae from which grown-up gall midges will hatch. In spring the adult flies will lay their eggs and this process will begin all over again.

THE 'HEALTH STORES' OF NATURE

When walking along the streets of a large town, you are sure to see grocery stores specializing in dietetic and children's foods, for the stomachs of invalids and babies are too weak to cope with what ordinary adults eat. This is why one must prepare different milk puddings, serve vegetables in grated form and steam special meat dishes. Animals do the same. Take for example our town sparrows which are grain-eating birds; when the time comes to feed their young, they knit their brows with disgust, but still bring small worms, midges and other insects for their little ones.

If it were merely the fact that the babies' stomachs are unable to digest any kind of food, Nature would have found a way out. The stomachs of wolf-cubs, for instance, have no enzymes for digesting meat, but their parents are not at all put out by this. The adult wolves swallow the prey and, when it has been processed sufficiently in the stomach, regurgitate it. They feed their cubs with this half-digested meat combined with gastric juices. This means that the young not only get food but also the gastric juices necessary for its further treatment. This method could be used by other animals but this would not solve the problem. The food on which adults feed may lack some substances necessary for growth and this is the very reason why animals of each species use their own kind of baby food for their young.

Baby food has to meet many requirements. It should contain all that is needed for normal growth and development and be easily digestible in the little stomachs. It must also be available in sufficient amounts and a constant supply ensured. This is not easy, even for Nature which has proved so ingenious.

In the long run the problem has been solved, but for this purpose parents were provided with store of food ready to use, or, to be more exact, with milk glands. Thus mammals made their appearance on the Earth. It was a far-reaching revolution.

The capacity to feed the young with milk, which originated in the remote ancestors of mammals, and the resulting viviparity, determined the entire course of further evolution on our planet. It ensured a very high survival rate in the offspring which, in turn, allowed a sharp reduction to be made in the number of babies born to an animal. The young are protected against all the changes in the weather: cold, drought, torrential rainfal, even a lack of fodder, are not dangerous to the young of mammals. As long as the mother's body retains just one drop of fat the milk factory will go on operating normally. The females of some mammals do not eat at all while rearing their young. European brown bears, for instance, give birth to cubs in winter, long before the mother can leave the den.

The long period of family life, when the parents and the young live together, has considerably changed the evolution of mammals. The young of mammals have a greater chance of survival; the better their parents are adapted, the better they are at getting food and defending themselves. Since children usually take after their parents, in the long run, the best-adapted young survive and this has accelerated the rate of evolution.

It is quite different in the case of fish and amphibians; the parents may be Olympic champions as regards strength and endurance, and they may be professors as far as intelligence goes, but their spawn or young often perish when they are still helpless whereas the offspring of stupid, less adapted parents may survive. This explains why the evolution of lower animals proceeds so slowly.

With the advent of the family the evolution in mammals took a different turn.

Among all animals it is primarily those which are the most quick-footed and large-toothed which survive. For mammals the mind, that is, the development of the brain, has become of greater significance. The parents not only feed and protect their children, but also train them to search for food and save themselves from enemies. They convey to their children what they themselves have gleaned from their parents and subsequently from their own experience. This makes it possible for mammals to accumulate experience and convey it from one generation to the next. It is natural that the more able and clever pupils survive longest. This is why the development of the brain is of prime importance.

In other animals the brain did not develop as rapidly as in mammals. This has given the latter a decisive advantage over other kinds of animals and has ensured a gradual development until the emergence of the highest being on earth—man. It is no exaggeration to say that milk was a prerequisite for the emergence of the human race.

It is difficult to say anything definite about the development of lactation. There is no telling whether viviparity provided the necessity for lactation, as the little helpless offspring had to be supplied with suitable food, or whether, on the contrary, lactation itself served as a stimulus for viviparity. Evidently, lactation originated first. At any rate some contemporary mammals lay eggs, for example the well-known duck-bills and porcupine anteaters. They lay eggs but feed their young on milk like all self-respecting mammals.

Much more information is available on the origin of mammary glands. It is very likely that they are derived from sweat glands. The ancestors of contemporary mammals had very many mammary glands which opened outwards, but they had no teats. Contemporary duck-bills have similar mammary glands. The duck-bill has as many as two hundred small glands, the ducts of which open out within a certain section of the skin on the abdomen known as a mammary gland area. The duck-bill has thus provided scientists with convincing proof that mammary glands are modified sweat glands. The entire body of that animal is covered with sweat and fat glands, the ducts of which open out in direct proximity to the hair sheaths.

Only in mammary gland areas within this complex of hair sheaths, fat glands and sweat glands are the latter replaced by mammary glands. The milk oozes out of the glands along special coarse 'milk' hair and is then lapped up by the young.

In the higher mammals the separate glands are formed into compact formations with many milk ducts joined into one or several common lactiferous ducts.

A mammary gland may become fairly large. Remember how large the udders of dairy cows are. But even the dairy animals specially bred by man over thousands of years cannot claim the record. The mammary glands of the common mouse account for seven per cent of its body weight, and when filled with milk they weigh as much as twenty per cent of the animal's body. This may suggest that man was not quite right when he chose to keep cows for milk. Scientists have actually designed an electrical apparatus for milking white mice and in some large mice-breeding stations one can even sample this drink.

The developed mammary glands of certain higher animals are provided with a special muscle apparatus made up of myo-epithelial cells. In kangaroos and other marsupials the young are born in a very immature state of development. They hardly have the strength to crawl into the mammary pouch where they grasp at a nipple and stay for a considerable period during the early months of their lives. Milk is forced into their mouths by the contraction of a special subcutaneous muscle. In the same way mother whales and other aquatic mammals force milk into their young. Although the young are born big and strong, it is not an easy task to suck under water and mothers have to help them.

The mechanism of the mammary glands is the same as that of all other excretory organs. In the kidneys, the salivary, sweat and mammary glands some liquid at first appears in the lumen of the ducts; it is very similar in its composition to ordinary intercellular fluid consisting of water and a little sodium. The sodium is then either re-absorbed, as is the case of the kidneys, or exchanged for osmotically active substances, proteins, sugars or such elements as potassium, calcium, manganese, etc., as is the case of the mammary glands.

The milk of all animals contains proteins, fats, lactose (a special carbohydrate present only in milk), calcium, sodium, manganese, chlorine, potassium and many other mineral substances, vitamins, and hormones. In other words, it contains everything a young developing organism needs. All this can be found in any milk but in different proportions. The milk of animals whose young grow up very quickly is especially rich in proteins and fats. The fattiest milk, containing over 53 per cent fat, is that of seals and grey whales. This is why a young whale gains 100 kilograms in weight daily. A hare's milk contains about 25 per cent of fat. The mother hare takes advantage of this and feeds her young no more than two or three times a week. Compared to the milk of such animals, that of the human female and of the cow seems almost fat-free since its fat content is as low as three to six per cent. But human milk is the sweetest. It contains about seven per cent milk sugar (lactose). In this respect only mare's milk can compete with it.

The period of lactation varies and usually the longe the period of pregnancy, the longer is the period lactation. However, there are many exceptions to th rule. The female duck-bill hatches her eggs within thi teen to fourteen days but keeps her young on milk f three to four months. The same is true of marsupial pregnancy lasts only a few days but lactation continue for several months. With guinea-pigs it is differen pregnancy lasts two months, whereas they suckle the young for only ten to twelve days. This difference even greater with seals: pregnancy lasts about 275 da and lactation only fourteen to seventeen days.

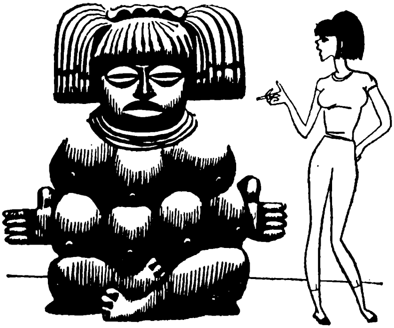
In many animals the lactation period can be considerably increased, a fact that is widely used in animal breeding. It is well-known that wild cows lactate for a shorter period than the domestic variety.

In man cases of protracted lactation periods are especially striking. In some regions of Polynesia it is a custom for the women to nurse their babies until they are six years old, while eskimo women do so for an even longer period, in some cases until the children are fifteen. Nor is such prolonged lactation a feature peculiar to a few nationalities. In Mohammedan countries the female slaves in the harems, who were of many different nationalities, were used for dozens of years as wet-nurses for the numerous offspring of their masters.

Each species of higher mammals has a definite number of mammary glands. Nature has given the human female two such glands, but sometimes there may be extra ones which usually do not develop adequately. Some nationalities very often have such extra glands: almost every fourth or fifth Japanese woman is known to have them.

The ancients were well aware of the occurrence of extra mammary glands. This is why the Phrygians reresented the Great mother of the Gods and of every-ing living on the Earth, the Goddess Rhea Cybele, ho personified fertility, as a young woman with seven easts. Incidentally, every modern woman is to some tent a Cybele. Scientists have found large glandules a women's necks which enlarge during pregnancy and gin to secret intensively. Axillary glands are similar nature. The secretion produced by these glands durg pregnancy and after birth looks like milk and conns microscopic formations similar to colostrum puscles which are produced at this time by the main mmary glands.

The functioning and development of the mammary



glands is associated with pregnancy and birth. However, in the case of the human female the size of the mammary glands becomes appreciable long before the first pregnancy. Scientists presume that this has occurred as a result of natural selection.

A woman's mammary glands may begin functioning long before she becomes pregnant. It is not infrequent that the mammary glands in newborn babies swell slightly and they secrete what is known as 'witch's milk'. This is accounted for by the fact that, even before the child is born, the hormones stimulating lactation penetrate into its blood from that of the mother.

Not only females but also all males possess mammary glands, although it is anybody's guess why they should need them and no other organ seems to be quite so useless. It is not for nothing that the saying exists that no matter how hard you try you can't get milk from a bull. In fact, male mammary glands, although apparently useless, have existed for millions of years.

But the conviction that male mammary glands are inoperative is, in fact, unfounded. Although the mammary glands of many male mammals do not develop completely, they may display signs of growth at certain periods in life and even reveal a capacity to secrete milk. Moreover, in some animals the mammary glands are equally developed in both sexes and during the breeding season both males and females secrete milk. The functional activity of the mammary glands is observed in the male duck-bills as well as in other related species. It should be pointed out that the male's milk is wasted because males do not help in suckling the offspring.

In the rudimentary form the mammary glands in many mammals are equally developed in both sexes. Therefore, male mammary glands can be made to function efficiently after certain endocrine treatment. In medical literature cases are cited when diseased organs of the endocrine systems in a male have caused their mammary glands to function. Furthermore, quite healthy males have been reported to begin lactating as a result of sucking their nipples. So, perhaps it is not so hopeless after all to try to extract milk from a bull.

It is common knowledge that fishes, frogs, snakes, to say nothing of birds, are unable to produce milk. It is not without reason that bird's milk has become a synonym for something absolutely impossible, unreal, in comparison with which anything seems feasible. For this reason, if you want to emphasize your willingness to do something for a friend, you say that he can ask you for anything but birds' milk.

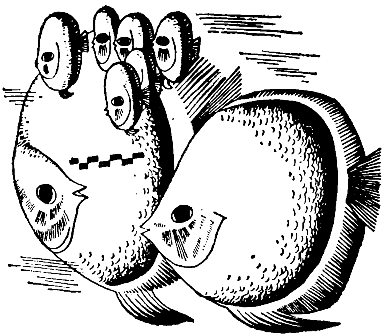
True, before the appearance of mammals on the Earth, Nature did attempt to provide the young of other animals with parental milk. These attempts were numerous. The larvae of some blood-sucking flies, for example, hatch inside the female, in a kind of womb, and are fed on the secretion produced by special glands containing proteins, fats and other nutrients; this goes on until they are ready to pupate.

A very common Russian honey-bee is provided with special 'mammary glands' located beneath its jaws. These glands only develop in the worker bee. They function most intensively from the fourth to the eighth day of its life, when the bee is employed as a wet-nurse to its large family.

'Bee's milk' is very nourishing and allows the queen bee to lay about two thousand eggs daily. The offspring hatched during one day may weigh more than their producer, but the mother does not get any thinner. If the hen competed with the bee in egg production, it would have to lay fifty eggs a day. So you see that bee's milk is an excellent food.

Termites and ants feed their larvae and even eggs on their saliva. Don't be surprised, that the eggs of these insects, like those of other animals, have neither a mouth nor a stomach. The wet-nurse merely licks the eggs continually all around. The saliva which contains nutrients penetrates the envelope and gets inside. The egg swells before your very eyes increasing to about three or four times its original size.

Fishes, too, have a mechanized canteen. The Amazon river discoid fish, which is as round as a pancake, feeds its fry on yellowish mucus from its own body. The first day the newly-hatched young lie on the leaf of a plant, but as soon as they feel hungry they attack their mother, who is watching over them, and eat up all the mucus they can find on her body. Having satisfied their appetite, instead of returning to their leaves, they attach themselves to the remaining mucus and hang in clusters on their mother's back and sides, travelling in this manner. But, when it is time to provide the young with the next meal, the female calls the male to help her and shakes the hungry offspring onto his back. Thus, the thoughtful parents take turns at feeding their numero-



us offspring. A long time elapses before the little ones begin to look after themselves.

The babies of the ocelot-skate feed on uterine milk, a liquid rich in organic substances, during their antenatal development. The walls of the oviduct where the ovicells develop form villi, which secrete fish milk directly into the oviduct cavity, and enrich the fluid in the cavity with oxygen. In flat-snouted skates and in Callorchynchus (a genus of chimaeroid fishes) the villi of the oviduct grow as long as the embryo develops. When they are long enough, they are sucked, during breathing, into the mouth and the spiracle (a special opening for the admission of water into the gill). Thus, the growing skates are suspended, like kangaroo babies, in their mother's pouch and spend a carefree childhood sucking the milk which runs down into their mouths.

Amphibians are not so clever as to produce milk, but some of them feed their babies with a pap of eggs. About 80 eggs develop in the ovary of the European proteus but only two larvae are born. The rest of the eggs dissolve to become a nutrient mass serving as food for the proteus larvae. The same is true of the two larvae which develop in the womb of the alpine salamander. These larvae float in a yolk pap made up of the rest of the eggs. When the larvae have eaten up the pap they emerge outside.

Most birds are known to be very solicitous parents and it is a real pity that they do not have milk. But, strange as it may seem, bird's milk does exist. It can only be produced by doves. Their milk is a whitish liquid, formed in the crop as a result of a sort of regeneration of its walls.

This milk, usually mixed with wetted grain, is used by the parents to feed their young. Both dove parents can produce such milk and, consequently, both of them can nurse the nestlings. The other peculiarity about dove's milk is that it is similar in form to mammals' milk: in both cases the production of milk is, to a certain extent, controlled by a hormone of the anterior pituitary known as prolactin.

Ventilation

A VITAL ELEMENT

Energy is necessary for the creation of new molecules and, in the long run, to build new cells. The organs and tissues also need it for their work. All the energy used by an organism is supplied by the oxidation of proteins, fats and carbohydrates or, in other words, by the combustion of these substances.

Oxidation cannot take place without oxygen. It is the task of the respiratory organs to deliver oxygen. In man this function is performed by the lungs. However, one should not restrict the term 'respiration' to those rhythmic movements of the chest which result in air being drawn into and forced out of the lungs. This is not respiration proper, but merely transportation of the oxygen necessary for it.

Respiration consists essentially of oxidation processes, which are only slightly reminiscent of combustion and can by no means be identified with it. During ordinary combustion oxygen combines directly with the substance being oxidized. But during the biological oxidation of proteins, fats or carbohydrates hydrogen is extracted from them. This hydrogen then, in its turn, reduces oxygen and forms water. Remember this scheme of tissue respiration because we shall return to it later.

Oxidation is a most important means of obtaining energy. This is why astronomers studying the planets' of the solar system are anxious to know whether they have oxygen and water, since life may be expected where they are present. It is quite understandable why the good news of the world's first soft landing by the Soviet interplanetary station *Venus 4* on the planet Venus was overshadowed by the report that its atmosphere contains hardly any free oxygen and very little water, while the temperature is as high as 300°C.

But one should not be too pessimistic about this. Even if there are no traces of life on Venus, that planet it still not without hope. It may be possible to populate its upper atmosphere, where it is not so hot, with primitive unicellular plants which would consume carbon dioxide and produce oxygen. The very dense atmosphere of Venus will make it possible for tiny unicellular living organisms to float in it without dropping onto the planet's surface. Such organisms would ultimately change the gas composition of the atmosphere on Venus.

This is quite a feasible task for green plants. The atmosphere of the Earth, in the form we know it now, was created by living organisms. Each year the plants on the Earth consume 650 thousand million tons of carbon dioxide and produce 350 thousand million tons of oxygen. There was a time when the Earth's atmosphere also contained much less oxygen and much more carbon dioxide than it does now. It is only a question of time. Several hundred million years will probably be sufficient for radical changes to occur in the atmosphere of Venus. There are grounds for supposing that by that time the temperature on the planet will have dropped considerably (wasn't it once hot on Earth too?). When this happens, Earthmen will be quite at home there.

Oxygen is essential for life and it has to be obtained from somewhere to supply every cell of the organism with it. Most animals on our planet take oxygen from the ambient atmosphere or breathe oxygen dissolved in water. They breathe through the lungs or gills, from which the oxygen is distributed to all parts of the body.

At first sight it may seem that the most difficult task is to obtain oxygen from water or the atmosphere, but this is not so. Animals did not have to invent any special mechanisms. Oxygen enters the blood through the lungs or gills by diffusion, since the blood contains less oxygen than the environment, and gasses and liquids tend to distribute themselves equally within the limits of any enclosing walls.

Nature did not hit immediately upon the idea of lungs or gills. These organs were virtually unknown in the earliest, many-celled, living organisms, which breathed with the entire surface of their body. All the subsequent higher-developed animals, man included, have evolved special organs intended for respiration, at the same time retaining their capacity to breathe through the skin. Only armour-clad creatures, such as turtles, armadilloes, crabs, and the like, are unable to breathe through the skin.

In man breathing involves the entire surface of the body, including the thickest skin on the heels and the hair-covered scalp. The parts of the skin that breathe most intensively are those on the chest, back and abdomen. It is worthy of note that these parts of the skin breathe more intensively than the lungs. If we take two equal sections of the breathing surface of the skin and the lungs, we will find that the skin can absorb 28 per cent more oxygen and expel as much as 54 per cent more carbon dioxide than the lungs.

The skin's superiority is very difficult to account for. One possible explanation may be that the skin breathes clean air, while our lungs are inadequately ventilated. Even after a very deep expiration some air remains in the lungs; the composition of this air leaves much to be desired: the oxygen content in it is much lower than that of the atmospheric air, while the carbon dioxide content is much higher. The air inhaled during inspiration becomes mixed with the residual air in the lungs, and its composition deteriorates. It would not be surprising if this were the phenomenon that gives skin breathing the advantage.

However, the skin's share in man's breathing as a whole is negligible compared with that of the lungs. This is understandable, if we take into account the fact that the total surface of man's skin is scarcely two square metres, while the surface of the lungs with all their seven hundred million alveoli spread flat is at least 90 to 100 square metres, that is 45 to 50 times as much. (Alveoli are minute thin-walled sacs, through whose surfaces the respiratory exchange between the environment and the blood occurs.)

Breathing by means of the skin can only provide very small animals with an adequate amount of oxygen. Therefore, right from the very beginning Nature employed a method of trial and error to find an adequate means for this purpose. The organs of digestion were the first to be selected for the test.

The coelenterates consist only of two layers of cells. The external layer takes oxygen from the environment, while the internal layer draws it from the water which freely enters the intestinal cavity. But flat worms, which have developed more complex digestive organs, could not employ them for respiration. They had to remain flat as in large volume diffusion is unable to supply the deep-lying tissues with adequate amounts of oxygen.

The many species of annelid worms which emerged on the Earth following the flat worms also manage to breathe through the skin, but this only proved possible as a result of the organs circulating the blood which they had evolved to distribute oxygen throughout the body. Incidentally, some species of annelid worms provided themselves with the gills, the first special organ for taking in oxygen from the atmosphere.

In all the subsequent animals similar organs mainly followed two patterns. If oxygen was obtained from water, special outgrowths or protrusions, which were directly in contact with the water, were developed, while depressions or cavities—from a simple sac such as the respiratory organ of the edible snail or the lungs of the newt and salamander, to exceedingly complex blocks of minute vesicles resembling clusters of grapes, like the lungs of the mammals—have been evolved to obtain oxygen from the ambient atmosphere.

The conditions for respiration in water and on land differ greatly. One litre of water, even under the most favourable conditions, contains as little as ten cubic centimetres of oxygen, while one litre of the atmospheric air contains 210 cubic centimetres, i. e. twenty times as much. It might, therefore, seem strange that the respiratory organs of aquatic animals cannot obtain an adequate amount of oxygen from such an oxygen-rich environment as the atmospheric air. The structure of the gills would allow them to cope successfully with their task in the air, too, but the fine plates (laminae) of the gills stick to one another and soon dry up without the support and protection provided by water. The blood ceases to circulate and the breathing function is thus arrested.

The history of the origin of the respiratory organs is of great interest. To create them Nature made use of methods previously tested in the most primitive creatures: at first, it employed the skin and the digestive organs for this purpose. The gills of the ship-worm are nothing but very complex outgrowths of the outer covering. The gills and lungs of all invertebrates are modifications of the anterior intestine.

Insects have overcome the difficulty of respiration in a curious way. They settled the question by allowing the air to get a direct access to the organs, wherever they may be. This is accomplished simply, by a system of ramifying air tubes which extends throughout the entire body of the insect. Even the brain is riddled with air-supplying tracheae, so that the insects are empty-headed in the literal sense of the word.

The tracheae branch out, all the time growing smaller, so that at their extremities they are very fine tubes which can come into contact with the individual cells of the body. Here they often ramify into the finest tracheoles with a diameter of not more than one micron, which penetrate into the very protoplasm of the cell. Thus, in insects oxygen is delivered directly to its destination. The tracheoles are most numerous in the cells which consume oxygen most intensively; in the large cells of the muscles used for flying they form an intricate mesh.

The air-passages of insects can independently detect which sections of their bodies are becoming short of oxygen. This ability is characteristic of the minute tracheoles of the epidermis, which are blind terminal tubes, less than one micron in diameter and less than one-third of a millimetre in length. When the adjacent sections of the tissues are intensively consuming oxygen, the tracheoles begin to extend, often becoming one millimetre longer.

It would seem at first sight that insects have successfully solved the problem of an oxygen supply. If the tracheae are constantly open, the strong draught passing through their bodies may dry them up in no time. To prevent this the external openings in the tracheae open up only for very short periods, and in many water-dwelling insects they are permanently closed. In this case oxygen diffuses directly through the skin or gills into the air-passages and also spreads through them by diffusion.

Large terrestrial insects breathe actively. Their abdominal muscles contract seventy to eighty times per minute and the abdomen flattens, squeezing the air out. When the muscles relax and the abdomen resumes its original shape, air is sucked in. It is interesting that these insects most often use different air-passages for inspiration and expiration, inhaling air through the thoracic openings and exhaling it through those on the abdomen.

Not infrequently the main respiratory organs are unable to cope with their task. This is encountered in animals which have migrated to an environment which is extremely poor in oxygen or is completely foreign

to them. In this case Nature proves very inventive in finding the means to assist the main respiratory organs.

In the first place, time-tested means are widely used and modernized. A small fish, common in the south of the Soviet Union and known as a slug, is found in streams which dry up in summer and in cut-off lakes. The bed of such basins is usually silty. There are very many decaying plants in the water and, consequently, oxygen is scarce there on a hot summer day. So as not to suffocate, the slugs have to 'feed on air'. They simply eat air, swallowing it and letting it pass through the intestines like food. The anterior part of the intestines is used for digestion and the posterior part for respiration.

To prevent the digestive process from interfering with respiration, the central part of the intestines is provided with special secretory cells which envelope the waste products in mucus. Thus, they can pass quickly through the part of the intestine used for respiration. Two other fresh-water fish, the charr and the loach which are common in the USSR, breathe in much the same way. It is hardly likely that an organ combines two functions (respiration and digestion) with ease.

This is obviously the reason why certain fresh-water fish living in tropical Asia have evolved an additional respiratory apparatus in the form of a labyrinth which is an intricate network of canals and cavities located in the wider part of the first gill arch. It took scientists some time to understand the significance of the labyrinth. The famous Cuvier was the first to detect this curious organ when dissecting a climbing perch (*Anabas testudineus*). He gave the name to the organ and suggested that the fish uses it for storing water when leaving the basin. The climbing perch is fond of travelling, easily moving from one pond to another.

Observation of fishes in their natural habitat failed to elucidate the function of this organ. The British zoologist Commerson was the first European to come across a rather large fish, known as the gourami, which for a long time had been bred in ponds in tropical countries. He gave it the name of *Osphromenus olfax*, which in Latin means 'one who smells'. Watching the fishes, the Englishman noticed that they constantly came to the surface and stuck their snouts out of the water to take a breath of air. It never occurred to anyone at the time that fish breathed air, so Commerson made the curious suggestion that the gourami came to the surface every now and then to find out how the air smelt.

It was not until much later, when the gourami began to be kept in aquaria in Europe that naturalists realized that these fishes use labyrinths to breathe air. Their gills are rudimentary and they rely primarily on the labyrinth for oxygen. Labyrinth fishes are so dependent on dry air, that they cannot live without it and will 'choke' and 'drown' if forced to stay under water, even in an aquarium with the purest oxygen-rich water.

Breathing is not easy for frogs either. As their lungs are far from perfect, frogs, therefore, sometimes have to tax their ingenuity. In 1900 a hairy frog was caught in Gabon (Africa). It excited interest and wonder among naturalists all over the world. Scientists took it for granted that hair growth was confined to mammals. Frogs are known to have no hair cover. It was not quite clear why Gabon frogs should have their sides and limbs covered with hair. Cold was hardly responsible for it. Why should African frogs be cold, while their close relatives, frogs living in Europe and inhabiting the area near the Arctic circle, do not feel cold.

The secret of the frog's fur coat was discovered shortly after. As soon as the strange fur coat was studied under the microscope it became clear that it was nothing but outgrowths of skin. Such fur coats cannot be warm. Besides, the hairy frogs do not need warming, as it is never cold in Gabon. Subsequent study revealed that the hair on frogs performed the function of gills of a kind used for breathing both in the water and on land. Only the male frogs have hair. But for the hair growth, they would not be able to cope with their functions which require a great deal of physical effort during the breeding season, when they would be short of breath and suffer from lack of oxygen.

Respiration in the mud-skipper, an inhabitant of tropical Africa, is still more fascinating. This fish spends most of its time in mud, which it prefers to water. It is mainly a land creature which can make long journeys overland and skilfully climb trees. When on dry land the fish breathes through its tail, the skin of which is abundantly provided with branching blood vessels.

When studying the respiration of the mud-skipper, naturalists were betrayed by the fish into a curious error. The scientists observed that, although the mud-skipper stayed on dry land for most of the day and provided itself with food, when out of water, by capturing insects, it is unwilling to abandon the water and prefers to sit on the edge of a mud pool with its tail, caudal fin, to be precise, in the water. After a jump in pursuit of a butterfly, the fish moves back and puts its tail in the water again.

Observing the habits of this fish, naturalists suggested that the mud-skipper depended on its tail for oxygen which it derived from the water. However, when they hit upon the idea of measuring the oxygen content of the water they realized that it was too low to be worth the fish's sitting by the pool with its tail in the water. It has been discovered that the mud-skipper uses its tail to draw in water which enables the fish to moisten other parts of the body and secrete an adequate amount of mucus. The amount of oxygen obtained through the tail, when in water, is negligible. However, having provided itself with a considerable amount of water, the fish leaves the basin and its tail becomes the main respiratory apparatus.

The umber, known also as the mud minnow, takes in oxygen through its swim bladder. The mud minnow is found in Moldavia and in the lower reaches of the Dniester and the Danube. Its swim bladder is connected with the alimentary canal by a wide duct. The fish fills its swim bladder with air by putting its head out of the water. The swim bladder is enveloped in a network of blood vessels and oxygen can easily enter the bloodstream. Now and then the umber exhales the used air which contains much carbon dioxide. It is no fun for the umber to breathe through the swim bladder. The fish can survive no longer than twenty four hours, if it does not breathe in fresh air.

Air is indispensible to many other fishes, too, but for a different reason. Young fishes of most species must make at least one inspiration after birth. This is why fishes prefer spawning in shallow places. Unless they do so, the fry would not be able to rise to the surface. The young fishes need air with which to fill their swim bladder. When the young are only a few days old, the duct connecting the swim bladder and the alimentary canal will close and the young fishes will perish of exhaustion, as they are unable to reduce their specific gravity at will.

Other fishes do not have their swim bladder closed. Even in their old age they are able to inhale fresh air when they are swimming on the surface, and expire the excess of air when going down to the lower depths. But coming up to the surface is, apparently, not always safe. Therefore, fishes frequently employ a different method of maintaining the required level of gases in the bladder. They have a gas gland which actively secretes gases into the bladder.

In the early days of studying respiration it was suggested that oxygen, on entering the lungs, is captured by the wall of the alveoli which later gives it off into the blood stream. But this theory was later abandoned. Fishes with closed bladders are completely dependent on this method, as they have no alternative. The main working part of the gas gland is a wonderful network consisting of three capillary systems connected consecutively. It has been calculated that the volume of blood that can fill the network is not large, about one drop. However, the area covered by this network is immense, as it is made up of 88 thousand venous and 116 thousand arterial capillaries, amounting to a total length of almost one kilometre. Moreover, the gas gland has many minute canals. The secretion discharged into the lumen of the bladder is believed to be disintegrated there, liberating oxygen and nitrogen.

As the gas in the swim bladder is produced by the gas gland and not taken from the environment, its composition differs greatly from that of atmospheric air. The contents of the gas are mainly oxygen which sometimes amounts to 90 per cent of the total.

DIVING SUITS AND AQUALUNGS

More than two thirds of our planet is covered with seas and oceans, leaving only one third out of water. The boundless expanses of water have long attracted the attention of men and it is little wonder that even the ancients attempted to explore them. However, not until the turn of the 19th century did people succeed in making diving suits, which enabled them to spend a long time underwater breathing air supplied under pressure through a special hose. Later a caisson was invented, which is a bell with the open end facing downwards. The bell is lowered to the bottom and air pumped under it, thus enabling the people inside to carry out various underwater operations.

The area in which divers, not to mention caisson operators, can work underwater is limited by the length of the air hose. Naturally, scientists have continued to search for some other method. Only quite recently have they succeeded in making the aqualung, which is a self-contained diver's apparatus with bottles of compressed air or oxygen, for free movement over long distances underwater.

Animals had to tackle a similar problem when they had to move to a liquid environment. Some did the same as man has done and thus anticipated the idea of diving millions of years ago.

Unlike man, the animals have had to deal not only with water but also with various other liquid media where there was no oxygen at all. Therefore, they had no choice but to take a stock of air from outside. Parasites in the bodies of animals and in plants are living in similar conditions.

The tiny larva of one of the parasitic insects that live in the body of the large African locust penetrates its victim through one of the tracheal tubes of its respiratory apparatus. In the early stages, the larva feeds on the walls of its premises and grows rapidly The parasite soon becomes cramped for space, makes a hole in the wall of the trachea and plunges into its host's tissues. But there is nothing to breathe there, and the larva needs air. So, it does as all sea divers do. It provides itself with an air-passage. It makes a hole in the hard chitinous layer of its victim and rests against it with the back end of its abdomen from which a breathing tube soon grows. In this way the larva lives in the locust's body, being supplied with air through the tube just as a diver is given air through an air hose. The breathing tube gradually grows, thus allowing the larva to penetrate deeper and deeper in the tissues. The tube may even grow to be twice the length of the larva itself.

The larvae of the *Eristalis* (the best-known species of which is the common drone fly) have an easily-extendible and very long siphon similar to a real diver's air hose. They live at the bottom of reservoirs of water and bury themselves in the silt. If the bodies of water are shallow, the larvae can bring their tubes to the surface of the water and breathe quite happily without leaving the silt.

The ancestors of aquatic insects were land-dwelling animals. Although they had moved to water no appreciable changes were sometimes observed in their respiratory system. They only breathed air. The only adaptation they made to an aqueous environment was the ability to store air in the way that aqualung divers do before a long underwater trip. The European diving beetle keeps stocks of air beneath the wing cases, whilst the back swimmer has them on its abdomen. The air bubbles are held in place by special hairs which are impermeable to water. The openings in the respiratory system are where the air bubbles are attached. In this way these insects obtain the oxygen they need.

The same is true of spiders. Most are typical land animals, breathing by means of special lung sacs. For this reason the silver or water spider is all the more remarkable, because it is the only one to have betrayed its species and deserted to an underwater environment. Its body is covered with fine waterproof fluff and when it dives into the water very small air bubbles become attached to the fluff, covering the body completely with an envelope of air. In water this envelope glitters and makes the spider look like a living ball of mercury. The spider also sticks the end of its abdomen out of the water and grasps a larger air bubble. It holds the bubble in its hind legs and then descends to Neptune's kingdom.

Once among the water plants, the water spider spreads its web very much as its relatives would on land. At first the web is flat, but it gradually assumes the shape of a thimble as the spider places air bubbles under it. Thus, a miniature caisson is formed to accommodate the spider for the greater part of its life. The female also lays the eggs from which the young hatch in this 'caisson'.

The similarity between the water spider's accommodation and an aqualung or caisson is, of course, merely one of appearance. The processes involved are much more intricate. The air bubbles carried by the insects are a kind of reserve. At the same time they help to extract oxygen from the surrounding water. This technique has even been given the special name of 'physical lungs'.

It is common knowledge that water contains, dissolved in it, all the gases which make up air, their amounts being proportional to their concentration in the atmosphere. As an insect breathes, the concentration of oxygen in the air bubble decreases and when it becomes less than sixteen per cent the oxygen dissolved in the water starts diffusing into the air bubble. Thus, the stock of oxygen in the bubble is continuously being replenished.

If the oxygen consumption is moderate, for instance, when the insect is resting, the physical lung can provide sufficient oxygen for an infinitely long time. But if the oxygen consumption is high, it cannot diffuse from the water sufficiently quickly to replenish the amount used. This means that the percentage of oxygen in the air bubble drops sharply, while the proportion of other gases (primarily nitrogen) rises, till it is much higher than is usual in air. As a result nitrogen dissolves in the water. The volume of the air bubble decreases due to part of the oxygen being used for breathing and to the nitrogen dissolving in the water. Consequently, the insect has to come to the surface to replenish its air supply.

The amount of air which an insect can carry is not large and would not last very long if the oxygen were not replenished. This can be clearly seen in cases where diffusion is impossible. For example, if water beetles and back swimmers are placed in boiled water, they will soon die, since it contains no dissolved gases and, consequently, the oxygen cannot be replenished.

The same happens if these insects are put into water containing only dissolved oxygen, and if the same oxygen in its pure state is used as the reserve. This reserve would last no longer than half an hour, since in such conditions no diffusion will occur. A back swimmer can usually stay in water for six hours without replenishing its air supply. This means that, owing to the fact that oxygen diffuses from the water into the air bubble, the time the insect can stay in water without replenishing its supply of air is very much greater.

Small insects which use very little oxygen can go for a long time without replenishing their supply of air. It has also been found that they suffer not so much from reduced reserves of oxygen as from the loss of nitrogen from the air bubble. If the air bubbles beneath the water are removed with a fine brush and replaced with bubbles of pure nitrogen, a water bug placed in water saturated with oxygen will feel fine for a long time, since the nitrogen bubble will rapidly acquire a sufficient amount of oxygen from the water for breathing.

Some insects cannot come to the surface by themselves to replenish their stock of air. Several species of lice closely related to one another live on seals. These parasites never leave the host animal and can thus replenish their stock of air only when the seal comes out of the water. This has resulted in their becoming adapted for long periods in water.

The species which live on the seal's body have their chest and abdomen covered with broad scales which allow to retain a larger amount of air. Those which live on the seal's head have no such scales. They do not need a large reserve of air since the seal itself breathes air and, therefore, frequently has to put its head out of water.

Physical lungs are used by the spawn of the labyrinth fish, for which the parents have to provide a special 'nest' of air bubbles enclosed in a saliva-like liquid. The spawn is surrounded by a thin film of the liquid and floats among the air bubbles, thus being supplied with sufficient oxygen. The loss of oxygen is made good from the air.

The polyacanthous fish, which lives in an environment richer in oxygen, does not build its nests on the water surface, but beneath the broad leaf of a water plant, or under a stone or a snag. Since water contains oxygen the physical lungs will operate at depth too. It is interesting that the polyacanthous fish builds its nest in any season and uses it not only during the period of reproduction, but also as an air store for itself. This allows the fish to stay on the bottom, in the thick plants, or the debris of a snag. The polyacanth takes the oxygen-rich air from its store and gives in return a bubble of nitrogen mixed with carbon dioxide to be enriched with oxygen and purified of carbon dioxide. Only when there is little nitrogen in the nest does the polyacanth come to the surface for air.

IN SEARCH OF OXYGEN

Our planet is very rich in oxygen, and this evidently explains why animals have not learnt to store it in large amounts. Only very few Earth-dwellers are able to provide themselves with large reserves of oxygen, although many frequently stock it in small amounts.

Although it takes the blood only two seconds to pass through the capillaries of the alveoli, this is sufficient for an oxygen balance to be set up between the air in the alveoli and the blood. However, the amount of oxygen which can dissolve in the blood during this period is infinitesimal (0.003 cubic centimetre per cubic centimetre of blood plasma). For an animal to obtain sufficient oxygen using this method the volume of the lungs and the amount of blood running through them would have to be increased almost a hundred-fold. This would obviously be very difficult to do.

Nature has chosen another method, by supplying the blood with a substance which can easily react with oxygen and thus retain it in much larger amounts than would be possible in a simple solution. For the tissues to be able to make use of the stored oxygen this substance must readily release the oxygen when necessary. This substance is haemoglobin. It possesses two properties which are indispensible for breathing. When the blood is in the lungs, where there is a great deal of oxygen, the haemoglobin immediately makes contact with the oxygen. Owing to this, one cubic centimetre of blood carries with it 0.2 cubic centimetre of oxygen, i.e., 20 per cent of the blood volume, and then gives it up to the body tissues.

Larger amounts of oxygen are required for some organs, mainly muscles, many of which work rhythmically for several hours on end. These are the muscles in the legs and wings, and the masticatory muscles, while the respiratory and cardiac muscles never cease working. It has been proved that they cannot be supplied with oxygen while they are working for, when a muscle contracts making the vessels constrict, blood cannot flow through them.

The tissues use the oxygen stored for them in the muscle haemoglobin. It is very similar to blood haemoglobin, the essential difference being that the muscle haemoglobin is much better at trapping and retaining oxygen, releasing it only when the oxygen level in the environmental medium is very low. The cardiac muscle of a warm-blooded animal contains 0.5 per cent muscle haemoglobin, which allows two cubic centimetres of oxygen to be stored for each gram of muscle tissue. This is quite sufficient to ensure normal functioning of the muscle for the time the blood flow is arrested.

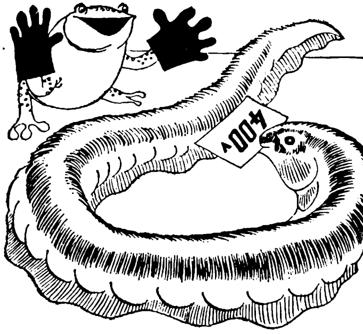
Water mammals and waterfowl which have to stay under water for long periods of time have converted their muscles, primarily the most important ones, to take larger stores of oxygen by saturating them with large amounts of muscle haemoglobin. This is how the sperm-whale can remain submerged for thirty to fifty minutes and swim long distances during that time. An alligator can stay in water for even longer, one and a half to two hours.

Our atmosphere contains a great deal of oxygen and its loss is constantly made good by green plants. It would seem that man will never have to face a shortage of oxygen. However, it must be acknowledged with some distress that this hope is fading.

A few years ago the Japanese were forced to make reserves of oxygen available in ordinary, everyday conditions. The streets of Tokyo and other large cities in Japan are always packed with cars whose fumes poison the air with carbon dioxide and carbon monoxide. Such air is unsuitable for breathing, although it still contains sufficient oxygen.

The traffic wardens who are working for many hours in the streets are unable to last out a whole shift. To avoid excessive poisoning, they have to be supplied with oxygen. It is now a long-standing practice to provide police stations with cylinders of compressed air so that the policemen can take a breath of good air from time to time. Now they have started to install oxygen machines in the streets of Tokyo for passers-by, too, similar to the aerated water machines that are to be found in many cities the world over. This means that everybody can put a coin in the machine and refresh his lungs with oxygen.

There are many places on Earth which have little or no oxygen. In most cases, living creatures themselves are responsible for this, bacteria being especially heavy consumers of oxygen. One milligram of bacteria is able to consume 200 cubic millimetres of oxygen per hour. It should be pointed out that a working muscle of comparable weight will, during the same period, use only twenty cubic millimetres of oxygen and only two and a half cubic millimetres when relaxed.



Due to the activities of bacteria and the larger micro-organisms many nooks on our planet are becoming quite unsuitable for life, and so animals have to be more inventive to settle in such ecological niches.

One such niche is successfully inhabited by electric eels. These large fishes live in the swamps and small rivers of South America. During the rainy season the rivers become turbulent, and the swamps are flooded with streams of muddy water. These streams are rich in oxygen and the dwellers of the underwater kingdom can breathe easily. But, during the drought which follows the rainy season, the rivers quickly become shallow, forming small lakes with narrow stretches of water between them, and the marshes begin to dry out. In the shallow pools heated by the tropical sun the plants rot and the micro-organisms multiply rapidly, consuming oxygen at a greater rate than it diffuses from the air. Thus, breathing becomes more and more difficult for all the water dwellers.

But the electric eel feels fine and does not seem to suffer from the lack of oxygen. What is more, food is plentiful. All the inhabitants of the disappearing pools are attracted to the place where the eels have settled. We shall have something to say about animal power stations later, but now we shall only point out that the electric eels do not hunt for their prey. Liquid mud is brown like coffee dregs in which you cannot even see the tip of your nose. It is obvious that one could not catch anything there, except quite by chance. The eels kill their prey with powerful electric shocks, without even looking or trying to see what kind of creature it is.

What is the reason for the eels' attraction? Do they occupy the best places in the pool? Not at all. It is simply because these terrible fish enrich the water around them with oxygen. An electric discharge of 600 volts can break down water into its constituents, oxygen and hydrogen, and this life-giving stream attracts the oxygen-starved fish from all directions.

With the electric discharge the water in the eel's body also decomposes. The oxygen so formed is immediately transported by the blood all over the body, but the hydrogen has to be expelled. It is eliminated through the gills and rises to the surface in long jets of tiny bubbles. The bubbles show the Indian hunters where this dangerous fish is and they lose no time in killing it so that they may have fish for their own table.

Besides the eels, another rather interesting fish, the lepidosiren, also lives in the swamps of South America. It can survive even in completely dried-up swamps where there is very little oxygen even in the rainy seasons. The adult fish manage with very little oxygen because their swim bladder has become a paired respiratory organ. They breathe air, but the problem is how to preserve the spawn in such water. The lepidosiren has developed a unique way of caring for its offspring, a method of supplying the spawn with oxygen. The male is responsible for this. As soon as the rainy season comes, he either finds a small, but sufficiently deep, hole on the bottom or else a burrow and takes his female there. When the spawn is laid and fertilized, the female swims quietly away leaving the spawn to the father's care.

With the onset of the breeding season the male lepidosiren dons his wedding outfit: extremely long thread-like shoots grow from his abdominal fins. The male in fancy dress is an interesting sight courting the female or guarding the nest, his fins lowered completely onto the spawn. This wedding outfit serves not only to attract the female; the fins serve as hoses to supply oxygen to the spawn. The temporary shoots of the lepidosiren males are filled with tiny blood vessels and this enables the oxygen to pass from their blood into the surrounding water.

Given a good spot—a small hole or a burrow in a shallow place, completely cut off from the main pool—it is simple to obtain oxygen supply for the spawn. In such conditions the male can readily take oxygen from the surface and, while remaining in position over the spawn, thus enrich his own blood, passing the oxygen at a greater rate into the surrounding water. This is easily accomplished in the stagnant water of the pool provided that the hole or burrow used for the nest is small.

Pools have yet another source of oxygen—green plants. If there are few green plants and the oxygen they liberate is not sufficient to saturate the water, the only thing to do, as large numbers of insects do, is to settle on the plants themselves as the concentration of oxygen will be greatest there.

Tiny oxygen bubbles can often be observed on plants. The macroplea beetles pick up these bubbles with their tiny legs and carry them to their antennae. After some time, the bubble disappears which makes us think that the beetles breathe with their antennae. If there are no gas bubbles of oxygen the beetles cut the plant and wait for air to escape from its air channels. The same method is used by water weevils.

The larvae of macroplea and donicia beetles make incisions in plants and attach their spiracles to them. Other insects stick their stylets into the plants and suck oxygen out from the intercellular space. These oxygen-rich intercellular spaces are places favoured for pupation.

However, the caterpillars of the Brazilian paraponyx are even more ingenious. They build themselves a house from bits of green plants and, when these wither away, they replace them. Consequently, during the hours of daylight, there is always plenty of oxygen in their nests, but at night, so as not to be choked by the carbon dioxide liberated by the plants, the caterpillars have to climb outside.

The amount of oxygen found in the stomach and intestines of vertebrates is negligible. But certain living organisms which could find no place under the sun have learnt how to obtain oxygen. Not the least among them is the bot (the larva of the botfly) which lives in the alimentary tract of horses. Like all other insects, the bot has a tracheal system for respiration which is stronger and more ramified than that of larva living in the open. It also has red organs which are a conjugate formation consisting of many large red cells. A tracheal stem enters each cell and then branches out into numerous tracheoles in its protoplasm.

As yet we do not know how the red organs function, but it is clear that they play a major part in supplying the larva of the botfly with oxygen. This is proved by the presence of a large amount of haemoglobin which accounts for the red colour of the cells and whose affinity to oxygen, i.e. the ability to combine with oxygen even when small amounts of the gas are present, is hundreds of times higher than in mammals.

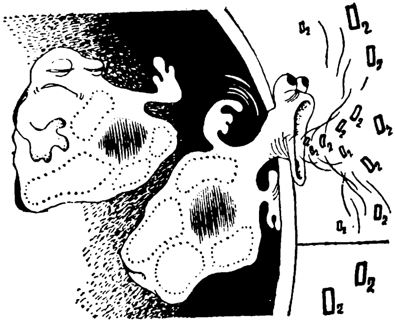
Ascarides are intestine dwellers often found in mammals. Even quite recently it was maintained that they could manage without oxygen. However, scientists were astonished to find two kinds of haemoglobin in the body of the pig ascaris *(Ascaris suis)*. This haemoglobin was concentrated at two points, in the wall of the body and in the parenteral liquid which fills the cavity of the body. The outer haemoglobin retains the oxygen 2500 times longer, and the inner haemoglobin 10,000 times longer, than the pig's own haemoglobin.

Now why does the ascarid need haemoglobin if it can manage without oxygen? Theoretical calculations show that a system of two haemoglobins with a growing thirst for oxygen may serve as the ideal carrier, especially where there is a considerable oxygen deficiency.

Still more primitive animals, primarily bacteria, have no haemoglobin and are therefore unable to actively extract oxygen from their surroundings. However, they are often doomed to environments where there is little or no oxygen at all. Nevertheless, these creatures are quite happy to reconcile themselves to an absence of oxygen. This has led to their being named anaerobes which means 'one who lives without air'.

How do anaerobes manage to live without air? Not so long ago this seemed to be a puzzle that could not be solved. Now we know that they do need oxygen all the same. Instead of extracting oxygen from the atmosphere the anaerobes simply take it from organic substances. Some bacteria even extract oxygen from inorganic substances, using nitrites and sulphites for the purpose.

Anaerobes breathe by oxidizing the products of metabolism without using additional oxygen and are quite content with the amount already present in the sub-



stance being oxidized. For, when a substance is oxidized it makes no difference whatsoever whether oxygen is added to, or hydrogen removed from it. Oxidation by abstraction of hydrogen is termed fermentation; it results in the splitting of organic substances to form oxidized and reduced products and the liberation of the energy required by the organism.

The best known form of fermentation found in single-celled organisms is the breakdown of a glucose molecule into two molecules of ethyl alcohol (the reduced substance) and two molecules of carbon dioxide (the oxidized substance).

In many-celled organisms, the most common form of fermentation is lactic fermentation which involves the decomposition of carbohydrates, as, for instance, when a sugar molecule breaks down into two molecules of lactic acid which have less energy than the initial substance. The breakdown of carbohydrates is a gradual process consisting of a series of reactions. As a result the oxygen in the molecule of sugar near to the inner carbon atom is transferred to the external carbon atom. Energy is thereby liberated.

There is also another method of oxidation, that of electron loss, but whether it can be used by living organisms has not been adequately studied.

The question arises why living organisms use atmospheric oxygen if energy can be obtained by mere fermentation. There are many important reasons for this. Fermentation never results in the complete oxidation of a substance and, therefore, little energy is released. If one gram-molecule of glucose is completely oxidized to carbon dioxide and water 673 large calories will be obtained. But with fermentation, which results in the formation of ethyl alcohol and carbon dioxide, only as little as twenty five large calories will be released, i.e. more than 93 per cent. This means that anaerobes have to use twenty seven times as much glucose as aerobes to obtain the same amount of energy. The difference is, of course, appreciable and Nature cannot tolerate such wastefulness.

Another important reason is that substances such as ethyl and butyl alcohol, lactic acid and butyric acid, acetone, etc., which are bad for the organism, are formed as a result of fermentation. It is not easy to dispose of these harmful substances.

Respiration frequently produces combustible gases. Micro-organisms often release hydrogen. This is how microbes living in the intestines of termites breathe. Of the many-celled creatures, the larvae of some flies in particular, release a great deal of hydrogen. Some organisms liberate not only hydrogen, but also methane and other gases, some of which are still not known, including spontaneously inflammable gases. It is a particularly beautiful sight when the gases, which have collected in the silt at the bottom of a pool, rise to the surface of the water and burn with a mysterious bluish flame.

How then have animals managed to change their way of breathing to such an extent and adapt themselves to an absence of oxygen? This did not prove difficult. At the dawn of life on the Earth there was little free oxygen and the earliest living creatures had to become anaerobes. It was not until the atmosphere became rich in oxygen that animals learnt to burn energy-forming products completely. At the same time, the anaerobic method of breathing did not disappear but was passed on and finally came down to us. As mentioned at the beginning of this chapter, in all animals without exception the first stages of energy release proceed without oxygen. When aerobic animals felt like returning to the places where no oxygen could be obtained, they again had to restrict themselves to partial utilization of the energy contained in nutrient substances. To do this they had to remember how to render partially oxidized products harmless.

Animal life emerged on our planet when the atmosphere was still very poor in oxygen. It is no wonder that living organisms had to adapt themselves to an environment where oxygen was in short supply. However, we usually fail to notice another much more puzzling phenomenon, namely, that animals living in the presence of excessive oxygen have managed to restrain the intensity of the oxidation processes taking place in their bodies as if they were always ready to extinguish a constantly threatening fire.

The amount of environmental oxygen is constant, and, if it does alter, it decreases. This explains why animals have different means of combatting oxygen shortages but no means of protection against excess oxygen.

Bert was the first to discover that breathing pure oxygen can be poisonous around a hundred years ago. This was such an unexpected discovery that scientists did not believe him and a suspicion arose that the oxygen used by Bert contained various poisonous admixtures.

The experiments were repeated many times, but no matter how thoroughly the oxygen was purified, the animals which breathed it for prolonged periods inevitably perished.

There was a good reason for the scientists' interest in oxygen poisoning. The problem had to facilitate the work of divers. A man can survive in an atmosphere of pure oxygen for about twenty-four hours. If he breathes oxygen for longer than that, pneumonia ensues and, strange as it may seem, death due to asphyxia, which is a shortage of oxygen in the most important organs and tissues. A man can endure a pressure of two to three atmospheres for not longer that one and a half to two hours. Then he becomes intoxicated with oxygen, loses coordination of movement, and suffers from mental distraction and loss of memory. If the oxygen pressure exceeds three atmospheres convulsions will soon follow causing death.

Oxygen proves even more poisonous for animals which live where there is a critical lack of oxygen. This is how ascarides living in human intestines are combatted. Oxygen is fed into the intestines, causing no danger to the man himself but surely killing the parasites.

An excess of oxygen is not only detrimental to animals but also to plants. It is interesting that, although plants saturate the atmosphere of our planet with oxygen, the Earth's atmosphere is not good for them. They are rather short of carbon dioxide and, strange as it may seem, there is too much oxygen for them. According to recent investigations not only the usual concentration of oxygen but even as little as two per cent, that is one tenth of what is to be found in the atmosphere, considerably retards photosynthesis. This means that plants have created an atmosphere quite unsuitable for themselves. Had there been less oxygen they would have grown and developed more rapidly.

It was quiet in the operating-room. A young anaesthetist was bending over a girl patient. Everything was ready for the operation.

'Give the anaesthetic,' ordered a tall man with a greyish hair who was standing at the washstand. 'I'll just finish scrubbing my hands.'

The operation to be performed was quite a simple one. Nevertheless, it is still frightening to be on the operating table, so it is not surprising that the patient became particularly frightened when the first drop of ether reached her lungs and she attempted to take off the mask. The nurse had to hold the mask on by force and the young anaesthetist involuntarily gave the anaesthetic at a greater rate, which soon brought about the desired effect. In a minute or two the patient's muscles relaxed and she became quiet. But why was she so unnaturally rigid? The patient was not breathing. The next moment the anaesthetist hastily removed the mask and began to give artificial respiration.

He asked the nurse in a tremulous voice for lobeline.

In the past, arrest of respiration, a hazardous complication, often occurred at the beginning of anaesthesia. It may develop if the amount of anaesthetic being administered is rapidly increased. Nowadays the technique used in anaesthesia almost completely precludes complications of this type and provides surgeons with reliable methods of combating its consequences. Nevertheless, it is extremely unpleasant for a student anaesthetist just beginning his career to encounter such a complication, and especially if it is the result of his own carelessness. This is why the anaesthetist was very energetic in administering artificial respiration. Two or three agonizing minutes elapsed before the patient made her first inspiration, then the second, and a third....

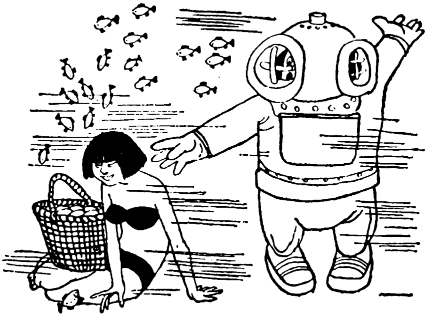
'That's enough,' ordered the surgeon, but the respiration ceased again. White as a sheet, the anaesthetist bent over the table once again to continue artificial respiration.

Now the surgeon stepped in and reassured his colleague, telling him that he had merely given the patient too much air. The long wait began once more. Finally the patient took another breath followed by another and yet another. Gradually her breathing became more frequent and regular.

'Now go on with the anaesthetic before the patient wakes up completely, but do not rush,' said the surgeon. Before long the people in the operating theatre resumed working at their usual pace. In another half hour the patient was back in the ward.

Why did the patient stop breathing twice? The reason for it the first time is clear: the excessive dose of a narcotic substance acted as a depressant on the respiratory centre of the medulla oblongata, and breathing ceased. The reason why breathing stopped the second time was more complicated. To comprehend this, we must first see how breathing is regulated. Three different receptor apparatus participate in controlling respiration. The first are the lung receptors which inform the respiratory centre in the brain of the extent to which they expand and contract. They send the signals to the brain informing it when to stop inhalation or expiration and vice versa.

The chemoreceptors are even more important. Some of these are in the carotid arteries and in the aorta. They control the concentration of oxygen in the blood. As soon as the respiratory centre is informed that there is little oxygen in the blood, it sends a command to make the breathing more frequent, but in such cases it



often becomes shallow. This is because a lack of oxygen easily inhibits the work of the respiratory centre and a signal reporting even a slight expansion of the lungs can interrupt inhalation.

The other chemoreceptors are right in the respiratory centre. Their function is mainly to control the concentration of carbon dioxide in the blood. If there is too much carbon dioxide, breathing becomes deeper. When the anaesthetist had to resort to artificial respiration, the ventilation of the lungs was considerably increased and the blood was thus completely supplied with oxygen. But the content of carbon dioxide became too low. The two main stimuli causing the respiratory movements disappeared and the impulses from the lungs arrived at the inhibited respiratory centre and therefore proved too weak to cause inhalation. Such a complication is not dangerous. If the normal concentration of carbon dioxide can be restored (since the tissues go on breathing, the content of carbon dioxide will inevitably grow), breathing will also continue.

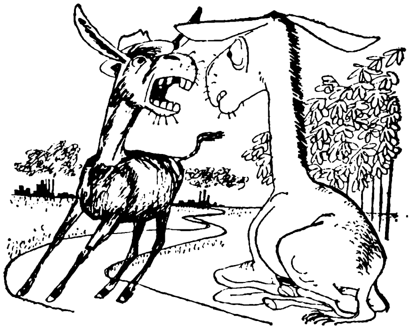
All this shows that carbon dioxide, a harmful and unnecessary waste product of metabolism, a kind of slag which the body hastens to dispose of, is not so unnecessary for man's organism after all.

When scientists discovered the basis of the respiratory movements, carbon dioxide began to be added to a mixture of gases to stimulate the work of the respiratory centre. Carbon dioxide is also added when giving anaesthetic. It excites the respiratory centre and, consequently, provides for a higher content of oxygen in the blood circulation.

The respiratory centre regulates the rhythm and depth of respiratory movements automatically. However, if we wish, we can interfere in its work, consciously changing the volume of lung ventilation, and even stop the respiratory movements for a certain time. We can train ourselves not to breathe for as long as possible. The Japanese girls employed in pearl-diving are able to stay under water for four to six minutes. Even their wages depend on how long they are able to stay on the bottom.

Training of this kind also has a negative aspect. Underwater work is particularly hazardous, since man has a receptor informing the brain of an insufficient level of oxygen in the blood, but it is unable to inform when the oxygen content is dangerously low. Amateur divers with little training have nothing to fear, since they cannot stay underwater long enough to exhaust their supply of oxygen. It is quite different with professional divers who have trained themselves to suppress the work of their respiratory centre, although considerable loss of oxygen occurs. They stay underwater until they have used up all the oxygen resources and may easily overstep the danger mark. This results in an acute shortage of oxygen, from which the brain is the first to suffer. A sudden loss of consciousness occurs, and the diver can only be saved if his condition is noticed by his mates and first aid is immediately rendered.

Carbon dioxide is a dangerous waste product. It is colourless and odourless and its specific weight is much



higher than that of oxygen or nitrogen. Carbon dioxide accumulates in places where the air does not move, for instance in limestone and water caves. The surrounding rocks supply a certain amount of carbon dioxide, which flows down the underground passages and may accumulate at the bottom of the caves to form 'lakes' of a kind. When a man who is not prepared for this gets into such a cave, he will most probably die. On Earth there are a few so-called dog caves in which the depth of the carbon dioxide 'lakes' is too shallow to be dangerous to man and which can be 'forded', but dogs will 'drown' there.

The third component of the atmosphere, which is the next most essential after carbon dioxide and oxygen, is nitrogen. It does not take any part in respiration. Under normal pressure no exchange of nitrogen occurs between the environment and the body, since there is as much nitrogen in the tissues as in the blood and the latter, in turn, is saturated with it to the limit.

If the external pressure is raised considerably, the blood will be under-saturated in respect with the gases in the atmosphere and it will intensively absorb and pass them on to the tissues until a balance is established between the three media.

Now, if the pressure returns to normal, or a considerable drop in pressure occurs, the gases dissolved in the tissues return to the blood. During this process oxygen will not affect metabolism but will be rapidly consumed, whereas nitrogen will accumulate in the blood vessels to such an extent that it cannot be dissolved in the blood and there will not be enough time for it to be expelled from the body through the lungs. Nitrogen bubbles may clog up the fine blood vessels. If cardiac or cerebral vessels are clogged the result may be fatal. The only way to save the patient will be to subject him to high pressure and thus allow the nitrogen to dissolve in the blood and the tissue fluids again, gradually bringing the pressure back to normal, so as to give the nitrogen sufficient time to escape from the body.

Atmospheric air usually contains dust particles and water vapour. Keeping the air over our towns pure is a major problem. Just think, the air is considered pure if one cubic centimetre of air does not contain more than six thousand dust particles. If anyone thinks this is too much, he ought to know that a cubic centimetre of the air we breathe at home often contains two million dust particles weighing about ten milligrams. It is not surprising, therefore, that in Kharkov and Leningrad, prior to their gasification, 300 to 350 tons of dust fell out annually per square kilometre, and in Magnitogorsk the figure was more than seven hundred tons. If man had no special devices protecting the lungs from dust, children living in towns would have their lungs clogged up with dust during their first year of life.

Unlike dust, water vapour is useful since it guards the body against excessive loss of moisture. According to hygienic norms, it is considered that the air in indoor premises should contain sixty per cent water vapour. If the humidity is lower than that human beings feel certain discomfort.

The last component which man receives from the atmosphere is electricity. Usually we forget that our lungs 'consume' a considerable amount of electricity every day, although the influx of electricity is essential for the normal course of the body's vital processes.

What kind of electricity do our lungs absorb and how does it come to be in the atmosphere? Scientists only discovered the existence of such electricity at the end of the last century. They learnt that the action of uranium and other radio-active elements present in infinitesimal quantities in any soil, the action of cosmic and ultraviolet rays, as well as electric discharges, splashes of water and the friction between particles of dust, cause electrons to separate from atoms and molecules of gas. An electron which separates and becomes free cannot exist for long in isolation. It soon joins one of the neutral atoms or a molecule. An electron is known to have a negative charge, which it imparts to the receiving molecule. On the other hand, the molecule which loses its electron becomes positively charged since the nucleus of any atom has a positive charge equal to the charge of all its electrons.

The charged molecules of atmospheric gases are called aero-ions. Some of them settle on the dust particles to form heavy ions. Others combine with a few neutral molecules to form light-weight ions.

Most aero-ions form in or near the soil. On average from eight to ten pairs of ions form in each cubic centimetre of the near-soil air per second. However, those ions do not accumulate, since some of them are destroyed when two oppositely-charged ions collide, and the remainder are adsorbed by solids or liquids or diffuse into a space where there are few of them.

Although the ions always form in pairs, the environmental air usually contains ions of one charge in prevailing quantities, the most frequent being light-weight positive ions. This is accounted for by the fact that the earth has a negative charge while the atmosphere has volumetric positive charges. The latter force the negative aero-ions upwards, while the positive ones go downwards and accumulate in the lowermost layers of the atmosphere. The amount of heavy ions depends upon the amount of dust in the air. Usually the predominance of heavy ions over light-weight ions is not more than fifty-fold.

Does an animal organism really need these charged molecules of gas? They have proved to be indispensible. A. K. Chizhevsky has carried out an experiment in which animals placed in an atmosphere lacking in ions fell seriously ill and, when made to breathe air with no electric charges, they died in from one and a half to five days.

On the other hand, an excessive concentration of ions, especially positive ones, is also bad for the organism. The foehn, a wind which blows in the mountains of the Tyrol (the Alps), the jasami, a south-east wind blowing in Japan, and the sirocco which blows from the South in Italy, carry many positive ions and act on the people depressively, causing headaches and indisposition, raising the blood pressure and aggravating tuberculosis and some other diseases. Changes in the charges in the ambient atmosphere are difficult to endure, but the negative aero-ions are themselves in most cases favourable. They are beneficial to those suffering from tuberculosis, and can reduce blood pressure. They also help to cure many other illnesses, including infectious diseases.

Large numbers of light-weight negative ions are responsible for the curative effects at many health resorts. Negative ions are especially abundant in some regions of the Baltic coast, near waterfalls, mountain streams, and powerful fountains. The electrical charges received by our bodies do not, of course, accumulate there. The tissues are good conductors of electricity and for this reason the charges we receive gradually escape into the earth.

There are many theories on the mechanism of the effects of atmospheric charges on the living body, two of which deserve special attention. According to one theory the electrical charges of molecules act upon the nerve endings of the lung tissue and thus strongly influence the functional state of the central nervous system as a whole.

The other theory maintains that aero-ions, having entered the lungs, pass on their charges to the blood and its erythrocytes. The blood carries the charges received in the lungs to individual organs and tissues and thus influences them in a definite way.

It is difficult to say which of the two theories is correct. The latter seems to be better substantiated by facts, but prolonged research needs to be carried out before final conclusions can be made.

Thousands of Millions of Carriers

IT JUST DARE NOT GET TIRED

On the eighteenth day after conception the human embryo is but a tiny pea-size bundle of cells. It is at that time that the heart starts beating regularly and continues to do so without stopping until death. The heart is probably the only organ which does not shirk its work and keeps functioning at a good rate, even if it belongs to the most inveterate lazy-bones. In a tiny three-week-old human embryo, that has no real blood as yet, the heart beats once every second. Later on, when the child is born, the pulse becomes more rapid, approaching one hundred and forty beats a minute. Fortunately, this is the peak and the pulse rate then gradually drops. In an adult the heart beats at a rate of some seventy six times a minute while a person is resting but may increase by as much as a hundred and fifty per cent during hard work. This means that in a hundred-year lifetime a man's heart beats about five thousand million times.

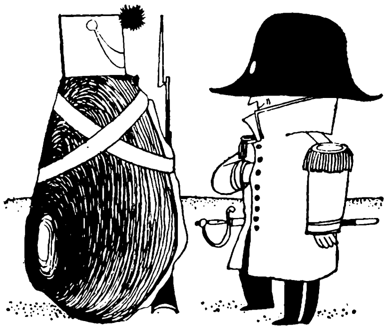
When one considers this figure, it is surprising that the heart never grows tired and, as long as it is healthy, copes easily with its task, literally without stopping for a second.

Man's metabolism is far from perfect and considerably inferior to that of small warm-blooded animals. The thing is that the smaller the size of a body, the less the area in which it decreases. For this reason smaller organisms have to produce much more warmth per gram of body weight than larger ones. Their metabolism is more intensive and thus the heart has to beat more energetically than in man. Indeed, the smaller the animal, the quicker is its heart beat. For instance, the heart of a whale whose body weighs one hundred and fifty tons beats seven times per minute, that of an elephant weighing three tons forty six times a minute, that of a cat weighing 1.3 kilograms two hundred and forty times, while the heart of a blue tit weighing as little as eight grams beats 1,200 times per minute.

Why is the heart able to work at such a high rate? First of all, it is not absolutely correct to think that the heart works without rest. The heart muscle quite often rests, but the periods of rest are very brief. A heart beat lasts for about 0.49 of a second and, if a man is resting, a 0.31 second interval follows each beat. The period of rest is actually longer, since not all parts of the heart work simultaneously.

The heart cycle starts with the contraction of the auricles, whilst the ventricles rest, and the ventricles contract while the auricles relax.The auricles take about 0.11-0.14 of a second to contract and this is followed by a 0.66 second rest. In other words, every day they work no more than three and a half to four hours and rest for about twenty hours. The ventricles take somewhat longer to contract, about 0.27-0.35 second, and rest for 0.45-0.53 second. Consequently, every twenty four hours the heart's ventricles work for 8.5-10.5 hours and rest for 13.5-15.5 hours.

In little birds the heart also rests, but their hearts contract and rest more frequently. The heart of a wil-



low tit contracts one thousand times per minute; a single contraction of the auricles lasts 0.014 second with an ensuing rest of 0.046 second. The ventricles contract for 0.024 and rest for 0.036 second. Thus, the auricles work for only 5 hours 40 minutes and rest for 18 hours 20 minutes, whilst the ventricles work for 9 hours 36 minutes and rest for 14 hours 24 minutes. This differs very little from man's.

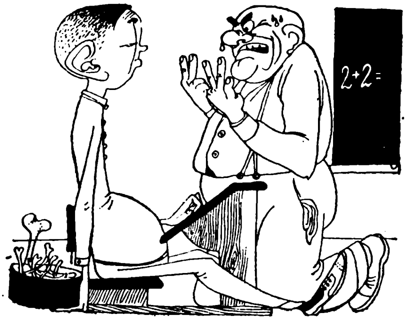
Nevertheless, man is quite able to considerably improve the way in which his heart works by prolonging the period of its rest. According to medical research, in a well-trained sportsman the heart, when at rest, contracts less frequently than the heart of other people, the frequency being as low as forty and even twenty eight beats per minute.

To cope with such a tremendous task as is the lot of the heart, rest alone is not enough. The heart must also be well nourished and have a good supply of oxygen. This explains why the heart in higher animals has its own, very powerful blood-supply system.

The lower animals have sought their own means of supplying the heart with blood. Nature proved to be thousands of millions of years ahead of Napoleon when he said that the way to a soldier's heart is through his stomach. In creating lamellibranch bivalve molluscs Nature decided to pierce their heart through. However, it did not use Cupid's arrow for the purpose but merely the rear intestine. No one knows why an intestine should go through the heart ventricles of a mollusc. This is, no doubt, the simplest way to supply the blood with nutrients, and perhaps the supply of nutrients to the heart muscle itself is most improved.

The main function of the cardiovascular system is to transport all the necessary materials to all parts of the body. Some substances move in the blood by themselves but others, mainly gases, travel on the back of the red blood corpuscles (erythrocytes). Every cubic millimetre of blood contains 4.5-5 million carriers, making a total of 35,000,000,000,000, the world's largest caravan. The size of the erythrocytes is negligible, only eight microns each, but if arranged in a chain, like camels in a caravan, they would encircle the Earth seven times around the equator. The red corpuscles of a whale, the largest living creature on the Earth, would form several caravans and each would stretch as far as the Sun.

The system of transportation in animals developed gradually. When the particles of a living creature first joined together to form an independent single-celled organism, and separated themselves from the ocean by means of an envelope, nature had to think of a way of organizing transportation within a single-celled body. A solution was soon found and Nature built the cell in the form of a microscopic ocean and provided it with its own currents. Thus, the simplest intracellular transportation system has been retained in many-celled animals, and in man. The protoplasm of any cell in our body is mobile and protoplasmatic currents exist even in the nerve cells.



Many-celled animals have had to develop a more complex system. The most primitive of them, for instance, sponges, use the water where they live for this purpose. The ocean currents proved to be unreliable, so instead they use cilia to make the sea water flow through the ducts and pores of their body, thus supplying all parts with nutrients and oxygen.

The higher animals have separated themselves completely from the ocean and provided themselves with their own 'aquariums' for transportation purposes. Nowadays the largest aquariums belong to the Gastropod (univalve molluscs, whose blood occupies ninety per cent of their body volume). This is evidently too excessive and the larvae of insects have an aquarium not exceeding 40 per cent of the weight of their body, whilst that of adult insects takes up 25 per cent. Birds and mammals have even smaller aquariums, only seven to ten per cent of their body weight, the tiniest reservoir being found in fishes where it is only 1.5-3 per cent of the body weight.

The smaller the aquarium, the more intensively it is used and the more rapid the currents in it have to be, so that the same liquid can be used over and over again. It is small wonder that insects can afford the luxury of having very slow currents in their aquariums, taking thirty to thirty five minutes to make one complete cycle. Man cannot afford this. The blood in our internal aquarium completes a cycle in as little as 23 seconds and performs over 3,700 cycles per day. This is, however, not the maximum. In a dog a complete cycle takes 16 seconds, in a rabbit only 7.5 seconds, and in the smaller animals even less.

In vertebrates the matter is complicated since the aquarium itself is very large but has little water in it. Nor can it be filled up. The total length of all man's blood vessels is about 100 thousand kilometres. Most of them are usually empty since seven to ten litres of blood is far from enough to fill them and only the most hard-working organs are supplied intensively. For this reason heavy-duty functions cannot be performed by many systems simultaneously. After a good meal the digestive organs are the most energetic. They receive a considerable amount of blood, while the brain is not adequately supplied to function normally. Hence, we experience drowsiness.

To set the waters of the internal aquarium in motion, it was necessary to have devices very different from the cilia of sponges. Muscle pumps proved much more dependable. The earliest pumps were nothing more than a pulsating vessel, i.e. a very simple heart, which drove haemolymph into the smaller vessels and thence into the interstitial and intercellular spaces. Having watered them, the haemolymph returned to the pulsating vessel. Such an open system could not provide proper circulation, and this is why insects, the highest representatives of the invertebrates, have developed pumps which not only force out, but also suck in. For this purpose their hearts are freely attached to special muscles known as the pterygoid muscles that stretch the heart thus creating a negative pressure that sucks in the liquid passing through the tissues.

A pulsating vessel is a low-capacity unit, and the lower animals usually have many pumping devices. In the earthworm the main pulsating vessel, that extends throughout its entire body, drives the blood from the rear to the front end. On its way, the blood flows into side vessels which themselves act as hearts pushing the blood into even finer arteries. All these numerous hearts function independently, co-ordinating, at best, their work with the partner in the segment. And this is the extent of the organization.

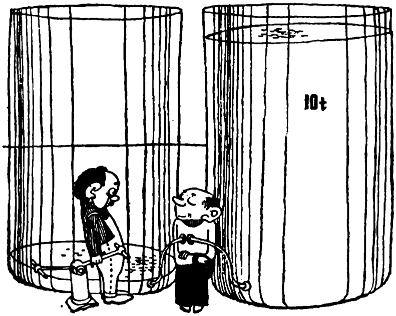
The higher animals found it expedient to separate themselves not only from the external but also from the internal ocean by providing themselves with a closed circulatory system. However, this problem has as yet not been completely solved. The main channel of the internal river, i.e., the cardiovascular system in mammals, is a closed one, but it takes in many streamlets, lymphatic vessels, through which the fluids from the interstitial and intercellular spaces flow.

This means that the tissues and organs have completely blocked themselves off from the waters of the internal ocean but have reserved the right to pour their waters into this mobile reservoir. Of course, the isolation of this internal ocean is only relative. In the arterial part of the capillaries, the walls of which are fairly thin, but the blood pressure is still high, a certain amount of liquid seeps into the intercellular spaces. This leakage would be still greater, since the banks cannot withhold it sufficiently, if it were not for the high oncotic pressure of the blood (caused by the proteins dissolved in it) which prevents the water from leaving the blood flow.

In a resting state a small amount of water percolates into the tissues, but it all returns to the venous part of the capillary where the blood pressure is lower than the oncotic pressure of the plasma; the liquid starts to be actively attracted into the plasma by the proteins dissolved in it. The force which acts inside the venous section of the capillary and makes the liquid return to the blood stream is about twice that in the arterial sections which forces fluid into the interstitial spaces. This is why it is all returned.

However, during periods of work it is quite another matter. In this case the blood pressure in the arterial section of the capillary will be so high that their walls will neither be able to retain water, nor proteins. In the venous section of the capillary the blood pressure will remain fairly high, while the oncotic pressure will drop due to loss of proteins; the liquid will have neither the stimulus nor the opportunity to return to the blood stream. The only alternative left to it will be to enter the lymphatic system. Thus, in the body the lymphatic system acts in a similar way to the system of drains in towns which prevents the streets and squares from becoming flooded during heavy rainfall.

One might think that a completely closed system would facilitate the work of the heart, but this is not so. A great deal of force is required to pump the blood through the capillaries and tiniest arterioles. As the arteries become more and more ramified their total cross-section increases and finally becomes 800 times that of the aorta along which the blood flows from the heart, and this leads to an increase in resistance. The thing is that we have from 100 to 160 thousand million capillaries with a total length of 60 to 80 thousand kilometres. I. F. Cyon, a well-known Russian physiologist, calculated that the work performed by the heart in a man's lifetime is equal to the effort which would be required to move a goods train to the top of the

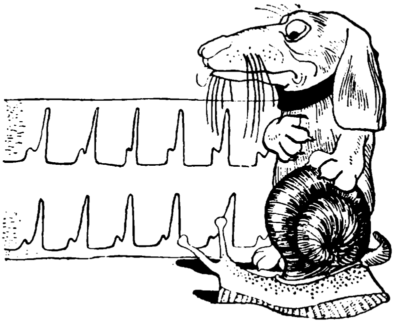


highest mountain in Europe, Mont Blanc, 4,810 metres high.

Even in man in a resting state the heart pumps six litres of blood per minute, i.e., not less than six to ten tons a day. During a lifetime our hearts pump 150 to 250 thousand tons of blood. But, in spite of all this, a man cannot boast of the work done by his heart.

Since a direct comparison between the work done by the hearts of large and small animals would not be accurate, scientists usually calculate how much blood the heart pumps per minute per 100 grams of body weight. Even in a slow-moving snail the heart works under about the same strain as in man, while the hearts of most animals work more intensively. A dog's heart, for instance, pumps about twice as much blood as a man's, and a cat's ten times that of a man's heart.

While the heart is working quite high pressure is maintained in the arteries. Even in such a small animal as the larva of a grasshopper, or in a frog, the mercury rises to 30 and even 38 millimetres. In most cases the pressure is even higher: in an octopus it is 60, in a rat 75, in a man 160-180, and in a horse it is as high as 200 millimetres of mercury.



Normally, the larger the animal, the higher is its blood pressure. This can clearly be seen in eels, sharks and other fish whose sizes vary considerably. The longer the eel or shark, the higher its blood pressure. There are, however, many exceptions to this rule, one of which is a cock whose blood pressure is the same as that of a horse.

There is no doubt that the heart of a great blue whale weighing 600 to 700 kilograms, even if it does not function normally, will do much more work than the heart of a blue tit weighing about five thousand million times less, i.e. only 0.15 gram. For a correct estimation, a comparison is made between the work done by one gram of heart muscle. In this case man also has nothing to boast about. Each gram of our heart does work equal to 4,000 gram-centimetres per minute, about the same as the heart of a snail. A frog's heart works three times as hard, a rabbit's five times as hard, whilst that of a white mouse works twelve times as hard.

Most of the earth-dwelling animals are horizontal. Their brain and heart, the two most important organs, are on the same level. This is very convenient since no additional effort is required on the part of the animal's heart to supply the brain with blood. It is quite different for man whose brain is on a much higher level than his heart. The same applies to a six-metre giraffe whose heart is situated two to three metres lower than is brain. All the creatures, following the same general plan (man, the cock, the giraffe) have high blood pressure.

The heart of typically horizontal animals is unable to supply the brain with blood when they take up an unnatural position. If a rabbit or a snake is placed in a vertical position they will soon 'faint' because of brain anaemia. Nor are such animals very comfortable when placed with their head much lower than the heart since the supply of blood to the brain is confused due to a disrupted outflow. However, the animal world abounds with virtuoso acrobats. An obvious example is bats who do not care very much in what position their body is.

There is an essential contradiction in the activity of the cardiovascular system. On the one hand, to maintain an adequate supply of blood, high pressure is necessary. On the other hand, higher pressure spells hazards, since it may disrupt the system at any time. If a major blood vessel is captured death will follow quickly and unavoidably due to a heavy loss of blood.

To maintain normal pressure, the system is provided with special controlling mechanisms known as barometric receptors. In mammals the most important receptors are located in the arch of the aorta, the sinuses of the carotid arteries transporting the blood to the brain, and in the auricles and in the pain-sensitive nerve endings. Should any change in the pressure occur, the receptors will immediately send a signal to the afterbrain. The pressure is brought back to normal partly by the heart but primarily by the blood vessels. The walls of the small minor vessels, the arterioles, have muscles and can easily constrict or dilate. When constricting, they create certain obstacles to the blood flow and cause higher pressure. Dilation, on the other hand, may reduce the pressure to a critical level and disrupt the circulation of the blood.

The heart beats continuously throughout a man's life, one contraction following another, day and night, whether it is hot or cold. By the twenty-ninth hour something is already pulsating in the tiny ball of cells which makes up a chicken embryo, and the fluid is already being transported by some route. What makes the heart contract? From where does the order come for the chicken embryo to begin working? As yet there is no indication of the brain which governs the organism in the future.

Although even in the adult animals the fundamental modifications in the basic rate of the heart beat are brought about by the brain, the heart can dispense with these commands and set its rhythm independently. Figuratively speaking, our heart works on its own initiative, a peculiarity which we somehow do not appreciate. If the fibres of an embryonic cardiac muscle are grown in a tissue culture on a special nutrient medium they will contract rhythmically in a vial too, without waiting for any orders. They just cannot live without contracting. Nonetheless, work cannot be well co-ordinated without a headquarters. If every muscle fibre contracted of its own accord the common contraction could take place only by pure chance. This is what really happens at the earliest stages of embryonic life. In the rat's embryo individual sections of the heart contract quite independently until the headquarters is set up and starts to operate. In birds and mammals it is located in a special region of the heart known as sino-auricular node.

The cardiac muscle has no nerves and commands are conducted over the muscle fibres at the rate of one metre per second. This rate is quite adequate for the auricles to contract normally. The ventricles of the heart, which are larger than the auricles, and which require commands to be communicated more rapidly, have a system, known as Purkinje fibres, over which excitation spreads five or six times more quickly.

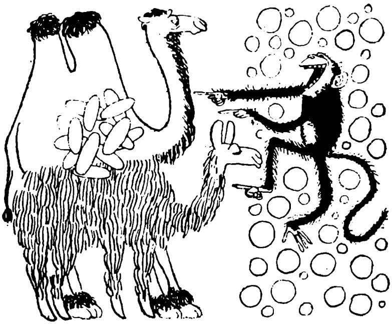
In the heart of every self-respecting animal there is only one headquarters known as the pacemaker. More pacemakers would certainly cause a mess. Strange things, however, are not uncommon. The ascidia and some tunicates have two pacemakers, one at each end of the pulsating vessel. In such animals the blood flow periodically changes its direction.

Owing to the automatism of the heart of the vertebrate, it can continue working even when removed from the body. All the latest cardiac drugs are first tested on a heart taken from a frog which, under proper experimental conditions, goes on beating for many hours.

It is a popular misconception that when death occurs the heart automatically stops beating. In reality, this is not always the case. The Russian physician Andreev succeeded in making the heart of a new-born baby beat again four days after its death.

Several centuries ago people did not even suspect that this was possible. The famous physician Andreas Vesalius, who treated the Emperor, Karl V, was among the few scientists granted the right to dissect corpses. He was sentenced to death by the Holy Inquisition on a charge of dissecting the body of a woman who was still alive. It was only thanks to the kindness of Phillipe II, the heir to the throne, that this dreadful and unjust death penalty was commuted to a penitent pilgrimage to the holy places on Mount Sinai and in Jerusalem. Vesalius did, incidentally, perish during this pilgrimage.

This accusation against this extremely popular scientist and famous physician of that epoch was mo-



tivated by the fact that the cardiac muscle of the woman who was undoubtedly dead continued to contract. The reason why her heart continued to function for many hours after death cannot be established. None of the many astonished spectators who witnessed this dramatic event had a shadow of a doubt that the woman was alive. As for Vesalius, he was sure that the accident was due to his own negligence and thought that the sentence proclaimed was just.

WAVES

The shores of our own 'personal ocean' are washed by waves, which are not blue but scarlet. However, blood saturated with carbon dioxide and other products of metabolism has a bluish tint, a fact which seems to have been known as early as the XIth century. At any rate, the highest nobility, the favourites of the King of Castile, an ancient kingdom in Central Spain which had overthrown the yoke of the Moors, claimed that the blood flowing in their veins was 'blue'. This was meant to prove that they had never been related to the Moors, whose blood was considered to be darker in colour. In fact, there are only some crustacea which really have blue blood.

The waters of our internal ocean have all that the cells of the organism require. The tissue fluids of the lowest animals are, in composition, very much like common sea water. The higher the animal, the more complex the composition of its haemolymph and blood. The blood contains, besides salts, physiologically active substances, vitamins, hormones, proteins, fats and even sugars. Nowadays, birds' blood is the sweetest, while that of fish contains the smallest amount of sugar.

The main function of the blood is transportation. It carries warmth all over the body, takes nutrients from the intestine and oxygen from the lungs and delivers them where necessary. In the lower animals, oxygen and all the other essential substances are merely dissolved in the fluid which circulates throughout their bodies. The higher animals have evolved a special substance which not only readily combines with oxygen when it is plentiful, but parts with oxygen equally readily when it is scarce. Such remarkable properties have also been found in certain complex proteins whose molecule contains iron and copper. Haemocyanin, a protein containing copper, is blue; haemoglobin and similar proteins whose molecules contain iron are red.

A molecule of haemoglobin may be said to consist of protein proper and an iron-containing part. The latter is identical in all animals but the protein-containing part has certain special features which enable even very closely related animals to be distinguished.

The blood contains everything that the cells of our body require. They simply remove what they need as the blood passes through the blood vessels. Only the oxygen-containing substance has to remain intact. If it is left in the tissues, broken down there and used for the body's needs, difficulties arise in the transportation of oxygen.

From the outset, Nature went in for creating very large molecules, from ones with a molecular weight twice that of an atom of hydrogen, the lightest substance, to ones occasionally even ten million times greater. Such proteins cannot pass through the cell membranes. They 'get stuck' even in quite large pores, and this is why they are retained in the blood for a long time and used over and over again. In higher animals the problem has been solved by haemoglobin which has a molecular weight more than 16 thousand times that of hydrogen. Moreover, so that the haemoglobin does not pass into the surrounding tissues, it has been placed in special containers, erythrocytes, which circulate in our blood stream.

In most animals these red blood corpuscles are round, but in some, for instance camels and llamas, they are sometimes oval, for which, as yet, no explanation has been found.

In early animals erythrocytes were large and cumbersome and in one extinct cave-dwelling amphibian they were 35 to 38 microns in diameter. In most amphibians they are much smaller but occasionally they may be as much as 1,100 cubic microns in volume. This proved inconvenient, since the larger the cell the smaller, relatively, is the surface area through which the oxygen passes on both sides. There is too much haemoglobin per unit of surface area and this prevents it from working to the full. Once convinced of this, Nature set about decreasing the size of the erythrocytes to 150 cubic microns for birds and 70 for mammals. In man they are eight microns in diameter and 90 cubic microns in volume.

In many mammals the red blood corpuscles are even smaller. In goats they are barely four, and in musk deer two and a half cubic microns in diameter. It is easy to understand why goats have such small erythrocytes. Domestic goats are descended from mountain animals which live in a highly rarefied atmosphere. It is not without reason that they have a large number of erythrocytes, as many as 14.5 million per cubic millimetre of blood, while in amphibians whose metabolism is low there are only 40 to 170 thousand erythrocytes.

In order to reduce their volume, in vertebrates the red blood cells became flat discs, thus minimizing the depth to which the oxygen molecules diffuse in them. In man the disc is biconcave. The volume of the cell is thus reduced even more, and, at the same time, the surface area increased.

It is very convenient to transport haemoglobin in a special container inside the erythrocytes but, as the saying goes, one has to take the wheat with the chaff. The erythrocyte, being a living cell, does itself consume a great deal of oxygen. Nature hates wastefulness and had to think hard of a way of cutting down this unnecessary expenditure.

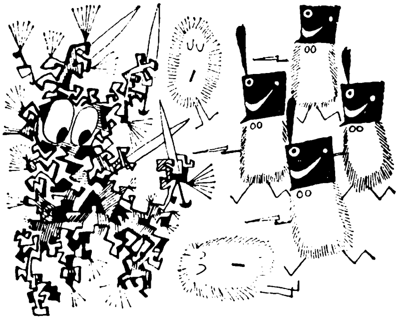
The most important part of any cell is its nucleus. If this is carefully removed (an ultramicroscopic operation within the power of modern scientists), then the denucleated cell, although still living, will become nonviable, its main functions will stop and metabolism will be drastically reduced. This is the very phenomenon which Nature decided to make use of and deprived the adult erythrocytes of their nuclei. The main function of the erythrocytes is to act as containers for haemoglobin. This function is a passive one and could not be disturbed, whereas a decrease in metabolism is very conveniently followed by a sharp reduction in oxygen consumption.

Recently we have considerably extended our knowledge of the chemical composition of haemoglobin. We know that every erythrocyte in a man's blood contains about a hundred million molecules of haemoglobin. The molecule, in turn, consists of ten thousand atoms, including four iron atoms. A molecule of myoglobin is considerably smaller, consisting of no more than two thousand five hundred atoms and has a single iron atom. The haemoglobin molecules in man's blood have four polypeptide chains in similar pairs: two α-chains and two β-chains, each containing one atom of iron. We know that the α-chains contain 141 amino acid radicals, and the β-chains 146 radicals. It has proved possible not only to calculate the number of links in each chain but even to determine what they are and in what succession they are linked. These findings have helped detect the cause of many diseases. In one such disease, known as sickle-cell anaemia, the round erythrocytes become sickle-shaped and look like new moons. The damaged erythrocytes cannot cope with their task and are rapidly destroyed; the condition results in premature death. Analysis of the damaged erythrocytes has shown that the α-chains are quite normal but that the β-chains are slightly changed. In a normal β chain the sixth link should be glutamine, but in people with sickle-cell anaemia it is substituted by valine. The succession in all the remaining links is normal. However, due to this seemingly insignificant alteration in the structure of the β-chain, the haemoglobin molecules stick to one another to form a compact mass and damage the container in which they are enclosed.

We have also discovered the nature of another serious blood disease, ferrihaemoglobinaemia. This disease results in two of every four iron atoms in the haemoglobin molecule becoming unable to absorb oxygen and, consequently, the blood of the sick person carries only half as much oxygen as that of a healthy person. The cause of this has also been discovered. The iron in the haemoglobin molecule is bivalent. In the presence of oxygen it usually captures a third electron, thus becoming trivalent. But this is not so with the iron in the haemoglobin of the diseased, since the third electron is detracted from the iron by the histidine molecule which is the fifty-eighth link in the α-chains and the sixty-third in the β-chains. The portion of this amino acid facing the iron is charged positively, allowing it to attract the negatively-charged electron of iron. In a sick person, histidine is substituted by a tyrosine molecule which has no positive charge at the side facing the iron atom and, consequently, cannot attract an electron. The iron atom becomes trivalent which makes it unable to retain oxygen.

Blood is not merely a means of transportation, it performs other important functions. Flowing through the body's vessels, the blood in the lungs and intestines comes into close contact with the environment. Both the lungs and especially the intestines are the 'dirtiest' places in the organism. It is no wonder that in these sites bacteria can easily penetrate into the blood. Why should this not happen? Blood is an excellent nutrient medium and rich in oxygen. Were it not for the watchful and merciless guards at the gate, the course of the organism's life would turn into the path of its death.

Guards proved readily available. At the dawn of life all the cells of the organism were capable of capturing and digesting particles of food. At about the same time organisms provided themselves with mobile cells, very similar to modern amoebae. They did not sit idly by and wait for the flow of fluid to supply them with something palatable, but continuously sought their 'daily bread'. These wandering hunters, which at the



very outset wage war against bacteria invading the organism, became known as leucocytes.

Leucocytes are the largest cells in man's blood, varying in size from eight to twenty microns. These white-smocked sanitarians in our organism continued for a long time to take an active part in digestion and they still perform that function on modern amphibians. It is not surprising that there are large numbers of leucocytes in lower animals. In one cubic millimetre of fish blood there are as many as 80 thousand leucocytes, ten times as many as in a healthy human.

It takes very many leucocytes to combat pathogenic microbes successfully, and the organism produces large quantities of them. However, it has proved very difficult to determine their life-span. The leucocytes are of course 'warriors' and as such they probably never live to old age but are killed off in battle, that is in the fight for health. This may explain why under different experimental conditions in different animals leucocytes possessed life-spans ranging from twenty three minutes to fifteen days. More accurate data have only been obtained for lymphocytes, one of the types of white blood corpuscles in our body. Their life is ten to twelve hours, which means that the organism completely renews its stock of lymphocytes at least twice a day.

The leucocytes are not only capable of wandering about inside the blood system but can, if necessary, easily penetrate deep into the tissues to combat micro-organisms which have got there. In devouring microbes which are of danger to the organism, the leucocytes are poisoned by the microbes' strong toxins and die, but they never surrender. They attack the site of infection, marching in a continuous line, column upon column, until the enemy's resistance is suppressed. Each leucocyte is capable of destroying up to twenty micro-organisms.

The leucocytes emerge on the mucous membrane, where there is always a host of micro-organisms. Two hundred and fifty thousand leucocytes come into man's oral cavity every minute and about one-eightieth of all leucocytes in our body die in the battle every twenty four hours.

Leucocytes not only combat microbes. They have been entrusted with another major function, that of destroying all damaged and worn-out cells. They constantly carry out demolition work in the organism's tissues to clear sites for the construction of new cells. The young leucocytes also take part in this construction work; at any rate, they help in building the bones, connective tissue and muscles.

In its youth every leucocyte has to decide what it wants to be. It may become either a phagocyte and combat microbes, or a fibroblast working on a construction site, or else it may turn into a fat cell, settling down near its fellow leucocytes and idly whiling away its time.

The leucocytes alone would doubtlessly be unable to protect the organism against the microbes invaiding it. However, the blood of all animals contains many different substances capable of agglutinating, killing and dissolving the microbes which penetrate the blood stream, and of converting the toxin released by them into insoluble harmless substances. We inherit some of these protective substances from our parents, whereas we develop others in the fight against the numerous enemies around us.

No matter how carefully baroreceptors may watch over the blood pressure, a breakdown is possible at any time. More often than not, the trouble comes from outside. Any wound, even the slightest, will destroy hundreds or thousands of vessels, forming breaches which immediately allow the water of the internal ocean to escape.

In providing every animal with its own ocean, Nature had to see to that that an emergency service was organized in case the shores of the ocean were breached. From the outset this service was not very reliable. This is why the internal reservoirs of the lower animals can be substantially depleted without detrimental consequences. For man a 30 per cent loss of blood is fatal, whereas a Japanese beetle can easily survive a loss of 50 per cent of its haemolymph.

If a ship at sea is holed, the crew tries to stop up the hole with any material at hand. Nature has supplied the blood with a good stock of patches of its own. These are special spindle-shaped cells called thrombocytes. They are negligible in size, being only two to four microns across. Such a small plug would not do for any sizeable hole, were the thrombocytes not capable of sticking together under the action of thrombokinase, an enzyme supplied plentifully to the tissues which surround the vessels, skin, and other places most subject to damage. On receiving the slightest injury, the damaged tissue releases a quantity of thrombokinase which comes into contact with the blood, and the thrombocytes immediately start sticking together to form a small clot, while the blood supplies it with more and more new building material containing, as it does, 150-400 thousand thrombocytes per cubic millimetre.

The thrombocytes alone cannot form an adequately large 'plug'. Clotting occurs by the action of a specific protein known as fibrin which is constantly present in the blood in the form of fibrinogen. The fibrin fibres produce a mesh in which small clots of thrombocytes, erythrocytes and leucocytes are trapped. It takes no more than a few minutes before a sizeable plug has formed, and if only a small blood vessel is damaged in which the blood pressure is not sifficiently high to force out the plug, the leakage will soon be stopped.

It would hardly be reasonable for the emergency service to consume too much power and, consequently, oxygen. The only task for the thrombocytes is to stick together at the moment of danger. This is a passive function requiring no considerable effort on the part of the thrombocytes and that means that oxygen should not be consumed while all is well with the organism. This is why Nature has deprived the thrombocytes, as it did the erythrocytes, of a nucleus and thus reduced the level of metabolism. The consumption of oxygen has thereby been considerably decreased.

It is obvious that a well-adjusted emergency service in the blood is quite indispensible but, unfortunately, it presents a grave danger to the organism. If, for some reason or other, the emergency service should operate at the wrong times, an unfortunate accident occurs. The blood would clot and stop the vessels up. To counteract this, the blood has another emergency service, a system of anticoagulation. This anticoagulation service sees to it that the blood has no thrombin whose interaction with the fibrinogen could result in a tangle of fibrin fibres. As soon as thrombin appears, the anticoagulation system immediately inactivates it.

This second emergency service is very effective. If a large dose of thrombin is introduced into a frog's blood, no severe consequences will result and the thrombin will immediately be rendered harmless. But if the blood of that frog is analysed it will be found to have lost its capacity to coagulate.

The first emergency service operates automatically, the second obeys the commands of the brain and will not operate unless a command is issued. If the frog's headquarters, which is in the medulla oblongata, is first destroyed and then thrombin injected, the blood will immediately clot. The second emergency service is on the alert, but there is nobody to raise the alarm.

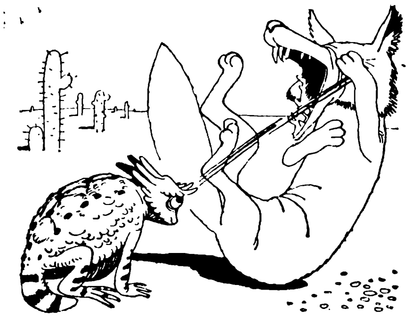
In addition to these emergency services, the blood has a major repair gang. When the blood system is damaged, it is important not only to produce a blood clot quickly, but to remove it in due time. While the broken vessel is sealed with a plug, it prevents the wound from healing. The repair gang, in restoring the tissues, gradually dissolves the blood clot.

The numerous sentry, control, and emergency services in our organism guard the waters of our internal ocean against all contingencies and ensure that its waves are kept in constant motion and retain a constant composition.

HYDRAULICS

Nature is always striving to allot an organ certain extra functions, which are not normally performed by it. Although the duties of the cardiovascular system are very specific and highly responsible, it could not avoid this common plight, since Nature was eager to utilize the pressure in the circulatory system.

Hypertension (abnormally high blood pressure) is



known to be very dangerous for the organism, as it may disturb the blood system and cause damage to the blood vessels. Nature, however, has turned this phenomenon to advantage. Thus, the lizards, known as horned toads, inhabiting the deserts of Mexico, use the local hypertension in the blood vessels of the head as a means of defence.

Generally speaking, this phenomenon is not terribly uncommon. When the blood, under abnormally high pressure, enters the crests, spines, and other outgrowths on the head and the body, they expand, straighten out, change colour and make the animal look fearful.

This is not the horned toads' only means of defence. Nature supplied them with a wonderful mechanism: when the lizard is standing at bay a specific muscle, known as the obturator muscle, presses against one of the major blood-vessels, markedly raising the pressure in the blood vessels in the head; it proves too high for the delicate vessels in the nictitating membrane and they rupture squirting blood into the face of a predator. This unexpected shower often makes the intruder take flight. This weapon is operative within the radius of one and a half metres.

The other function of the obturator muscle is connected with moulting. The reptiles continue growing throughout their lives. Horned toads change their skin every year. Casting off one's clothes can sometimes be difficult. This is where the obturator muscle comes into play. When the pressure in the head vessels increases, all the blood vessels, major and minor, distend and the head expands, tearing the old skin. When the skin on the head has ruptured the lizard simply crawls out of it through the newly-formed opening, as if it were taking off its overalls.

It was not very good to employ the cardiovascular system to perform secondary functions. But after the pumps and the communicating systems had been invented, Nature took a profound interest in hydraulics. To begin with, it seems to have guessed that by forcing liquids into the cavities and interstitial spaces it could considerably contribute to the turgescence of the tissue, i.e. impart to the tissue a certain degree of mechanical strength. This is but one step from the foundation of the hydrostatic skeleton.

It sounds funny, but man only began using similar constructions in the XXth century, and they are still not being used on a wide scale. The utilization of compressed air is particularly effective. Picture in your mind's eye a column of bulldozers and cross-country vehicles which have forced their way through the taiga to the projected construction site. Within a few hours the space for builders' settlement has been cleared. Then not very bulky packages are unloaded from the vehicles. The pumping facilities are switched on, and about half an hour later a settlement of two-storey canvas houses with inflatable beams and supporting structures have sprung up in the place won from the taiga. Convenient and efficient, this time-saving method of construction is surprisingly reliable. Besides, these canvas houses can also be made up of two or three layers of rubberized canvas, warm enough if their walls are similarly inflatable.

Animals can also make effective use of a hydrostatic skeleton, its main advantage being that it can be created for as long as it is needed. When it is no longer required the pressure in the system can be reduced, so that nothing remains of the skeleton. True enough, the hydrostatic skeleton is not as reliable as a bone one, and, where the supports have to be permanent, the hydrostatic skeleton has given way to more rigid constructions. But for non-permanent skeletons hydraulics have proved more advantageous. Nature has applied this invention throughout the history of the evolution of the animal kingdom, right from the lowest creatures up to the most developed ones, man included. Cavernous bodies employing blood as the working fluid is a good example.

Hydrodynamic mechanisms are still more fascinating. These range from extremely primitive devices to rather sophisticated ones. The most primitive of them include the excretory siphon-tube in bivalve molluscs. These living creatures derive oxygen and food, microscopic organisms and particles of plant and animal matter from the surrounding water, which they suck into the mantle cavity. The water saturated with carbon dioxide and polluted with excretory products is ejected through a special siphon-tube. The mollusc, no doubt, wishes the waste material to be removed far away from its body, so that it would not return into its mantle cavity. This explains why the excretory siphon-tube is rather long, though it has no special muscle and cannot stretch. When the shell is closed and water stops moving into the mantle cavity, the siphon-tube contracts, but as soon as the fluid resumes its flow the siphon straightens and stretches.

The hydrodynamic (water-vascular) mechanisms in the spider's legs are concerned with locomotion. These eight-legged creatures whose legs consist of six or seven segments, flex them, like all animals do, by contracting certain specific muscles, but they extend them by increasing pressure within the chitin-clad legs.

Hydrodynamic mechanisms are also very good for digging burrows. When tunnelling through moist soil the earthworm contracts the circular muscles at its front end to the utmost. Thus, its head becomes a kind of a sharp awl (if the soil is dry the worm moistens it). Then it looks for some tiny gap between the particles of soil. If it fails to find one, the worm drives its front end into the earth by delivering blows against it from the inside with the aid of its gullet which is operated by a hydrodynamic mechanism. An increase in pressure from two to fourteen millimetres of the water column allows it to strike blows with a force of 8.5 grams. As soon as the earthworm succeeds in burrowing itself to some depth, it increases the pressure in the front end, making it swell out and thus widen the burrow. If the soil is not very hard the earthworm will, by repeating this operation, bury itself in the soil before our very eyes. Still more energetic are siphunculides which, when digging their burrows, develop a pressure of up to 600 millimetres of the water column.

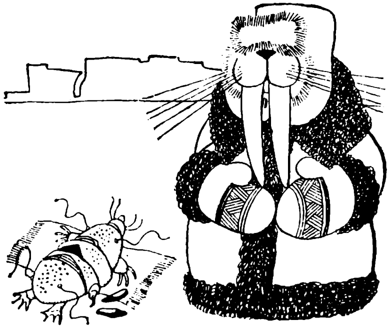
Among the most perfect hydrodynamic mechanisms is the locomotion device found in the *Echinodermata*, which is particularly well developed in the starfish and sea-urchins, brittle stars and various sea cucumbers. The arms of the starfish are permeated with symmetrically radiating grooves filled with a watery fluid. Small branches extending from the grooves enter each of the numerous tube feet located on the under surface of the arms. When the starfish moves the fluid is forced into the tube feet making them swell out and stretch in the direction in which it is moving; after the tube feet get a foothold by means of the suckers on its arms their muscles contract forcing the fluid from the grooves and thus helping the starfish to crawl forward a little. Then the tube feet detach from the ground on which the starfish is moving, the fluid is forced into them again, and the cycle begins anew. This shows that the heart is not the only pump employed by Nature to help the organisms of various animals in performing their most vital functions.

WHERE CAN ONE GET SOME FIREWOOD?

The Earth, like other planets in the solar system, has an extremely varied climate. Thus, in the Antarctic there are some fascinating spots where the temperature drops to 88°C below zero, whereas in Africa it may occasionally rise to +55°. These, certainly, are extremes only found in very few regions of the globe. In the main, the climate on Earth is somewhat milder. This, in all probability, is the reason why the vital activities in living creatures take place in a body temperature ranging from zero to forty degrees. This is a fairly wide range, and yet many animals and plants find it too narrow.

For instance, some species of algae can live, multiply, and obviously feel at home in the streams as hot as 70° to 90°C. Life can be found amidst the eternal polar ice, too. This startling discovery was made about two hundred years ago by the expedition headed by Horace Benedict Saussure, a Swiss naturalist. The scientists of the expedition, however, encoutered another phenomenon which amazed them. The expedition discovered areas of blood-red snow. This was a startling sight.

It was soon discovered that the unusual colour of the snow was due to minute single-celled algae cover-



ing its surface. These algae, which were given the name of 'snow chlamydomonas' occurred in various regions of the Arctic and Antarctic, and on the eternal snow of the highest mountain ridges, including those of the Caucasus.

At present scientists know of over 140 species of plants which live permanently in ice and snow. Many of them are violet, red, brown or green and they impart this colour to the snow.

In order to develop properly the snow chlamydomonas need plenty of sunlight and sufficiently low temperatures. This explains why they are found in large numbers only in the polar regions and high up in the mountains. The exceptional resistance to cold possessed by the snow algae, which at first astonished scientists, is now taken for granted. It is much more amazing that they are afraid of 'heat'. The snow chlamydomonas cannot survive even such a moderate temperature as 4°C which for us is rather cold. Of all the living creatures inhabiting the Earth the chlamydomona seems to dread the heat more than any other.

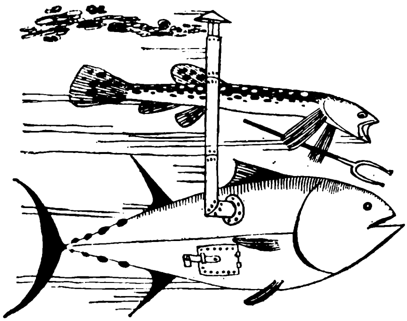
It is worthy of note that one and the same species of animals is found in all the climatic zones, even those as cold as the polar regions and as hot as the Equator. Some strains of these cosmopolitans differ enormously in their resistance to heat and cold. The terebellid worms living in the Arctic Ocean near Greenland cannot withstand 'hot' water of 6° or 7°C, while their southern relatives in the Indian Ocean easily survive in water as warm as 24°C.

Crustaceans which live in the very warm, slightly salty lakes of the Arabian Peninsula are considered to be the most heat-loving creatures. They feel very cold when the temperature is as high as 35°C, and die of 'cold' if the temperature drops below this.

But the majority of animals do not feel the cold so much. Spores and primitive creatures (rotifers and tardigrades) can survive in the temperatures close to absolute zero, that is around—273°C. Even such highly-developed organisms like insects, their eggs, and pupae can withstand considerable cooling. Some of them spend winter living in the open in the northern countries and endure winter frosts of —30 to —50°C. They are known to have survived temperatures of —80 to —250°C during laboratory experiments.

Why then do many animals, which are highly resistant both to heat and cold, remain active and are capable of carrying on their vital functions only within a limited range of temperatures?

Temperature regulates the movements of molecules in any substance, including the substances which make up the bodies of animals. When the temperature drops, there is a gradual decrease in the rate of molecular activity and, consequently, chemical reactions are retarded, until ultimately the rate becomes too slow for the organism to carry on its vital functions. This happens when the temperature drops below 0°C, as the fluids in the body freeze, for the main chemical reactions in the organism can only take place in water solutions.



In animals the maximum temperature of the body depends on the stability of the proteins and fats. When heated to over 40°C they change to such an extent that the cells will die. For this reason all animals try to live in the most favourable temperatures. They achieve this aim in various ways.

On the earth poikilothermic or cold-blooded animals exist whose body temperature depends to a large extent on the ambient temperature. When it is cold they often have to resort to extremely sophisticated methods of keeping themselves warm.

The higher (homoiothermic or warm-blooded) animals keep their body temperature constant by producing heat.

This can, incidentally, be done by any cell in any organism, if it takes an active part in metabolism. Such a cell is always warmer than the surroundings, even if it is by only one-thousandth of a degree. Therefore, the statement often found in school textbooks claiming that the body temperature of cold-blooded animals is the same as that of the ambient atmosphere, is somewhat misleading. Naturally, small animals generate little heat and quickly lose it to their surroundings.

Obviously, in these circumstances it is difficult to tell whether the animal's body temperature is higher or lower than its environment. It is different with larger animals which produce more heat and retain it longer. The body of the small trout which lives in cool mountain streams is only 0.012 degree warmer than the water, while the body temperature of a large tunny or marlin is at least six degrees warmer than the water.

The simplest way for poikilothermic animals to keep warm is to find themselves a comfortable spot with a suitable microclimate. During cold weather some of them go into burrows, others try to take refuge at the bottom of deep rivers or lakes, and still others create their own microclimate. Even plants can do this. The forest is known to be warmer than the open fields.

The problem which remained a complete mystery for a long time was how the snow algae, mentioned above, manage to keep up a high rate of metabolism and multiply intensively at low temperatures. Where do they get their energy from? No other organisms on this planet are able to do this.

In recent years it has become obvious that the snow algae provide themselves with favourable surroundings. They are not just scattered about the snow as solitary individuals, but unite into minute colonies. During sunny weather dark conglomerations of algae are heated, making the surrounding snow melt. As a result each colony finds itself in a miniature pit. The water on the surface often freezes, and a small basin with the algae is covered with a thin layer of ice. This basin acts as a sort of tiny greenhouse where the temperature is about 0°C.

However, a temperature of 0°C is not the only thing the algae need. Scientists suggest that the chlamydomonas are supplied with a device similar to semiconductors. In order to create an electric current, one part of the semiconductor unit is heated, while the other is cooled. As the difference between the two temperatures increases, there is a progressive growth in the amount of electricity obtained.

With the snow algae one side is heated by the sun, while the other loses a great deal of heat. This seems to be the mechanism supplying the algae with the energy they need for their activity.

Rich supplies of snow micro-organisms are never wasted. If there is food, there will be those who want it, even in the Antarctic regions. This continent appears to be a vast dead area covered with kilometre-thick ice, a place where bitter frosts and snowstorms reign for ten or eleven months, only to give way to slightly milder frosts for the rest of the year. It is generally believed that the few animals inhabiting this continent—the seals, pinguins and several species of birds—live near the ocean coast,while the rest of the continent is absolutely lifeless, but this is not so. Having studied the Antarctic regions for many years, scientists have found about fifty species of insects and other animals amidst the eternal snow. It follows, therefore, that life has penetrated deep into this harsh continent.

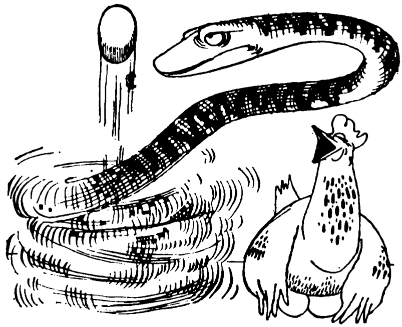
The creature found in the most remote areas is a tiny spider discovered by a British expedition only 500 kilometres away from the South Pole. This little spider lives in the gardens of algae and fungi. If the algae colonies are close to one another the little greenhouses merge to form a united system under the snow. It is here that the spiders settle. The food in such greenhouses is plentiful and it is much warmer there than in the open. Besides, the spider, being black, absorbs the warmth of the sun well. When the brief polar summer is over, the spider goes into hibernation.

Other animals also use the sun's energy. The insects dwelling in polar regions and high up in the mountains are also dark in colour so as to absorb the sunrays better. This is why the body temperature of such insects during sunny weather is higher than that of their environment.

There are also animals that have learned to regulate the amount of heat received. This is very important, since they might, otherwise, run the risk of becoming too warm in sunny weather. Many amphibians and reptiles have special pigment cells in their skin which are able to change their size. When the pigment cells are small, the skin is light and reflects the sunrays well. When the cells expand the skin becomes much darker and absorbs the sunrays better. The body of the animal is warmed, but not beyond a certain point. As soon as it becomes too warm, the pigment cells begin to contract and thus prevent further heating.

The pearl-butterfly has adopted a different method. It keeps its body temperature at 32.5°-35.5°C. In sunny weather the butterfly maintains this temperature fairly precisely, irrespective of the temperature of the ambient air. It uses its wings as the main heat-receiving surface. The butterfly is best warmed when its wings are completely exposed to the sunrays and perpendicular to them. The smaller the angle of exposure, the less intensively it is warmed. Butterflies control the amount of heat received by changing the position of their wings. When the body temperature is low the wings are kept in the position where they absorb the greatest possible amount of heat. As soon as the body temperature is 35°C, the butterfly begins to move its wings till it finds a position where they are no longer heated.

Termites use the same principle in constructing their dwellings. The reason why insects living in the earth build such conspicuous nests is that they are not warm enough in the earth. In very warm countries termites build very high, flat termitaries with the narrow



edge facing south. At midday when the sun is very hot, its rays pass over their house causing no overheating, but during the rest of the day, from sunrise to sunset, the sunrays fall on the side walls heating the nest.

Warm-blooded animals are able to keep their body temperature constant without the warmth of the sun. When it is cold they produce a great deal of heat and when it is hot they are able to give off excess heat. Generally speaking, the animals on our planet are better adapted to low temperatures than to high ones.

Many animals can easily withstand frost, keeping their body temperature constant, even when there is a difference of 80° between its temperature and that of the environment. A great many animals of this type are to be found among the Arctic fauna. For instance, the body temperature of a willow grouse is 43°C. The grouse is able to maintain this temperature even when it is —40°C outside.

The warm-blooded animals have evolved a variety of mechanisms to keep their body temperature fairly constant and protect them against freezing. When the temperature of the air drops, the heat-insulating mechanisms begin to operate. The skin vessels are the first to constrict, the skin becomes cold and gives off less heat. Fur and feathers are erected and more air is let in between them. It is a well known fact that motionless air is the second best heat-insulator, inferior only to a vacuum. This phenomenon does, incidentally, also occur in man. When we are cold, we develop goose flesh and the small hairs which still persist on our body stand on end. Unfortunately, this does not make us any warmer.

If these measures do not bring about the required results, and cooling of the animal's body continues, shiver begins. Contrary to popular belief, shivering is not completely useless. The contraction of muscles is accompanied by the liberation of a considerable amount of heat; thus, shivering helps to generate heat.

Only warm-blooded animals are able to shiver but other animals also resort to muscular activity aimed at increasing heat generation. Reptiles, with the exception of a few species, are known to show very little concern for their offspring. But scientists have long been aware that certain types of female pythons do not crawl away after laying their eggs, but coil themselves around them and 'stand on guard' till the young snakes hatch.

Of course, very few animals would dare attack such a formidable guard as the incubating mother. But the thing is, however, that, although the female python does protect its eggs against predators, its main concern is to keep the eggs warm. This may seem strange since snakes are known to be cold-blooded creatures. Nevertheless, if a snake 'runs' for a while it can also warm up a little. When the temperature of the air is sufficiently high the python lies motionless, but as soon as it becomes colder its striated muscles begin working, that is they contract and distend at the python's will, making the body of the snake now thinner, now thicker.

The python works as hard as it can, using its enormous strength, till it gets warmer and warms its eggs like a brooding hen.

The same method is used by insects. They can only fly after they have warmed up. For this purpose, the peacock butterfly flaps its wings to get warm and, even during cold weather when the temperature is 10°C, it manages to raise its body temperature to 35° or even 37°C, which is the body temperature in warm-blooded animals.

This strenuous muscular activity results in the liberation of large amounts of heat, but warm-blooded animals cannot warm up by shivering alone; their metabolic processes become more intensive and, consequently the chemical heat production is drastically increased.

The poikilothermic animals can also intensify their metabolism, but they do so in a much simpler way. They begin to eat more in order to generate more heat. Bees are the most striking in this respect. One bee on its own, like any other insect, cannot maintain the required body temperature, but a bee family as an integral, self-contained community is warm-blooded. In contrast to other insects, bees do not hibernate. During extremely cold weather, when the temperature drops to −30°C, the bees are busy keeping the temperature inside the nest, their 'winter club', as high as +35°C.

The 'club' is founded when the winter cold sets in. As soon as the temperature outside drops, the bees gather round the queen, crawling about the honeycomb, to form a large, compact spherical cluster. The bees nearest the queen consume a great deal of honey of high calorific value and liberate a great deal of heat, thus warming those in the outer layers; the latter form an effective insulation zone and prevent the bees in the centre from getting cold by huddling together in a compact cluster. When they cannot stand the cold any longer, they push aside other bees, making their way inside and thus exposing the layer of bees beneath them. This monotonous shifting continues throughout the cold period and the bees winter on honey which they consume kilogram after kilogram.

The best heat producers among the bees are their larvae. This is no wonder since the wet-nurses feed the offspring entrusted to them about 1,300 times a day. During cold weather, however, the larvae laid singly in separate cells are unable to keep warm. For the larvae to survive, the temperature in the hive must be 35°C. To ensure this temperature the worker bees get together on the honeycomb to form a compact insulating layer and protect the larvae against cold with their own bodies. If this proves insufficient, playing the role of the brooding hens the bees begin to move their feet and fan their wings, and thus raise the temperature in the nest to save the brood.

A constant temperature is only maintained in the middle of the nest where the offspring grow and develop. The temperature on the periphery of the nest may be considerably lower. In the same way, in warm-blooded creatures only the temperature right inside the organism can be maintained constant, the temperature of the skin, and especially that of the limbs, being much lower. In the fins of whales and seals, in the legs of mountain goats and reindeer it can be as low as 10°C. The remarkable thing is that the muscular activity in these animals is not affected by such low temperatures.

It is quite possible to train a person to withstand low temperatures, with some parts of his body exposed to the cold, without damaging his health. People living in the north do not protect their faces, even against severe frosts. The Australian aborigines can easily bear their feet to be as cold as 12 to 15°C. Even on cold nights they sleep, as always, in the open, near feebly smouldering fires, without even covering their bodies. Only one side of their body is warmed by the fire. The other side and the limbs remain cold. Europeans, no doubt, cannot sleep in this way, for even when their legs get slightly cold they wake up.

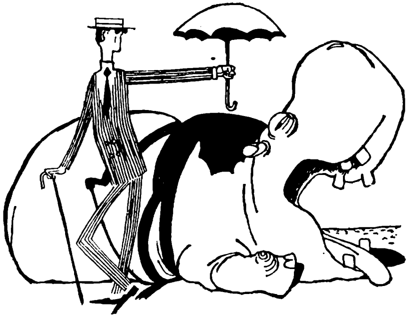
For aquatic animals it is also very important that their limbs should not get cold. The body of whales and seals is enveloped in a thick layer of fat containing poorly developed blood vessels. This is why these animals, which normally live in very cold water, give off almost no heat via their fat. It is quite different with fins and flippers which are not protected with fat and have a well-developed blood circulation, since muscular activity requires a considerable inflow of blood. When the hot blood comes into the limbs a great deal of heat leaks out through these natural 'weak points'. Seals, walruses and other pinniped animals would not be able to exist, if it were not for the amazing contrivance they acquired in the course of their evolution.

The major arteries which transport the hot blood into the fins and flippers of whales and seals are entangled in a dense network of fine veins. These veins carry the blood, which has lost its heat in the extremities, back to the heart. The arterial blood gives off most of its heat to the venous blood before it reaches the muscles of the fins and flippers, and does not lose much heat after that; the warmed-up venous blood, on the other hand, runs back into the general blood stream and does make the organism cold. This wonderful heat exchanger designed by Nature makes it possible for the blood flowing to the extremities to leave the excess heat at the beginning of the fat barrier. Devices of this type are found in the penguin's armpits; they prevent heat from being given off through its flippers.

The lungs of warm-blooded animals are another hole through which the cold enters the body. In the lungs, cold air comes directly in contact with the blood. The internal surface of the lungs is extremely large (in humans of average height it constitutes about 90 square metres, that is almost fifty times as much as the entire surface of the skin). The blood in the lungs might be expected to become cooler than the body and this would, inevitably, result in the cooling of the whole organism. This, however, is not the case. During hot weather, the temperature of the blood flowing out of the lungs becomes lower than that of the inflowing blood, whereas during cold weather it is the other way round. Though these changes are negligible, not more than 0.03 of a degree, they are sufficient to maintain a constant temperature in winter and summer.

The blood outflowing from the lungs is cool during hot weather, because heat is expended in vaporization. Until recently, relatively little was known of how the blood manages to keep warm during cold weather. It has long been established that the air passing through the respiratory tract, the nose, larynx, trachea and bronchi gets warmer by combining with the warm air present in these organs, smoothing out, to a considerable extent, the difference in temperature. Yet, the winter air entering the lungs is still much colder than the blood and inevitably cools it. Nevertheless, in man and other warm-blooded animals the lungs themselves are one of the main sources of heat in the organism. The lung tissues contain many highly calorific fats. When it is cold, and only then, they 'burn' these fats liberating a great deal of heat and producing an insulating barrier which stops the organism from getting cold. Thus, this gap has also been safely filled.

Man can achieve cooling by vaporizing water from his lungs and skin. Many animals find it more difficult to cool themselves off. Rodents have no sweat glands

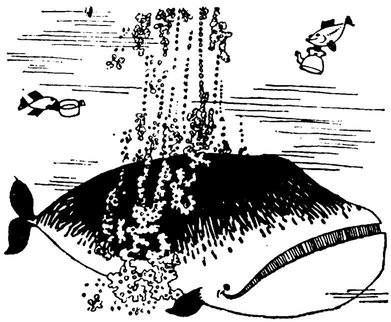


whatsoever. When it is hot, the rodents begin to pant, thus allowing an increasing amount of water to escape from the lungs. Dogs and cows also pant in hot weather.

If the quickened panting does not keep the rodents cool, they begin moistening their fur with saliva. The opposum and Australian marsupials which live in hot deserts also do this.

Bees use both evaporation and ventilation. When the temperature within the nest becomes dangerously high, some of the bees sprinkle water on the honeycombs while others line up near the entrance of the nest and fan energetically with their wings, causing an indoor hurricane to enhance evaporation.

It is not easy for aquatic animals to keep cool either. Although water conducts heat twenty to twenty seven times as quickly as air, the body of whales and seals which has a thick covering of fat does not, practically, become any colder. But for special device that the whale possesses, its body could begin to boil, because, when a whale is swimming at a speed of thirty-six kilometres per hour, it generates so much heat that its body temperature would be expected to rise by one degree every five minutes. Whales and seals cool down by means of

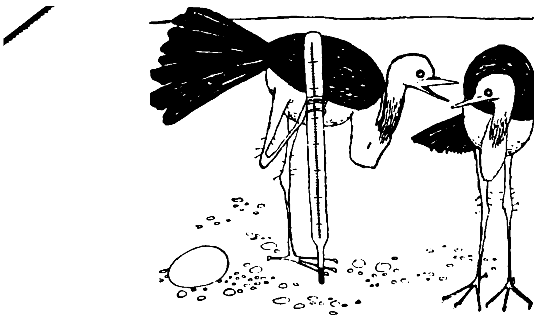


vascular network in their skin. While the whale is cold, the arteries coming up to the skin through the layer of fat are constricted and the skin vessels empty. When the animal is moving, its body temperature rises and the hot blood is sent to the skin to be cooled.

Another mechanism also exists. Strenuous work by the muscles always results in higher blood pressure. Of course, during this process, the arteries going to the flippers swell up, pressing against the veins closely entwining them. The blood starts outflowing from the flippers and enters veins which were previously idle. The operation of the heat-exchanger is thereby disturbed, and the heat is given off through the flippers into the surrounding water.

The whales can employ yet another method to lower their body temperature. When they are hot, they begin rinsing out their mouth and nasal cavity with cold water, spurting it out as powerful fountains of heated water.

If the energetic measures taken by the organism are not sufficiently effective and the body temperature continues to rise, a shock may occur as a result of the damage to the brain caused by too high a temperature. It is noteworthy that the external temperature that can



be endured by the organism is much lower than the endogenous increase in temperature (brought about by the vital processes within the organism). Man will faint if his temperature only rises to 38.6°C due to the sunshine or warm atmosphere, whereas very strenuous work may, without any harmful effects, cause his temperature to rise to 40°C, and disease-provoking bacteria may cause the temperature to be as high as 42°C.

A definite, constant body temperature is not always what the organism needs. Creatures living in the deserts, regions where the temperature varies greatly during the day and at night have, therefore, deviated from orthodox warm-bloodedness.

The camel, known as the ship of desert, is better adapted to life amidst the sands than other large warm-blooded animals; it can easily endure daily fluctuations in the body temperature of up to 5.5°C. During the cold nights in the desert the camel's temperature drops to 35°C. This is advantageous, since the camel need not use up its energy raising its temperature. During the day its body temperature rises to 40.5°C and the camel does nothing to reduce it. But when it gets cooler, even by only one or half a degree (which very often happens), the camel easily gives off the excess heat that accumulates when it is working.

The body temperature cannot be retained within narrow limits without incurring problems, if there is no special apparatus for this purpose. Primitive organisms which have not yet acquired a thermometer of their own often find themselves in trouble.

The heat-loving micro-organisms dwelling in peat heaps are absolutely unable to take precautions against fire. They often liberate so much heat that it causes the peat to ignite spontaneously. Their fellow micro-organisms which settle on balls of cotton, flax, or hemp carried in damp holds are just as thoughtless as the heat-loving peat dwellers. If their numbers increase too quickly, they may set fire to the vessel while at sea.

In warm-blooded animals the temperature of the blood (and, consequently, the body temperature, too) is under vigilant control of the heat-regulating centre in the brain and of the thermoreceptors in the skin. If Nature has chanced on an interesting find, it is usually unwilling to stop half-way. In some animals the thermal receptors have been developed to such an extent that they are the main means of detecting food.

Cold-blooded animals are acknowledged experts with thermoreceptors. It is easier for them to use these instruments than for the warm-blooded animals, whose high body temperature prevents them from detecting weak thermal forces at a distance. Many insects have sensitive thermoreceptors, for example, bees, ants, bugs, crickets, ticks, as well as adders, pythons, rattlesnakes and other reptiles. In insects thermoreceptors which detect remote thermal signals are in the antennae, whereas those responsible for determining the temperature of the soil are in the legs. The two antennae at their disposal allow sources of heat to be detected fairly accurately. Having received a thermal signal indicating that its prey is near, the mosquito turns its body till both of its tiny antennae, not more than three millimetres long, receive equal amounts of heat.

Insects are very accurate in taking aim locating the target. The designers of intercepting guided missiles, sensitive to heat radiation, rockets and working aircraft engines, cannot compete with insects in the sensitivity of their instruments.

Large blood-sucking bugs can easily detect a source of heat with only one antenna. Having turned its antenna in various directions, the bug easily notices that, when its antenna is, say, pointed to the right, it gets warm most quickly. This means that it is closer to a source of heat, so it immediately sets out to the right.

The skin temperature of human beings varies greatly. Therefore, some of us attract blood-sucking insects more than others. If you have ever happened to walk by a river or a lake on a warm evening, when swarms of insatiable mosquitoes thirsting for blood do not leave you alone for a few seconds, you may have been amazed at the endurance of the anglers who are able to put up with them for the whole of the evening spent fishing on the river bank.

But this is not just a question of endurance. The skin of a man who is walking along intensively trying to protect himself from the mosquitoes is considerably warmer than that of a man standing quietly on the bank, and is much more attractive to the mosquitoes. This is the reason why anglers suffer from mosquitoes much less than people walking near the water.

In reptiles, the paired thermoreceptive organs are to be found on the snout, a little below the eyes, and sometimes on the lower lip. They are of simple design: it is a recess, on the bottom of which there is a delicate membrane, no thicker than fifteen microns, which has numerous free nerve endings. This membrane covers an air-filled cavity which prevents loss of heat, negligible as it is, from being spent on warming the surrounding tissues. The membrane can detect changes in temperature as small as 0.002 degree centigrade resulting from the consumption of only 0.000,000,005 calory per second.

Thus, a snake is able to detect quite remote objects whose temperature differs from that of the surroundings by only 0.1 degree. It is obvious that, due to such astonishing sensitivity, the snake will never miss a 'hot' mouse or a slightly warm frog hiding in the bushes on a pitch-black night.

The thermoreceptive organs in warm-blooded animals are simple in design. The megapodes or mound birds, found in Australia and New Guinea, hatch their eggs in specially built incubators—large mounds of rotting plant debris. A high temperature is maintained in the incubators due to the process of decay taking place. The incubators of the mound birds are looked after by the males who are considered more technically-minded than the thoughtless egg-layers. This distribution of duties is quite reasonable as the cock's beak is an excellent thermometer. By plunging it well into the debris the bird is able to determine the temperature very precisely. If it is more than 33°C, the cock begins raking the mound to allow some of the heat to escape, but when the temperature is lower the bird adds fuel in the form of more rotting debris.

This thermometer is an extremely simple one; the temperature of the beak is 33°C. All that remains for the cock to do is to see whether the temperature in the mound is higher or lower. Man can also do this.

The Fire-bird

JUST LIKE A FAIRY-TALE

Once upon a time, in a certain kingdom there lived a tsar called Berendey. He had a wonderful orchard with an apple tree on which golden apples grew.

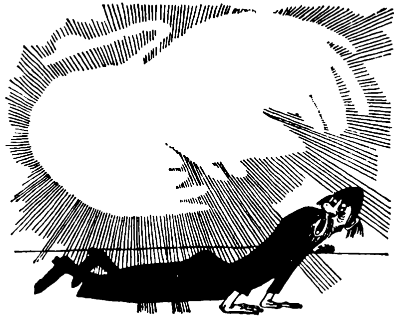
A thief began to visit his orchard and steal the golden apples. The tsar then ordered his youngest son, Ivan, to guard the orchard. Ivan walked about the garden till far into the night, but did not see anybody. At midnight the orchard was suddenly lit up by a bright light and he saw the Fire-bird sitting in the apple tree and plucking off the golden apples. Ivan almost seized the Fire-bird by the tail, but it broke free and flew away. Only one feather was left in Ivan's hand but it emitted so much light that the whole of the garden seemed to be aflame.

All this is told in an old Russian fairy-tale about the marvellous fire-bird. Everyone has probably heard this tale, but very few may know that the fire-bird is real and it is not only the tsar's sons who have been lucky enough to set eyes on it.

On September 9th, 1864, Theodore, the verger at the Cathedral of St. George at Staraya Ladoga, which stands high up on the banks of the mighty Volkhov river, was returning home after a christening party. The evening was warm, and the sky was full of low, heavy clouds. It was drizzling, as it often does in autumn. The verger had had a drop too much to drink and his aged feet, which had long ceased to obey him, refused to move any more. Entangled in the flaps of his wet cassock, Theodore stumbled and slipped about on the muddly ground. He could hardly find the path.

The patter of the rain muffled all other sounds. The silence was now and then broken only by the tinkling bell of a horse tethered near the river, or by flocks of ducks now and then rising from the Volkhov. Theodore, frightened by the ducks, trembled and crossed himself with a faltering hand. Then he dragged himself farther, looking out for the cliff which, in the darkness, he thought was quite nearby. All of a sudden, a light, like a falling star, rushed in his direction. The next moment it became a radiant ball of light and at the same time the noise of wings could be heard. Then both the light and the noise ceased. The verger was so startled that he fell down on the wet grass. When he got to his feet he shook his fist for a long time at the bird which had already flown away. In the morning Theodore told his parishioners about the devil which, in the guise of a fire-bird, had tried to throw him from the cliff. But that he had rebuked the devil and driven him away.

The dean of the cathedral disliked Theodore going to parties. He, therefore, decided to safeguard the verger from further ungodly apparitions and forced him to make fifty bows a day to the ikon of the Mother of God. This, however, did not help. Soon rumours spread around the village that a fire-bird had made its appearance in the neighbourhood. Every evening one villager or another saw it somewhere. As soon as darkness



had come and the ducks had started their evening flight, a luminous duck also appeared.

It was seen till late September, and was always alone. Then it disappeared, apparently having flown away to the south.

Fire-birds are said to have been seen in other places too. Not far from the town of Archangel, hunters living on the sea-coast saw two luminous geese and even attempted to catch them, but failed. Luminous owls have frequently been seen by people in the Yaroslavl and Simbirsk provinces, in Germany, France and England. But probably the most interesting event occurred on the Black Sea, near the Lebyazhi (Swan) islands. A local fisherman told a warrant officer from Sevastopol about a luminous swan. At night the officer not only succeeded in experiencing this wonderful sight, but also killed the rare bird. It was only the bird's feathers that emanated light. When the bird had been brought to the fisherman's house it lit up the room rather feebly, but still sufficiently to read a book. The feathers continued to glow all through the night, but the next day when they were brought to Sevastopol they had almost lost their radiance.

Strange things sometimes happen in this world. And Father Theodore was not the only one to have shifted all the blame onto the devil. Many people have done exactly the same under such circumstances.

At the end of the last century the inhabitants of some remote islands in the Indian Ocean were excited by events which were no less mysterious than those described above.

The Island of New Guinea was discovered as early as the beginning of the sixteenth century. However, its virgin forests were so impenetrable and were inhabited by such warlike tribes that the European colonial powers did not for a long time attempt to conquer the island. It was not until three hundred years later that the Dutch set up a colony in the western part of the island. By that time, the natives in the coastal areas had got to know the white enslavers well and resisted them vigorously. The Papuan warriors were well adapted to life in the jungles and very good marksmen with poisoned arrows. No wonder the settlers were terrified of them. The Papuans had black tattooed skins and their ears and noses were richly decorated which made them look fierce. Besides, they had a knack of appearing and disappearing quite noiselessly. It was only natural that their enemies should be filled with superstitious fear. For this reason the Dutch nicknamed their colony 'the land of the devil'.

The settlers found themselves in a tight spot and had to build their settlements in inaccessible places in order to protect themselves. So they founded the town of Babo on a small stretch of sandy beach separated from the rest of the island by thirty kilometres of impenetrable mangrove thickets, quagmires and swamps. They still had to guard their settlement vigilantly against the Papuans who attacked the town, approaching it both through the mangroves and from the sea.

One night, which the people of Babo did not forget for a long time, the weather was particularly frightful. The whole of the sky had been filled with heavy, low-hanging clouds since the afternoon. At night it became pitch-black and the wail of the wind and roar of the waves drowned all other sounds. The guard on duty on the beachside felt particularly insecure as he was quite alone and involuntarily kept as close as possible to the nearest buildings, trying to keep out of the spray from the surf. He strained his eyes to see in blackness of the night and he listened carefully to the roaring waves, as he tried to detect in that cacophony any unusual sound which might foretell danger. Suddenly his attention was drawn to a feeble, hardly visible light on the shore. The light seemed to come closer. It ran along the shore like a narrow strip. Then it became brighter, appearing as a chain of luminous spots coming nearer and nearer. The next moment the guard saw on the sand a row of glowing, human footprints made by a man. They appeared as if from nowhere, then faded and vanished in a few seconds.

Almost faint with fear, the soldier waited for his replacement. The mystery became even more terrifying when they learnt in the morning that a man living next door had disappeared. He had gone out at night and did not return.

Everyone believed that only the devil himself could have left these fiery footprints and have abducted a man. The Papuans were also interrogated and they confirmed that it was 'Soangi, the Devil'.

Since that time Soangi's fiery footprints have appeared every now and then in Babo. The devil preferred to pay his visits on dark stormy nights and his comings invariably spelt trouble. One time a boat would be swept out to sea, another time a pig would run away into the forest.

Soangi must have been a sea devil, since his footsteps were only seen on the beach. However, belief in the existence of the devil was soon dispelled by the experience of one of the Dutch settlers. One evening when the dusk was thickening he went to see whether the boats were safely moored. As his neighbours watched him, they were horrified to see that he was followed by a trail of luminous footprints. The unfortunate man was suspected of being connected with the evil spirit. He would have to face mob law and, most probably, death. Rescue came unexpectedly: the people who had been ordered to follow him also left fiery footprints on the wet sand. Later they learnt that there were occasional nights during which everybody who walked on the shore left fiery footprints.

Who then was that mysterious 'Soangi of the sea' and how did he manage to make the wet sand glow? Where did those strange luminous beings come from which were the prototypes for the fairy-tale fire-bird? It was a long time before scientists were able to solve the mystery. Meanwhile, the Dutch settlers had to live through a great deal of horror.

The devil, whether he be a seafarer or lives on dry land, definitely had nothing to do with fire-birds or luminous footprints. Luminescence is widespread in nature and anyone may have come across it. The reader probably has had occasions to observe pieces of rotting wood emitting a marvellous light in the dark, or sea water sparkling. This phenomenon was already known to the ancients, but its cause remained a mystery for a long time. Later on, people realized that the luminescence of wood or water is always due to the presence of micro-organisms in them. These bacteria are not the only luminous creatures on our planet. Many animals and plants have this property. Modern science knows of more than 1,100 species of animals whose luminescence makes the gloom of their habitat more agreeable.

Luminescence can either be external (extracellular), or intracellular. Animals with the external type of luminescence have two kinds of cells. Cells of the first type contain large yellow bodies of a specific substance called luciferin, the other cells contain fine granules of an enzyme known as luciferase. When the animal wishes to turn on its luminescence, it contracts its muscles to eject the luminous material into the space between its cells, or even outwards. The luciferin oxidizes with the aid of luciferase and the animals begin to glow. Luminescence can only take place in water with sufficient oxygen.

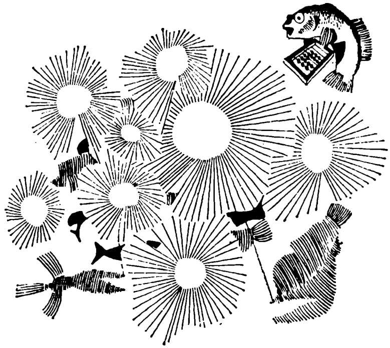
In intracellular luminescence both luciferin and luciferase are in the same cell. The actual mechanisms of this type of luminescence are not yet clear. One possibility is that the animals intensively give off free oxygen into the cells.

The luminescence of living creatures or bioluminescence usually causes surprise. Indeed, what might be the origin of such a seemingly unusual property? More than one generation of scientists was disconcerted by this question. It is only now that this phenomenon has ceased to be puzzling.

Investigations which shed some light upon bioluminescence were started over thirty years ago. The Soviet scientists V. Lepeshkin and A. Gurvitch discovered extremely weak luminescence in the most common plant cells. The luminescence was so weak that the investigators at that time could not even design a device sensitive enough to detect and measure it. Such devices have only been made recently. Using these instruments, modern scientists have succeeded in establishing that chemiluminescence, that is, light for which a chemical reaction supplies energy, is a very common phenomenon. Many substances, including some fats, are able to emit light during oxidation. Apparently, the tissues of plants and animals glow constantly, and particularly intensively when they are working. For instance, the surface of a frog's contracting heart is continuously radiant.

Bioluminescence in animal tissues mainly results from the oxidation of fats, known as lipids. As a result of chemical reactions there appear excited molecules, in which an electron is moved to a higher energy level. On the electron's return to the previous ground level the released energy is used for constructing new chemical links or appears as a quantum of light. The processes taking place in this event are directly opposite to photosynthesis, where light causes the electron to move to a higher level and the energy liberated is used to synthesize carbohydrates.

Later on, it became clear that extremely weak luminescence is caused in the organism not only by occasional oxidation of lipids, but also during the chemi-



cal reactions necessary to maintain life. Since such a phenomenon exists, it would be strange if there were no organisms capable of developing and utilizing it. There are quite a few such animals on our planet but the majority of them, including ourselves, can only emit a very feeble light.

Most of the luminous organisms live in the seas and oceans. Most numerous among them are the peridineans, tiny flagellated plant organisms. They are responsible for the extremely beautiful luminous patches in the sea. When calm, peridineans do not glow. They only emit light when disturbed by the motion of the water; hence, the glow that appears on the crests of the waves in the wake of a ship is really peridineans which have flared up only to consume their energy and burn out in a few moments.

If a diver ventures into the sea at night, when the water abounds in peridineans, he will experience a fantastic sight. Each of the diver's movements evokes fireworks. Outside his mask thousands of sparks shoot about, as if someone has lit dozens of sparklets, a sight to be remembered to one's dying day.

When peridineans are cast ashore by a wave, they do not perish but, having rested on the wet sand, are soon able to luminesce again. A person walking along the shore leaves in his wake a trail of glowing footprints. This glow is the peridineans' response to being disturbed by a person's foot.

Fiery footprints on the sea shore have not only been seen in New Guinea, but in other places in both tropical and polar climes. Nordenskjöld, a well-known explorer, described fiery footprints on snow wetted by sea water. He saw them on the Spitzbergen coasts and on the De Long islands. In this case the organisms responsible were again the peridineans or copepods also known as metridia.

Very few large animals are able to produce luciferin. If they do emit light, this is due to luminous bacteria living on them. For instance, the head and the whole of the body of the Brazilian shark radiate a bright green glow thanks to its tenants. Such co-operation is called symbiosis, that is, an association of dissimilar organisms for their mutual benefit. The host organism provides its little luminous friends with the necessary amenities, and the grateful animals reciprocate with a cheering light.

Only a definite combination of two species can live symbiotically in each particular case, the species being unable to live separately. However, besides such constant century-old associations, sometimes temporary alliances come about where conditions are favourable. Occasional luminous settlers making themselves at home on birds' feathers are the very creators of fairy-tale fire-birds. Such fire-birds are mostly to be found among waterfowl dwelling on the coasts of the seas and oceans. Their feathers are probably full of sea micro-organisms. As to eagle-owls and common owls, they are infected with luminous fungi, because they permanently reside in the hollows of old, rotting trees.

Most luminous representatives of the animal kingdom live in oceans. They are especially numerous in the depths of the oceans. This is quite understandable, since the perpetual darkness of the ocean depths can only be illuminated by living creatures. The smallest of them produce light with the whole of their bodies, while larger creatures have special organs for the purpose. A few species of animals, for instance, some of the cephalopod molluscs and deep-sea fish have brought their luminous organs to perfection. But the creatures which live on the surface of the ocean are not far behind them in this respect. Near the coast of America, in the Pacific and Atlantic oceans, one can encounter small schools of sea fishes called sergeants, little fishes 25-35 centimetres in length. These fishes are best observed when they spawn, since they do so near the coast, in the mouths of rivers and in shallow bays. When spawning is over, the females swim away and the males stay to guard the spawn until the fry hatch.

The expression 'as dumb as a fish' does not refer to these fishes, because they can make sounds. The male guarding the spawn is continuously buzzing, probably to frighten predators away. The sergeants may have become widely known due to this habit. They were so named because of their specific colour and luminous spots arranged in regular rows like the polished buttons on an officer's tunic. They possess the most complex lantern-like luminous organs, of which there are about three hundred. They are like live, miniature spotlights.

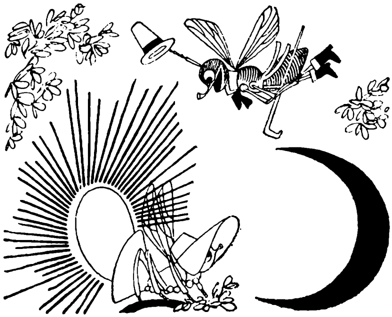
On the outside the luminous organ is coated with a dark opaque film, the inside of it is shiny and, consequently, able to reflect light. The front part has a transparent lens which concentrates the light flux. Inside, there is mucus luminescing in the dark. The fish hardly uses its 'lanterns' for lighting purposes. Some believe that it only emits light during the mating season.

In edible squids and many other animals, the luminous organs are used for illumination. They are usually rather large and located in the front part of the body, sometimes over the eyes or even right on the eyes and, consequently, they light up the spot at which the animal is looking. The eyes of such animals are often equipped with a device for the purpose of turning their lights off. More often than not it is a skin fold that covers the luminescent organ like an eyelid.

The light emitted by living organisms can be of different colours: white, blue, ruby-red. Occasionally, an animal may have lanterns of three or four colours. Coloured light seems to be advantageous in many respects, since many animals, which do not know how to produce it, pass a flux of achromatic rays through the coloured lenses in their lanterns and in this way produce a cheering coloured illumination. The luminous substances inside a live spotlight is actually an accumulation of luminous micro-organisms. Thus, small animals live on large animals.

But things may be quite different. In almost all of the world seas there are flagellates, protozoans known as noctilucae; they are tiny balls of not more than two millimetres in size. On one side of the ball there is a mouth which is a deep depression. If one examines a noctiluca with a magnifying glass, it is possible to discern a long transverse tentacle and a short longitudinally transverse flagellum.

Noctilucae are able to phosphoresce. The bodies of these animals, which inhabit the tropical seas, harbour hundreds of *Cryptomonadina,* also microscopic flagellates. What makes them live together? The body of the cryptomonad contains chlorophyll. Like green plants, it can extract carbon dioxide from its surround-



ings and synthesize starch from it, but this synthesis can only take place in light. So the cryptomonads using the free illumination as well as the carbon dioxide abundantly liberated by the noctilucae, can synthesize starch even at night. The noctilucae also benefit from this symbiosis. The cryptomonads help them get rid of detrimental carbon dioxide and in exchange supply them with the oxygen formed during starch synthesis.

The favourite habitats of the live lanterns are the sea depths and the tropical forest thickets, but the northern forest may also shelter tiny, living lights.

Midsummer is the best season in Russian forests in the European part of the USSR. A boundless sea of multifarious grass spreads beneath the trees. The clearings in the forest are flooded with sunlight and the early strawberries are already ripening. When dusk descends upon the forest bright little greenish lanterns light up at the roadside and in the forest thicket, enveloping all in beauty and mystery. One can almost imagine that very new little mischievous stars, which have previously been playing somewhere high up in the sky, have descended to hide from their strict tutors in the thick grass. These are, however, not stars, nor pieces of charcoal dropped by some careless visitor to the forest. Take one of these pieces in your hand and you will find that it is cold. The light comes from a small insect known as a glowworm. It is a nocturnal insect, and is seldom seen in the daytime, when it hides in the thick grass. But, when night falls, it ventures out on the hunt. The glowworm is a predacious insect, feeding on snails, little spiders, and other tiny insects.

The male and female are extremely dissimilar in appearance. The female is larger, being two or three centimetres in length. It has a small head and breast segments with three pairs of legs. Its abdomen is large and fleshy. The entire body is greyish-brown, except for the lower aspect of the three terminal segments of the abdomen which are white. It is these segments that emit light. The light easily spreads through the chitin envelope of the abdomen whereas the heavily pigmented chitin coat on the back lets almost no light through.

In the daytime the female presses its abdomen close to the ground and becomes barely visible. But as soon as night shrouds the forest, she hurries away from her hiding-place, climbs a high blade of grass and hangs with the lower part of abdomen upwards. Its light is to be clearly visible from above, so as to attract the opposite sex. The light emitted by glowworms is quite bright and can be seen from a distance. If you take a glowworm and follow the lines of a book, you will be able to read.

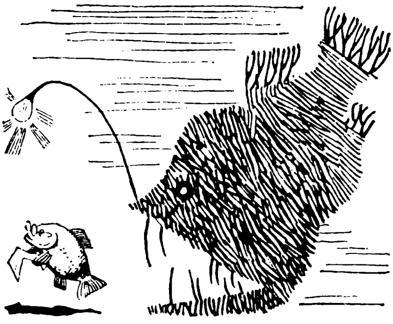
The male glowworm is much smaller than the female. It flies well but it gives a very poor light.

Only one species of luminous insects lives in the forests of European Russia. Another species is to be found in the Caucasus. It glows while flying hither and thither like a reddish sparklet, enchanting observers during the dark southern nights.

Luminescence is a very widespread phenomenon but, strange as it may seem, we do not yet know how most living creatures use the light they can produce. This is not the case with forest fireflies. We know that the light helps the male to find a mate during the mating season. In tropical regions, where there are many different kinds of glowworms, they emit brief scintillating flashes of light. If the females merely glowed, their male counterparts would invariably be misled and the fireflies would become extinct, because every mistake by a male would spell his death: the female encountering a 'strange' admirer would be sure to devour him.

To avoid any possible confusion, the fireflies have developed a very sophisticated signalling system. Males flying through the forest at night send out rhythmic flashes to appeal to their mates. The female on the ground or in the branches of a tree sends reply signals, which follow the appeals at strictly regular intervals, so the various flashing patterns act as signals between the male and female. The intervals between appeal and reply help the male to distinguish a female of his own species from those of other species. Should the female make a mistake, sending her reply either a bit too early or too late, the winged admirer may pay dearly for it.

However, this signalling system was not adopted everywhere. Self-respecting gentlemen refuse to be dependent upon their capricious ladies. Fireflies in south-east Asia never rush about searching for a girlfriend, when it is pitch-dark. Instead, they make themselves comfortable in the branches of a tree, in a clearing in the forest, and send light messages into the darkness. All of them do so simultaneously, no matter how large the company, illuminating the forest at night with rhythmic flashes, producing something like the huge streamers mounted in towns on public holidays. All the females have to do is to find their admirers, who are



eagerly awaiting them, paying close attention to the frequency of the flashes, so as not to approach strangers. After this each female selects her partner.

Luminescence may also be used as a means of defence against enemies. The depths of the ocean are inhabited by squids and cuttlefishes. They defend themselves against the attackers by ejecting a cloud of liquid fire which very much resembles themselves in shape and size. This is why a bloodthirsty pursuer is often deceived into attacking this glowing imposter, while the creature itself is hastily escaping into the gloom.

The same trick is also practised by many small sea crayfishes. Deep-sea shrimps have special glands near the mouth which release a screen of light when the animal is exposed to danger. In this way, when a school of shrimps is attacked, it is immediately screened from the predator by numerous fiery spots. Then the shrimps quickly disperse in different directions.

Many animals 'light up' only when they are in between the predator's teeth. This is also a defensive trick, as the predator may open its mouth in fright or astonishment, and this is just what the prey needs in order to flee. Some worms are especially ingenious in this respect. Cut into two halves, they emit light only with their rear half, but the front part is dark and escapes.

Descending into the depths of the sea, William Byb, a pioneer deep-sea explorer, observed a large feebly glowing worm through the scuttle glass. A careless worm, which the scientist could not identify, was bitten in two right before his very eyes. The tail end gave off a bright flash and was immediately swallowed up, but the head end quickly put its lights off and escaped in the darkness. Most worms are very good at regenerating the parts of the body they have lost, and this worm, too, will probably regain its tail before long. One might think that luminescence serves only one purpose, that of diverting the attacker's attention, so as to sacrifice a less valuable part and save the main one. The same function is fulfilled by the convulsing tail which lizards leave behind them.

It is not out of the question that animals know and make use of other ways of protecting themselves with the help of live light. There is no doubt that the bright flash, given off by a tiny crayfish when in a sardine's mouth, is nothing but an alarm signal, warning the rest of the school of the danger. The flashes sent out by the miniature noctilucae floating on the crests of the wave may also serve as a warning signal to the rest to descend deeper. But these are only guesses, and one cannot say how close they are to the truth. For instance, no one knows whether the noctilucae gain anything from being luminous.

The majority of luminous organisms dwell in the total darkness. It would, therefore, seem that these creatures use their lights for actual illumination. But on close examination we find that most animals use their luminous organs merely to find one another, to recognize their kin, or to attract their prey.

The eyes of a huge but very sluggish polar shark are inhabited by minute, luminous crayfish. Their light attracts prey, while the shark lies restfully on the bottom, leisurely waiting for some curious fish or seal to swim up close to it.

Deep-sea angler fish have a very interesting device. One of their rays on the dorsal fin is very long and, unlike the rest, is pointed forwards, not backwards. Suspended from that peculiar rod, right in front of the monster's mouth, is bait in the form a pear-shaped, bright-coloured, thicker piece, which is very often luminous. It goes without saying that, when curiosity gets the better of an underwater dweller's caution, it finds itself between the teeth of that insidious, huge fish, before he can say Jack Robinson.

When tsar Berendey of the well-known Russian fairy-tale learnt of the Fire-bird, he wished to have such a marvel in his estate. He was not the only one beset by such a desire. Even the ancients used living light in their homes.

The tropical forests of Brazil boast a mushroom with a luminous-bottomed cap. The natives have been using them as flashlights. True, the light is not very bright, but enough for the natives of the forest to pick their way through a thicket.

The luminous sea crayfish were used during the war by the Japanese army. Each officer had a small box of these crayfishes on him. When dry, the crayfish emits no light but as soon as it is wetted it becomes a veritable lantern. No matter where a soldier might find himself, be on board a submarine surfacing noiselessly in the night, in the dense tropical jungles, or boundless steppes, he would always need a light to read a map or write a dispatch. But he could not use an electric flash light in the night or even a match, for it can be seen from a distance. Unlike the latter sources of light, the feeble glow of a crayfish cannot be discerned even a few dozen paces away. Such a light is convenient because it does not reveal its user.

Luminous organisms can be used for lighting our homes. This calls for special bacterial lamps, very simple in design. They consist only of a glass retort with sea water and micro-organisms suspended in it.

The light given by each individual bacterium is infinitesimal. For a lamp to produce one candle-power of light the retort must contain no less than 500,000,000,000,000 bacteria. The micro-organisms, however, are so small that quite bright lamps can be made of them. Such lamps were used in 1935 to illuminate the great hall of the Paris Oceanographic Institute, where an international congress was held.

Man may still make use of luminous organisms in the age of atomic energy and giant power stations. Recent years have seen intensive development of the sea depths. Houses have been built on the sea bottom where man can live and work for a prolonged period. The idea of using natural illumination—the light of marine micro-organisms—in underwater exploration is very tempting and is gaining support among scientists.

Of even greater interest is the idea of converting chemical energy directly into light energy in artificial conditions. Lamps based on this principle might be expected to be more economically efficient than conventional incandescent lamps. The point is that bioluminescent energy turns completely into light, whereas only twelve per cent of the power consumed by incandescent lamps becomes light. Another advantage which should not be disregarded is that such lamps would need no electrical cables over long distances. This idea may quite possibly be realized. Chemistry at its present rate of development may bring us even more spectacular discoveries.

Live Electricity

HISTORICAL HIGHLIGHTS

Living on a globe covered by a dense network of high-voltage lines and huge electric power plants, our contemporaries forget that the origin of electricity is associated with humble animals. The Egyptians, living four and a half thousand years ago, already knew of electricity: a tomb in Sokkara carries the effigy of the electric catfish which inhabits the upper reaches of the Nile.

In Europe, electricity was discovered by the Greek philosopher Thales of Miletus in the seventh century B.C. He noticed that a piece of amber, when rubbed, acquires the power to attract and then repel various small objects.

His discovery, however, failed to attract any attention for the next twenty centuries, until William Gilbert got the idea of rubbing pieces of glass, sealing wax, sulphur and other substances to see what would come of it. He gave a full and frank account of what happened in the book *On the Loadstone and Magnetic Bodies and on the Great Magnet, the Earth,* published in 1600. It was he, incidentally, who coined the term 'electricity' from electron, the Greek for 'amber'.

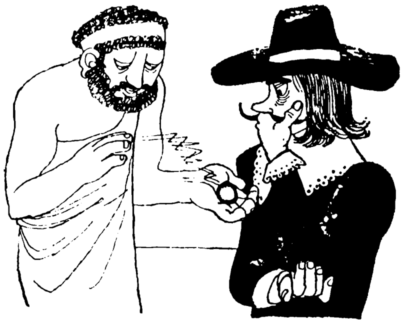
Gilbert's book stirred certain interest in this phenomenon, but electricity continued to be studied only by whimsical individuals for a long time afterwards and never seemed in those days to hold any particular promise for mankind.

It would probably have been even longer before electricity attracted any real attention, if Signora Galvani, the wife of a professor of anatomy in Bologna, had not had to go to the butcher's to fetch her joint of beef and the frogs' legs which Italians so much enjoy eating.

The story recounts that it were the frogs' legs, hanging down in picturesque clusters from copper hooks fixed on iron bars, that caught Signora Galvani's imagination. To her utter amazement and horror she saw that when a frog's leg cut off from the body touched iron, it quivered as if it were alive. People say that the lady never ceased boring her husband with stories of this horrible phenomenon, which she explained by the butcher's intimacy with the evil one, until the professor finally made up his mind to visit the butcher's shop in person and see for himself what was going on.

Luigi Galvani already knew of observations made some thirty years earlier on a human corpse whose muscles contracted under a discharge from a Leyden jar*. Naturally, Galvani attributed the twitching of frog's legs in the butcher's shop to the influence of the discharges of atmospheric electricity. So, to pacify his wife, the scientist decided to make observations on frogs at home. The experiment, staged on a stormy night, proved a brilliant success: the legs of a dead

* Leyden jar is a glass jar partially covered inside and outside with tin foil or other metal; it is used as a condenser or collector of electricity.—*Ed.*



frog hanging on a copper hook from the balcony rail twitched time and again, as if they were alive.

The thunderstorm certainly had no more to do with the contraction of the muscles than the evil spirit. In all probability, when the wind swayed the frog's body it sometimes touched the iron rail of the balcony and thus closed the circuit between the iron and the copper. An electric current was produced, as always happens in such circumstances, and contracted the muscle. The man who first understood this was the Italian physiologist and physicist Alessandro Volta, but, of course, this detracts nothing from the credit we owe to Galvani.

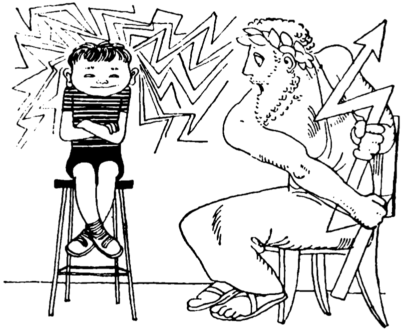
Galvani was so greatly intrigued by his experiments with electricity that he continued to occupy himself with this problem till his dying day. He published the findings of his first observations as early as 1791. As a result of these publications and, perhaps, of the communicative nature of Signora Galvani, the sensational rumour soon spread far and wide in Italy and beyond that electricity can be used to 'revive' a dead animal, fascinating minds and giving rich food for the most daring imaginations.

Subsequent investigations finally convinced Galvani of the existence of an intrinsic relationship between life and electricity and of the dependence of all manifestations of the life of an organism on the 'electrical force'. It was this firm conviction that prevented him from believing in Volta's hypothesis. Galvani touched dead frogs with copper and iron objects and saw that indeed it was not from the atmosphere that electricity was extracted. But did it arise between the copper and the iron, as Volta suggested, or inside the frog itself? Galvani just could not bring himself to believe that a phenomenon so closely connected with life could originate in inanimate objects.

Only two sources of electricity were known to science at that time—friction and the electric fish, the torpedo ray, or skate. But even friction never produced electricity in metals and this relieved Galvani of the remaining grains of doubt. This was particularly so, as he later managed to demonstrate that electricity can really be generated in the organism of an animal.

The experiment was quite simple. The nerve of a frog's leg was cut off and bent into an arc. The nerve of another frog's leg together with the muscle was also amputated and placed upon the first nerve so that it touched it at two points—at the end that had been cut off and at a point in the uninjured part of the nerve. The instant the two nerves came into contact the muscle contracted. This proved the existence of 'animal electricity'.

These experiments were repeated in dozens of laboratories. Biologists, physicists, mathematicians, physicians—all became fascinated by frogs. Formerly a favourite object for biological experiments, in the hands of physicists the frog soon became a convenient source of electric power and an extremely sensitive measuring instrument. It is no wonder that with this universal instrument in hand and dealing daily with



'live electricity', physicists came to regard it as true electricity, whereas the electromotive force generated between dissimilar metals was considered a rather paradoxical phenomenon. It was not accidental that, when Volta built his galvanic battery, he called it an artificial electric organ.

Nor was it the demands of technology that promoted further progress in knowledge of electricity. The following is an illustrative example. Back in 1838, a Russian Academician B.S. Yakobi, astonished strollers in St. Petersburg, when he sailed along the Neva in a motor boat driven by a one-horse-power electric motor that he had constructed himself. You may also recall that the first steam engine was also powered by no more than 1 h.p. Another twenty years had to pass, however, before an attempt was made to use an electric motor in industry.

From that time on, progress in electrical engineering forced the more than modest accomplishments of electrophysiology into the background. Still, this line of research never ceased to make some progress. About a hundred years ago it was shown that electrical phenomena not only arise in the peripheral nerve conductors but are also generated by the brain. At that time the conditions necessary for the study of such weak electrical processes did not yet exist, but this did not deter scientists. Nikolai Vvedensky, an eminent Russian physiologist, used a telephone to listen to the information transmitted by the peripheral nerves. It was not until the 1930s, however, that adequate research equipment was finally developed. Since then, electrophysiological studies have been snowballing.

THE METAL CONDUCTOR AND THE NERVE

Nature, designer and architect, has done a good job in constructing, constantly updating and improving, the millions of living species that populate the Earth. In the process she has come across a great many admirable finds and discoveries. So many indeed, that whatever new principle in control, location, or spatial orientation scientists propose, it invariably turns out to have been employed by Nature from time immemorial. Perhaps the only thing Nature failed to invent was the wheel. This is the only invention which Man has completely to his credit.

It is not surprising that it has long been traditional to compare the ingenious creations of Nature with the simpler, but more easily understandable, artifacts of the human genius. Such comparisons help scientists visualize many involved phenomena, since it is always easier to speak one's own language.

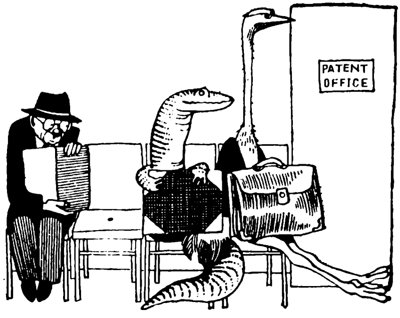
It is no wonder, therefore, that even in the last century as progress was made in brain research, mostly in deciphering the structure of the brain, a similarity was noticed between the central nervous system and the telephone network of a large city. Indeed, this resemblance cannot be denied. The telephone exchange, the brain, receives from the peripheral nodes, that is from all the organs of the body, a continuous flow of information which runs along the nerves just like a current along wires. In the brain the relevant information is selected, sorted out and channelled into the strictly specialized departments, which exchange impressions and discuss the information they receive. These rapid mutual consultations culminate in a decision, and, in an instant, instructions are sent back along the nerves to the peripheral points, the muscles, glands and all the other organs.

The resemblance is the more striking, since it is electricity that flows both along the telephone wires and along the nerves. The first to establish this fact was Galvani, and since his time thousands and thousands of experiments have confirmed that stimulation of any of the sense organs is encoded into electrical impulses and sent to the brain. Within the brain itself, all information circulating between its various sections is also transmitted as electrical impulses.

An engineer who chose to examine the operation of this natural telephone exchange would primarily be surprised by the unbelievably slow speed with which the electrical impulses are transmitted through it: in the nervous system of mammals this speed varies between 0.5 and 100 metres a second.

It will be recalled that electric current is a regulated flow of electrons. Although the electrons move at a speed of about a millimetre a second, an electromagnetic field that generates their movement, spreads almost at the speed of light. If electricity is transmitted from Moscow to Vladivostok, ten thousand kilometres away, the electrons at the other end of the cable will be set in motion in a thirtieth of a second.

Our engineer would gasp with even greater bewilderment if he measured the resistance of the individual nerve fibres comprising the nerve trunk, which is enor-



mous. The resistance of one metre of nerve fibre equals that of a copper wire 16,000 million kilometres long. After some thought, the engineer might come to the conclusion that such an exchange can only transmit messages if its transmission lines are furnished with energy amplification substations.

This would be a very close guess. What spreads excitation is indeed not the energy of the receptor, or of the nerve centre, but the energy produced by the nerve.

The fibres that make up the nerve are processes that branch off from the nerve cells. Compared with their length, their diameter is negligible, varying from 0.1 to ten microns. The nervous system in mammals consists of two types of nerve fibre: thin naked fibres, enveloped only in a membrane so thin that it is invisible through an optical microscope, and the so-called medullated fibres encased in a thick myelin sheath.

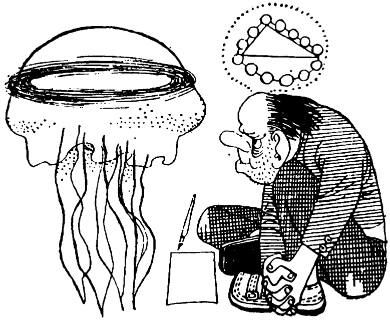
The purpose of this sheath is obviously to serve as an insulator to separate the closely packed fibres in the nerve trunk from one another. The myelin sheath does not allow the impulses to pass from one nerve fibre to another and prevents the unimaginable confusion that would be inevitable otherwise.

The only thing that scientists could not understand was why the other insulating sheath is not continuous like the jacket of any cable should be, but is made up of small pieces, which are separated from one another by small constrictions situated at intervals of about 1 millimetre and producing what is known as Ranvier's nodes.

The thin membrane of the nerve fibre is pervious to some substances and impervious to others. Potassium and hydrogen cations can pass through it freely, but it is an insurmountable barrier to larger cations, for example, those of sodium, and to anions. (You will recall that cations are positively charged and anions negatively charged.)

Usually, the concentrations of the ions on either side of the membrane are not equal. Inside the fibre, the amount of sodium and chlorine ions is one-tenth of that in the tissue fluid, while the amount of potassium ions inside the fibre is twenty times greater than outside. The potassium ions, therefore, rush out of the nerve fibre and create a positive charge on the outer surface where they settle down. The anions cannot follow the potassium cations and pile up on the inner surface of the fibre, producing a negative charge there. This is why, in the state of rest, the inner aspect of the membrane is always charged negatively and the outer side positively. The difference between the two charges, or the potential of rest, varies between fifty to seventy millivolts.

This potential of rest is maintained until some stimulus causes excitation somewhere in the nerve cell, nerve ending or any other section of the nerve fibre. Excitation immediately changes the permeability of the membrane for an instant in that section. The membrane becomes pervious to sodium ions, which rush in, and the charge of the membrane is inverted as a result.



It becomes negative outside and positive inside. This leads to the two adjacent areas of the protoplasm of the nerve fibre, which are not separated from each other, becoming oppositely charged.

Such a situation certainly cannot be kept up for long: electric current is bound to flow between the two areas, giving rise to an electric impulse. The electric current will result in excitation of the neighbouring, negatively charged, section of the nerve fibre. This will immediately make the membrane pervious to sodium and it will become positively charged. The same phenomenon will occur between this newly excited section of fibre and the next section, and the process is repeated again and again. The nerve impulse is transmitted through the nerve fibre as a result of the innumerable repetitions of this process.

So much for the way an excitation is propagated through the thin, non-medullated fibres. Such short loops of current cannot arise in the myelin-insulated parts of the fibre, and in the medullated nerves the process only occurs in Ranvier's nodes, which are apparently for this purpose. In the medullated fibres, the excitation spreads by leaping from one Ranvier node to the next, and its speed there is much higher than in the thin fibres.

Electric current flowing in a metal conductor is thus a regular movement of electrons, arising almost simultaneously throughout its length. In contrast to this, a nerve impulse is the movement of the excitation along the nerve fibre, giving rise to an electric current which, in its turn, conveys the excitation to the adjacent section of the nerve.

The fact that excitation is passed on in this manner elucidates two peculiarities of the spread of the nerve impulse. The first is that the nerve impulse is never extinguished on its way along the fibre, but always retains a constant intensity from start to finish. Secondly, all the impulses flowing along this or that fibre are absolutely identical. They reflect neither the intensity nor the peculiar nature of the original stimulus, but are completely determined by the properties of the particular nerve fibre that conveys the impulse.

This was once demonstrated by an interesting experiment. The jellyfish has a nerve ring in the marginal part of its dome. (In actual fact its nerves are different in structure to our own, but in this case it is irrelevant.) An impulse spreads both ways along this ring just as it does through a nerve. Should a section of the ring be irritated, the two impulses run in both directions along the ring, until they meet on the opposite side of the dome and extinguish each other.

Scientists have succeeded in irritating a section of the ring while blocking the adjoining area, so that the excitation could only spread in one direction. When the nerve impulse had made the complete round of the ring, the blockade was removed and the impulse passed through this section making a second, third, fourth round, and so on. The experiment was continued for twenty-four hours and the impulse kept on flowing, never losing its speed or intensity. The experiment could have been continued indefinitely, until the animal died or became completely exhausted.

AN UNDERWATER ELECTRIC POWER STATION

It took Europeans about two and a half thousand years from the initial discovery of electricity till they began to use it in technology. Doctors used electricity for medical treatment even before they knew anything about it. Many outstanding physicians of the Roman Empire, such as Claudius Galen, treated their patients with electricity generated by the live power-plants of deepsea fish.

Big skates or torpedo rays are encountered in the Mediterranean and other seas. The peculiar hunting habits of this fish were known to Romans. They knew that the skate would never chase its prey or pounce upon it from ambush. It swam along slowly and quietly, but if a small fish, crab or octopus happened to come near it, something terrible suddenly happened to them. The unwary creature died in a fit of violent convulsions. The skate coolly picked up its prey and slowly went its way.

The Romans believed that, on seeing its prey, this peculiar fish secreted a poisonous substance into the water. The poison also acted upon humans, directly through the skin, but was not lethal to them. When touching the fish, it was as though the hand had been struck by a blow, and it automatically jerked back. Roman physicians believed that the poison of the skate possessed a great curative power. Skates were caught and kept in special sea-water fish-ponds for medical purposes.

Such views were common two thousand years ago. The true mystery of the skate was only unravelled quite

recently. This dangerous fish was found to be a live, floating power station that produced electric discharges strong enough to kill smaller animals which came near it. What the Romans ascribed to the action of poison was in fact electricity. Afterwards, many more species of 'electric' fish were discovered, some of them far more dangerous than the skate.

Europeans only learned about these huge electric power stations several centuries later. Soon after the discovery of America, swarms of cruel and hardy adventurers rushed there in quest of gold. It was their lot to experience the force of the fish's electric discharge.

The first Spanish conquerors of America invented the tale of a fabulously rich country, Eldorado, hidden deep in the jungle of the southern continent, where even the streets were paved with pure gold. Detachment after detachment was sent in search of this mythical country. One such detachment, commanded by De Sicca, had the good or bad fortune to penetrate as far as the upper reaches of the Amazon. The Spaniards sailed up the river for several months before reaching its source. A giant river, one of the Amazon's tributaries, was a shallow streamlet there. It was no longer possible to sail on up the stream, so the group went through the jungle on foot.

Impenetrable thickets and impassable bogs barred their way. Dangers haunted them at every step: huge crocodiles, venomous snakes and boa constrictors, hostile Indian tribes already aware of the unpleasant surprises the white conquerors had in store for them, and the hovering swarms of gnats and mosquitoes infecting people with malaria, tropical fever and other dangerous diseases. The group literally had to cut every foot of their way through the dense green wall of the jungle.

One day the detachment emerged from the thicket on the edge of a huge marsh. It was during the dry season and the marsh had almost dried out. Only far ahead in the middle of the marsh a few remaining pools were glistening in the midday sun. The Europeans sighed with relief, thinking that the going would be easy for a few hours.

So it was indeed, until the detachment reached the string of small pools in the middle of the marsh. The Indian bearers, their eyes filled with horror, refused point-blank to walk through the water. The white men could not understand why the natives were afraid. The pools were so shallow that no crocodiles or giant anacondas could hide there, nor could they be inhabited by the piraya fish, the terrible scourge of South American rivers.

One of the white men walked forward to set an example to the frightened bearers. He had only taken a few steps when he fell flat on his back with a dreadful yell, as though knocked down by a mighty blow. Two of his companions who instantly rushed to his help were also immediately lying in the mud, knocked off their feet by the same invisible enemy.

It was only hours later that their fellow-travellers

dared warily to step into the water and to carry out onto dry land the bodies of their injured friends. The three men survived but the detachment was unable to go any further. The legs of the victims of this invisible foe were paralysed. By nightfall they began to get the movement back into their legs gradually, but they only recovered completely after several days. Since De Sicca was superstitious, like all conquistadores, he gave the order to go back.

This is how Europeans first learned of another underwater electric power-plant located in the body of the fresh-water electric eel. This is a big fish measuring up to 1.5 to 2 metres in length and weighing as much as 15 or 20 kilograms.

The electric eel is a nocturnal animal. It hunts for prey only after nightfall. Its electric shock is so powerful that it can even stun large animals. South American Indians know this dangerous fish very well and never risk wading through rivers where it lives.

In one of the Indian languages the eel is called *arima*, which means 'movement-depriving'. Many local tribes believe that the meat of the fish and its electric discharges are curative. Electrotherapy may very likely have been used in America far earlier than in Europe, although we shall probably never be able to establish the original date.

The fact that fish can produce electricity is in itself not surprising, after what has been said at the beginning of this chapter. What is really surprising is that, instead of weak impulses, such underwater electric power-plants as the African electric catfish, the American eel and the torpedo ray can generate extremely strong discharges.

The catfish generates a current of 400 volts, and the eel an even higher one, of 600 volts! (Just recall for comparison's sake that the usual voltage in our household electricity networks is 127 or 220 volts.) The capacity of the eel's power station is as high as 1,000 watts. The eel needs this high voltage because fresh water is a poor conductor of electricity. A current of a lower voltage would only be dangerous at close quarters. The torpedo ray, which is a sea fish, is content with a much lower voltage, that of 60 volts, as sea water is an excellent conductor, but the intensity of the current is as high as 60 amperes.

Impressive figures, indeed!

How did Nature design its live power-plants? What did she use for the prototype model?

The most powerful current in the body of an ordinary animal is produced in large muscles—the heart and the muscles used in movement. An electric field can be observed around some fish when they swim. It is particularly big around the cyclostomes (lamprey and hagfish) and the ancient primitive fish which had not yet learned to be thrifty in expending energy. Electric impulses of several hundred microvolts can be recorded around the head of a swimming lamprey.

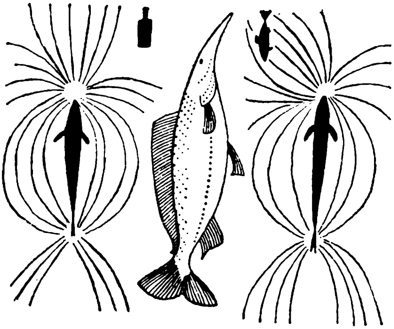
It would have been surprising if Nature had failed to make use of this phenomenon. She seems to have had a passion for electrical engineering right from the time when the first fish appeared on our planet. She had just finished the first models of the brain and the peripheral nerves, the control-communication organ with its sophisticated electrical installations, and was puzzling over some other possible uses for electricity. We must do her justice, for this search was not in vain. At any rate, electricity means much more to a fish than to any other animal.

The so-called electric fish set out to build powerful electric stations. The material they used were muscles and nerve endings, the end plates, which turned into electroplates, that is the electrical organs.

Electrical organs are large, they may weigh as much as a quarter or a third of the body of the fish. The eel's electrical organ is equal to four-fifths of its length, while in the catfish it covers the whole of the body. The organ consists of an enormous number of electroplates assembled in columns. All the plates within a column are connected in series, and the columns themselves are connected in parallel.

Contraction of the skeletal muscles (around which the electrical organ is built) is caused by a nerve impulse that is accompanied by an electrical discharge. When an impulse reaches the nerve ending in the muscle tissue, a special mediator substance is secreted there, which causes the muscle cells to contract. This contraction is also accompanied by an electrical discharge. When designing the electrical organ, Nature used the end plates and modified muscle cells for this purpose. These have lost their ability to contract but continue to act as generators of electrical impulses.

The plates of the electrical organ produce impulses, using roughly the same mechanism as the nerve, the terminal node, or the muscle fibre. Even the strength of a single impulse, 150 millivolts, is quite usual for nerve



and muscle cells. But as in the eel these plates are connected consecutively and assembled in columns, each consisting of 6,000 or 10,000 plates, the overall tension being as high as 600 volts. In the torpedo ray, there are no more than a thousand electroplates in a column, but there are 200 such columns connected in parallel. This explains why the voltage of the torpedo ray's electrical organ is not very high, while the intensity of the current is considerable.

To control such a complex organ a special command unit in the brain was needed, and the electric fish developed electric lobes and the oval nuclei in their medulla for the purpose. The oval nuclei are the supreme headquarters where decisions on whether this terrible, strategic weapon is to be used or not are taken, and from which the appropriate commands are sent to the electric lobes. The latter are responsible for the complicated job of co-ordinating the discharge. Indeed, to ensure the maximum discharge, all the electroplates must give off electricity exactly at the same moment, and the electric lobes see to this.

To produce a simultaneous discharge, all the electroplates must also receive the corresponding command, or nerve impulse, simultaneously. This is the crux of the problem. Nerve impulses travel relatively slowly. In the medulla of a fish they move at 30 metres a second. The electroplates in the front parts of the organ, nearer the head, may receive the command much earlier than those in the hind part, situated a metre and a half farther along towards the tail.

How do the electric fish ensure that the commands are received simultaneously? Commands to the hind parts of the organ are probably transmitted a little earlier than those intended for the fore quarters, or perhaps the fish are able to control the speed of propagation of the nerve impulses. Moreover, the pattern of control changes throughout the fish's lifetime for the fish grows, its electrical organ becomes larger, and the commands must be modified.

LOCATORS AND OSCILLOGRAPHS

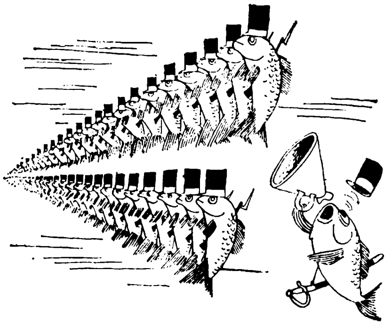
The eel, the torpedo ray and the catfish are not the only fish with electrical organs. At present, we know of some three hundred other fish species capable of producing weak electric discharges ranging beween 0.2 and 2 volts. Scientists were previously inclined to believe that these fish kill very small animals. But thorough observations have not confirmed this hypothesis. It was only very recently that scientists have understood the purpose of electrical organs producing a feeble electric current.

The electrical equipment of these fish evolved not towards greater discharge force, but towards higher electrical sensitivity. It was noticed that many of these species are nocturnal and live in very muddy water, while some of them, for instance the Nile mormyrus, always keep their heads down in the mud in search of food. In muddy water and at night it is very difficult to catch sight of a dangerous enemy. The electric fish have developed a wonderful device that enables them to detect an approaching enemy even in complete darkness.

Unlike the fish which use electricity for hunting, the Nile mormyrus possesses not only an electric power-plant, but also a special, very delicate organ sensitive to electricity. Its electric power station generates three hundred discharges every second, creating around the fish a weak electric field, constant in pattern, with the lines of force converging at the level of its head. Unlike all other fish, electrical fish do not bend their bodies when they swim, so that they do not disturb the electric field that surrounds them. But if a large fish appears in the neighbourhood, the uniformity of the electric field is disturbed. The body of a fish is a better conductor than the surrounding fresh water and the lines of force, therefore, shift towards the approaching fish. The electric-sensitive devices of the mormyrus immediately warn it of the enemy's approach and it flees.

The mormyrus not only escapes from its enemies with the aid of this peculiar locator, but also easily negotiates obstacles, just like bats do with their echo-sounding device. Most objects a fish can knock against in water are poor conductors of electricity. Such objects repel the lines of force, so the mormyrus can distinguish animate beings from inanimate objects.

Sea and fresh-water lampreys use electrical location to find their prey. This is especially useful in the muddy water of fresh-water basins. The amazing knife-fish, living in the tropical part of the Atlantic near the coast of America, has a locator on its tail. It explores the rock fissures and passages in the underwater jungles by moving backwards and thrusting its tail into every hole. The fish can conveniently flee if an enemy is waiting in ambush.



The gymnarchus, a near relative of the mormyrus, uses a radar system to locate the prey it is chasing. The radar system of the mormyrus and other fish could not have fulfilled its function, if the receptors in the skin that perceive electricity had not been extremely sensitive. Indeed, the gymnarchus can 'notice' a change in the intensity of the current as small as 0.000000000000003 ampere! Such sensitivity enables the fish to distinguish an ordinary gudgeon from bait in whose body an angler has hidden a tiny steel hook. There can be no doubt whatsoever that the gymnarchus would never touch such dangerous bait.

Many fish and even amphibians are highly sensitive to electricity. The organ with which they perceive electricity is the lateral line, while the torpedo ray has Lorenzini's ampullae for that purpose.

All ordinary skates, as well as the gymnarchus, have their own low-power electric stations. So far, we know almost nothing about the purpose of these stations, but some information has already been obtained on the skates' electric sensitivity.

Lorenzini's ampullae have been known since 1678 when they were described by the Italian explorer whose name these organs now bear. Lorenzini believed that the ampullae were a kind of mucous glands, which are numerous in the skin of the fish. However, the dense, gelatinous matter in the gland's duct, in contrast to the lesser density of the contents of the ampullae proper, suggested that the organ had a function other than just secreting a skin lubricant. Lorenzini's point of view continued to hold firm for the next two and a half centuries, apparently for the simple reason that nobody had ever subjected these organs to any profound study. In the past decade, however, it was discovered that Lorenzini's ampullae possess an extremely high sensitivity to very weak tensions in the electrical field. The thornback ray responds by a motion of its spiracles to the impact of an alternating electrical field with a gradient of 0.1 microvolt per centimetre, which means that it is three times more sensitive than the gymnarchus. Moreover, even that is not its limit. It has recently been established that the thornback can sense an electric field with a smaller gradient, as low as 0.02-0.01 microvolt per centimetre, responding to it by decelerating the contractions of its heart muscle.

This clarified the structure of Lorenzini's ampullae. The receptors could not be located right in the skin, for in that case the low conductivity of the skin would not permit great sensitivity to electricity. Neither could they be placed on the surface of the skin because in this case they would be subject to all kinds of external influences. The only possible solution was to locate the receptors in the skin, connecting them with the surface by a special conductor. This is precisely the function of the duct filled with highly conductive matter. The walls of the duct and of the ampulla proper insulate the receptor from the electrical discharges produced in the fish's own muscles. In the epithelium of the ampulla there are receptor cells, supplied with nerve fibres. The top parts of the cells, furnished with a tiny cilium, stick out through the opening in the ampulla. This cilium is the sensing element of the receptor.

Using its electrical receptor, the thornback detects the bio-electrical potentials arising in the bodies of other fish. This enables the ray to find and attack the skilfully camouflaged, seductive and unsuspecting young flatfishes, guided solely by the rhythmical electric discharges that arise in the flatfish's muscles during respiration.

The underwater oscillograph is a windfall for the parapsychologist. If you have ever had the occasion to observe the behaviour of such typical shoal fish as scombroid fish (the common frigate, spanish or horse mackerel), you must surely have admired the co-ordinated manoeuvres of the shoal, during which scores, hundreds and even thousands of fish change their direction all at once, as if on command. We do not yet know who gives this command and how it is transmitted. It is plausible that this 'mind reading' is stimulated by feeble electric signals. Biological currents are known to be generated in all the muscles and nerves and, first and foremost, in the brain, which sends orders to the working organs. It may well be that these orders are transmitted outside the fish's body, because sea water is an excellent conductor of electricity.

Information Service

THE ALL-PURPOSE ANTENNA

From morning till night, a continuous flow of information comes to our brain through innumerable communication channels. The acoustic nerve is made up of 30,000 conductor fibres, while the optic nerve has even more, about 900,000. The amount of information coming in every second from the auditory organs alone is equal to tens of thousands of bits per second, while the information sent in by the eye in a single second amounts to millions of bits! The brain has to sort all this out, glean from it the important information and separate it from what is minor or of no relevance. For the human brain can digest no more than 50 bits in a second.

In the morning, before it wakes up, the brain gets down to work. It has to tune in its receiving devices to ensure the unfailing supply of important messages. This is no easy matter, for human and animal organisms have numerous diverse receiving devices, each perceiving only a definite kind of encoded information.

How many communication channels does an organism possess? In how many ways can it get information?

The receiving devices for gathering information, the receptors, are what we commonly call the sense organs. Scientists distinguish six sense organs which they consider the principal ones: sight, hearing, equilibrium, taste, smell and skin sensibility.

As for the 'non-principal' senses, they are innumerable. The skin, for example, contains a great number of receptors. Some respond to a slight touch (these are responsible for the 'sense of touch'), others respond to a stronger impact and their stimulation is perceived as pain. A third type responds to cold and a fourth is sensitive to warmth. These are but a few of the long list of skin receptors.

The internal organs also have many specific receptors. There are receptors to determine the quality of the food that enters the stomach, others to measure the blood pressure, and still others to test the amount of carbon dioxide dissolved in the blood. We are never even aware that they are functioning. The information being constantly sent to the brain from the internal organs does not penetrate our consciousness.

Scientists have always been eager to understand the structure and function of the sense organs. Research has been especially intense in the past few years, after the electron microscope came on the scene. This is understandable, since the ordinary microscope only magnifies ten to fifteen hundred times, while the electron microscope has a magnification of twenty, forty, sixty, and even a hundred thousand times. Certainly, it has helped scientists to pry out quite a lot of interesting secrets.

They made the astonishing discovery that the receptor cells (the ones that perceive stimulation) in all the sense organs of all animals on Earth are very similar in structure. Each of them has a tiny mobile hair, or cilium. These cilia are also very similar in different receptor cells. Each cilium contains two central fibrils surrounded by a ring of nine pairs of motile fibrils. The structure of the cilium rarely varies.

The cilia in a receptor cell play the same part as the antennae in radio sets, and they are therefore called receptor antennae. Through these antennae we perceive the outside world. The antennae in the receptor cells of the eye, for example, respond to light energy, to photons. The antennae of the organ of smell perceive the energy of the molecules of odoriferous substances. The antennae of the auditory cells respond to sounds, to the energy of sound waves.

The sensitivity of the antennae is astounding. The energy of a single photon, the most minute amount of light, is sufficient to stimulate the optic cell. The olfactory cells (that is, the cells of the mucous membrane of the nose) are no less subtle; they sense a single molecule of odoriferous substance. For the auditory cell to be excited, it is sufficient for the ear-drum to vibrate with an amplitude of 0.0000000006 millimetre, which is one-tenth of the diameter of the smallest atom, that of hydrogen.

The antennae are continuously moving so as to pick up stimuli coming from the outside world. These antennae actively search for external stimuli.

The sensory receptor cells of the different organs are not absolutely alike. For example, the optic cells contain a special substance, known as visual purple, which can change under the impact of light. This photochemical reaction makes the perception of light possible. There is no visual purple in the receptor cells of the other sense organs. The substances by which they perceive stimuli are not yet known.

The great similarity in the structure of the various receptor cells is hard to explain. Probably, the overall design scheme proved to be so practical that this prompted Nature to make use of a standard model in constructing all the diverse sense organs.

Over millions and millions of years, the animal world on our planet trod the long path of evolution from primitive single-celled creatures which were hardly able to perceive external stimulation, to modern humans with their perfect and highly receptive sense organs. One might think that man could have nothing in common with infusoria, but this is not so. The receptor cells of a man and a bird, a fish and an insect, a mollusc or any other animal perceive the outside world and respond to any stimulation from the environment using motile antennae which are very similar in design.

Even single-celled organisms, such as the euglene, use moving antennae. These antennae are so well designed that they have survived for thousands of millions of years. The living organisms of the Earth have preserved their motile antennae from the very inception of life up to the present day.

WHERE DID IT ALL COME FROM?

Of the six principal sense organs three are the most important to us. We can lose the sense of taste and, certainly, smell, and not even bother about it. One could even somehow put up with the loss of the sense of touch, but the loss of the eyesight, hearing, or sense of equilibrium seriously incapacitates a person. These are the principal senses we use to perceive the world we live in. Man's main sense organs do not always coincide in importance with the main analyzer systems of animals. Many representatives of the animal kingdom have very feeble eyesight and some are completely blind. Others are deaf, or only hear very badly, and yet they still manage quite well.

As to the organ of equilibrium, this is an extremely important analyzer system and almost all many-celled animals have it. Even in the single-celled animals zoologists have discovered certain structures remotely resembling the organ of equilibrium of higher animals. The parasitic infusoria possess a device of this sort. They have a special vacuole, a small peripheral sac with some crystalline inclusions, similar in structure to the statocyst (the sac of the labyrinth maintaining static equilibrium) in multicellular animals. If it is some day discovered that the vacuole does indeed fulfil the same function, it will not be surprising. There are many remote corners on our planet plunged in pitch-darkness, many spots where no sound ever penetrates, but the attraction of the earth's gravity is ubiquitous and inescapable.

There are grounds for believing that light has played an active part in the origination of life. At any rate, light sensitivity, which seems to have been possessed even by primary living matter, soon gave rise to a special organ, the organ of sight. Even contemporary single-celled flagellata perceive light. The unicellular animals, particularly the Peridinea, many of which can themselves emit light, have rather large eyes. Their eyes are a bowl-shaped accumulation of reddish, fatlike, light-sensitive pigment located in the anterior part of the Peridinea, at the base of the flagellum. In the pigment there is a transparent grain of starch which serves to refract and focus light.

Of the three main sense organs which are most essential to man, the two oldest are the organs of vision and equilibrium. These organs which are, on the whole, very dissimilar, have one interesting feature in common. Although the organs of vision and equilibrium have greatly modified in the process of their evolution and perfection, they are still more alike in design and specific function, and differ from the auditory analyzers and the sound receptors in various animals. This is obviously because the organs of sight and equilibrium were both shaped under the impact of some single, constant global factor: the sense of equilibrium was formed under the influence of the force of gravity, and eyesight under the impact of sunlight. But on the Earth there has never been any unique and standard source of sound.

When life began on our planet profound silence prevailed. The only sounds to be heard were those of thunderbolts and the roar of breakers against the sombre desolate cliffs by the primordial seas, but these sounds were of no interest to most animals. It was only after the animals themselves had achieved a higher stage of evolution and learned to roam around and devour each other that faint sounds began to be distinguished on Earth. They were sounds of a biological origin produced by animals themselves. This prompted the development of the acoustic analyzer and the systems of acoustic signalization.

Extremely multifarious receptor devices, from wide-range to those only detecting a very narrow band of sounds, had to be evolved to cope with the gamut of sound sources.

Certain bats can best hear very high-pitched sounds of up to three hundred kilocycles, but they can also hear very low sounds. Their auditory organ has a range of fifteen octaves. The nocturnal moths on which these bats feed would have no use for such an enormous sound range. The tympanic organ inside their wings is only able to pick up the ultrasonic signals of the bats. The organ for this limited function is similarly very simple in design. It consists of a membrane, air-sacs and two sensory nerve cells. Their sole function is to perceive the sound produced by the bat in flight and to give the command so that the moth quickly changes direction.

The optic analyzer developed under the influence of sunlight, so it did not need to be so complicated. The eyes of various animals can perceive no more than a three-octave light flux. The range of visual perception is thus only one-fifth that of the auditory range.

Few animals on our planet are indifferent to light. Even the eyeless protozoa can distinguish light from darkness. Sensitivity to light is based on the property of some chemical reactions to be accelerated in the presence of light. Hence, the protoplasm of practically any cell in a multicellular organism can perceive light, and it needs no eyes for this.

The forerunners of the organ of vision were special light-sensitive cells which could react to feebler light than the other cells in the organism. There are some creatures in which these special light-sensitive cells still exist. One that we know well is the earthworm. It has no eyes, but is quite happy with the numerous light-sensitive cells in its skin. With these cells it feels negligible changes in the lighting which man cannot perceive. It was from such light-sensitive cells scattered all over the body that the eye gradually developed in the course of evolution. At first it was just an accumulation of light-sensitive cells in one spot. Such eyes readily distinguish light from darkness, but they can not tell from where the light is coming.

The eye then evolved in the following way. The light-sensitive cells gradually acquired a transparent cover and screens of pigment cells that did not allow light into the eye from all directions. Then the light-sensitive spots turned into pits, of even sacs, the first eyes worthy of that name. These eyes could catch light coming only from a certain direction and easily established thereby the direction of the incident light rays. From this primitive optic device there remained but one step to the eye of higher animals: the eye only had to acquire light-refracting systems, the accommodation devices modifying the light refraction index and, last but not least, the oculomotor apparatus that made an active search for visual information possible.

Cephalopod molluscs possess the best eyes among invertebrates. Their eyesight is in no way inferior to that of higher vertebrates. Another branch of invertebrates, the arthropods, attained a high level of evolution, but, for some reason, this did not apply to their eyes. They compensated for this shortcoming by combining a great number of primitive eyelets (pyramids with the base turned outwards and covered by a chitinous crystalline lens) into a few big eyes of an involved pattern, each eye consisting of hundreds and even thousands of such pyramids. By the joint efforts of their individual, usually rather short-sighted eyelets, insects and crustacea can perceive the size and shape of objects.

The history of the eyes of vertebrates began in a different way. The off-shore area of many seas and oceans is inhabited by curious small animals called lancelets. They look like small fishes and resemble the blade of a surgeon's lancet, from whence their name came. The organ of vision of the lancelet is its brain. Light-sensitive cells are scattered all along the nerve trunk of the lancelet which has a translucent body. It can thus differentiate between light and darkness, which is all it needs for its way of life.

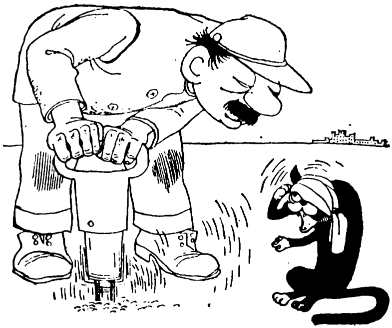
The ancestors of the vertebrates, like lancelets, also, apparently, saw with their brain. But when their bodies lost their translucence, bundles of light-sensitive nerve cells had to move off the brain outside. This has become the pattern of the evolution of the eyes in all vertebrates. At a certain phase in an embryo's development two pieces separate from the brain and gradually develop into eyes. So, our eyes are, in fact, pieces of the brain that have moved outside to the sunlight.

The further development of the eyes in vertebrates followed the same pattern: they acquired refraction systems, an accommodation apparatus, and oculomotor muscles. The design became more and more involved, until it resulted in our present eyes, capable of deciphering the jungles of the worst scrawl in the world and of distinguishing the slightest nuances in colour. At the same time the animal brain also became more complex. The eye as such is merely a light-receiving device, like a camera. What we actually 'see' with is the brain. The brain pieces together the information it receives from the millions of the light-sensitive cells in the eye into a single picture. The snapshots made with the eye are developed in the laboratory of the brain.

The acoustic analyzer, the ear, appeared comparatively late in the course of evolution. It does not exist in lower invertebrates. Fishes were the first vertebrates to acquire an organ of hearing. It evolved from a small part separated from the labyrinth, the organ of equilibrium, which later, in higher animals, developed into the cochlea with a well-developed organ, known as the organ of Corti, the most essential auditory device.

The organ of Corti is essentially a receptor capable of following the rapid and very slight changes in ambient pressure. Rapid increases and decreases in the volume of the surrounding medium affect the ear-drums which vibrate with the alternating pressure waves. Vibrations of the ear-drum are transmitted through a system of auditory ossicles to the oval window and the labyrinth fluid. Thus they reach the organ of Corti whose fibres undergo sharp resonance and stimulate the corresponding receptors in the acoustic nerve.

The sensitivity of the ear is really miraculous. The



human ear can perceive a sound producing a pressure of 0.0001 bar (a bar is a unit of pressure of 1 megadyne per square centimetre). Such a pressure displaces the membrane of the cochlea by a 1/10000000000th of a centimetre. This distance is equal to one-thousandth of the diameter of a hydrogen atom, the smallest of all atoms!

Man is far from being the world champion in hearing. Many animals are able to hear much weaker sounds. However, since man is an extremely noisy being, it is perhaps an advantage that he fails to hear more. It is far more important that he can stand loud sounds of up to 2,000 bars without being hurt. Loud sounds cause convulsive seizures in certain kinds of albino rats and a number of other animals, and may even be fatal for them.

What would have become of mankind, if the human ear were unable to stand loud sounds! However, there would have been one advantage: bloody wars would never have occurred, for soldiers with such sensitive ears would have been killed not by the enemy's bullets, but by the sound of their own rifles. The stage of inventing artillery would never have been reached.

Loud sounds are not fatal for humans, but the impact of prolonged noise may lead to grave diseases of the ears and central nervous system. The anti-noise campaigns must therefore be welcomed and supported everywhere. Trees are our chief allies in this campaign in towns and cities. The spreading branches of the maple, the curly tops of the limes and the thick foliage of the poplars are first-rate sound mufflers.

The human ear is not only inferior to that of animals in its keenness. First of all, we only perceive a narrow range of sound waves. When the sound frequency is sixteen to eighteen vibrations a second, or, as physicists say, the vibration frequency is 16 to 18 cycles per second, we do not perceive a continuous sound. On the other hand, when vibrations attain the level of 20,000 a second, the sound fades away. The ear can no longer follow such rapid fluctuations in pressure. It ceases to inform the brain of them, and it seems to us that there is complete silence.

Twenty thousand vibrations a second is not a very high figure. Our true friend, the dog, can perceive sounds at 38,000 cycles per second. Even this is a low figure, if you bear in mind that the whale and the dolphin are able to perceive sounds with a frequency of 100,000-125,000, and the bat even up to 300,000. Animals whose ear can detect ultrasounds (that is sounds whose frequencies are beyond the upper frequency limit of the human ear) can themselves produce them, but, regrettably, we are unable to hear them. Thus, the saying 'mute as a fish', is absurd from the standpoint of contemporary science. If fishes chose to be as fault-finding with us as we are with them, they would certainly have coined the saying, 'deaf as a man'. Anyhow, in creating man unable to hear very high sounds Nature was wise, as always. In effect, we lose nothing by it apart from an opportunity to hear the squeak of hunting bats or to eavesdrop on secret fish talks. In our own speech we manage wonderfully well with sound waves ranging between 500 and 2,000 vibrations a second.

Man and higher animals are binaural, that is to say, they hear with two ears. This helps them greatly to identify a sound source. Sound waves spread in the air at a speed of 340 metres a second. Usually a sound does not reach both ears at the same moment. Only if one turns one's face towards the source of the sound do both ears hear the sound simultaneously. Humans can perceive that a lag of 0.0001 second occurs between the different times when the sound reaches each of their ears.

Just think what a small time difference the brain can sense! The fox can locate a sound source far more precisely than man. Its two ears are only some ten centimetres apart. This means that a sound reaches one ear not more than 0.0003 second after it has come to the other, and usually much more rapidly. To detect the source of a sound the fox turns its head until the sound reaches its both ears at precisely the same time.

Animals are, in general, very apt to measure and memorize time intervals in perceiving individual sounds. A dog can readily distinguish between a metronome beating at a hundred strokes a minute from the same metronome beating at only ninety eight strokes a minute. Even the keen ear of a well-trained, professional musician perceives these two rhythms as exactly the same.

The human ear is inferior to that of animals in many respects, but in one respect it is unrivalled. No animal can analyze a flow of rapidly alternating sounds. We need to be able to do this, since human speech would be impossible without it.

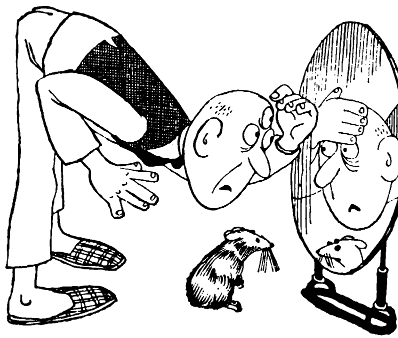
A THIRD EYE

A train full of holiday-making children slowly pulled into the station. The huge red electric locomotive slowed down with a screeching of its brakes. Behind it, snaking slowly down their track, a dozen large, handsome dark-green carriages followed, with wide clean windows. White noses were pushed up against the glass; pairs of eyes—black, grey, blue, green—could be seen everywhere, aligned in three and sometimes even four horizontal rows. Like a fabulous monster, the approaching train was looking at the town with a thousand attentive eyes.

'Like a thousand-eyed monster,' said a voice in the crowd meeting the train. That was a fortunate choice of metaphor. Indeed, the train resembled the turbellaria worm. For the front part of this worm's body is studded with a chain of tiny, almost microscopic eyes. It moved like a worm, too, wriggling slowly and smoothly.

The eye is a very important sense organ. It is no wonder that many animals are provided with dozens and sometimes hundreds of eyes. The more primitive the eyes of an animal, the more of them it has to have to survive. Conversely, the more perfect the optic receptors became, the fewer of them were needed. Even a one-eyed animal exists. It is the copepod, also called 'cyclope' after the one-eyed giants of the Greek myth. The unique eye it has in the front seems to be quite sufficient.

What would be the ideal number of eyes? This question is not as simple as you think. The number of eyes an animal needs depends on their quality and on its way of life. Some animals in existence today once had very good eyes, but later came to live in a completely dark habitat and gradually their eyes



disappeared. This happened to the Mexican cave-dwelling fish.

It would seem that one can safely rely on Nature in this matter. During its evolution each animal species acquired as many eyes as it needed for survival. In particular, the vertebrate animals, of which man is one, with their complex, highly developed brain and perfect eyes, found it quite enough to have... three. This is not just a slip of the pen; the number really is three!

Fishes, amphibians, reptiles, birds and mammals, and every one of us as well, have three eyes. Usually, we forget about the third eye or never even suspect that it exists. The reason for this is that this extra eye is hidden deep inside our brain, and is not visible from without. Neither is it called an eye, but the pineal gland. In the course of evolution in vertebrates this formerly genuine eye became an actual gland.

The mysterious eye is not big. In humans it weighs only 0.1-0.2 grams, that is far less than in the contemporary crocodile or extinct giant reptiles. In lower vertebrates the structure of this organ hardly differs from the normal eye. It has a crystalline lens on the outside, and inside it is filled with a transparent jelly known as the vitreous body, and has rudimentary retina with light-sensitive cells and the remnant of a vascular membrane. This eye, like any normal eye, has its own nerve.

Imagine the astonishment of scientists when they first discovered this third eye a hundred years ago! A host of extraordinary hypotheses were proposed. What could this eye be spying out in the brain? Might it not be that a man employs this eye to see and grasp his own thoughts and emotions? Lots of fantastic ideas were put forward.

The function of the third eye was only elucidated when it was discovered that it exists in all vertebrates. In most vertebrates, for instance, the frog, it is located in the skin on the crown of the skull, in the sincipital area, and in lizards it is found immediately under the skin, although it is covered with scales. In the iguana, a large South American lizard, however, these scales are transparent, while in the tuatara lizard of New Zealand the eye is only covered with a thin, transparent film. Evidently, it can see!

Scientists were eager to discover the function of this extra eye. Experiments have proved that it responds to light and even discerns colours. That is, incidentally, no trifle, for even the ordinary paired eyes of many animals cannot distinguish colours.

The tuatara is a very ancient species, virtually a living fossil. These lizards already existed in that distant epoch when the Earth was inhabited by giant reptiles and they have not changed at all since then. Perhaps, in those ancient times, all animals regularly used their third eye. This hypothesis has been confirmed.

Palaeontologists, the scientists who study extinct animals, had for long racked their brains over a strange hole in the upper part of the cranium of extinct giant

reptiles. Now it is clear that this hole was a third eye-socket, just a bit smaller than the two lateral ones. There could be no doubt whatsoever that animals in ancient times made extensive use of all three eyes. Just picture how convenient it is to bring your head close to the surface before you emerge from the water to see with your third eye how things stand in the world. Nor was this third eye too great a precaution for the formidable beasts, wary of scaring off their prey, or, it goes without saying, for their victims.

The origin and the ancient functions of the third eye were thus clarified. It still remained a mystery, however, why contemporary animals have a third eye. Most reptiles cannot see with this eye since it is covered with scales. On the other hand, had it been utterly useless, it would have had no greater chance of being preserved than the hind paws of the whale. Scientists are well aware that organs which no longer have a use are doomed to disappear. So the very survival of the third eye suggests that it must have some function in the contemporary animals. But what kind of function? Scientists had to continue their investigations.

Soon they discovered that cold-blooded animals use it as a thermometer. These animals cannot keep their body temperature constant. All they can do is to regulate it by hiding from the burning sunlight during the day and from frost on chilly nights. But, when the body is already too hot or too cold, it is too late to hide. The animal can get sunstroke or freeze to death. The third eye measures the ambient temperature, warning the animal that it is high time to hide in order not to get too hot or too cold. The skin of the animal is, indeed, no obstacle to heat rays.

This, however, is not the sole function of the third eye. In amphibians it also regulates the skin colour. The skin of a tadpole placed in a dark room for half an hour becomes lighter. But a tadpole whose third eye has been removed is no longer capable of changing colour. It has been established that the third eye produces a special hormone—melatonin, which causes the skin to lose some of its colour. Light inhibits the production of this hormone.

Although in mammals the third eye is hidden deep inside the cranium, it is kept perfectly well informed about all the happenings outside. And it certainly feels whether it is day or night. It seems to receive news first-hand. The only nerves coming into the third eye of mammals are branches of the sympathetic nerve from the upper cervical sympathetic ganglion, which, among other things, innervates the muscles that dilate the pupils. We all know that the pupils dilate in the dark. It may well be that the alternation of day and night and other changes in lighting affect the activity of the pineal gland. The weight of the pineal gland of rats kept permanently in the light for a long time palpably decreased. On the other hand, a lengthy stay in the dark did not affect the 'incipital eye' in the least.

The functions of the third eye are not confined to changes in the skin colour and thermal regulation. A thorough investigation has shown that the third eye in human beings has become a proper gland, although this gland is unusual. Except for the pineal gland, no other gland contains astrocytes, the ordinary nerve cells which are abundant in the cerebral hemispheres. The purpose of this close intertwining of glandular and nerve cells remains obscure.

Today research on the pineal gland is being undertaken in many laboratories throughout the world. The tadpole suggested to the scientists that the third eye may also produce hormones in higher animals. This hypothesis has been confirmed. The hormones it produces for the most part act upon another formation of the brain—the hypothalamic-hipophyseal complex, which takes a very active part in regulating the water-salt balance, the composition of the blood, digestion, sexual maturity, sexual activity and, above all, controls our emotional states. Hence, in the last count, it determines the character of the whole of our mental activity. Experiments on animals show that young rats whose third eye has been removed grow faster and are larger in size than normal animals. They achieve puberty sooner and bear offspring more often. The same is observed in chickens without a third eye. They grow more rapidly, and the hens lay more eggs.

Human children whose pineal gland activity is disturbed, or has ceased altogether as the result of illness, reach sexual maturity too early, and their genitals grow too fast and are extremely large in size. On the other hand, a regular administration of a preparation from the pineal gland decelerates sexual maturity and causes atrophy of the sex glands in adult animals. Such animals bear offspring less often, and are sexually less active.

Subsequent studies disclosed many other curious facts.

The pineal gland has been found to take part in the regulation of the sugar level in the blood, acting either through the pituitary gland or directly on the pancreas. If extracts of the pineal gland are introduced into the organism, sharp changes occur in water metabolism. Some scientists hold that the third eye influences the functioning of the adrenals and the thyroid gland.

Studies carried out on man and animals suggest that the pineal gland remains active from birth until a venerable age, though perhaps the essence of its functions changes with time. This is suggested by the appearance of grains of calcium, magnesium, phosphorus and iron in the tissues of the third eye. Newborn babies never have this strange brain 'sand'. It rarely occurs in children of less than fifteen years, but at a later age its amount grows every year. We know by experience how much trouble it causes if a tiny piece of grit gets into our outer eye. Is it difficult to believe that a pinch of sand in the body of the third eye does not interfere with its functions?

Since its discovery we have learnt a lot of surprising things about our third eye. Even now it is unlikely that we now know all of its functions. Experiments are continuing, and, probably, this mysterious and still unexplored organ will more than once bring us new surprises.

THE WONDERFUL WORLD OF LIGHT

Physics is an ancient science. The first optical device, the flat mirror, has been known from time immemorial. Spherical mirrors that can focus light rays into a single beam, or scatter them uniformly, appeared much later. The first mirrors were made of metal. The invention of glass opened up new vistas to optics, but a long time passed before people thought of polishing glass lenses.

A magnifying glass captured the imagination of the educated men of that time. Many of them enjoyed scrutinizing small objects through a magnifying glass, while the more ingenious attached such glasses to a helmet or cap and used them as a kind of spectacles. For the time being these were mere baubles. A great deal more effort was to be expended before these glasses became our modern binoculars, telescopes, microscopes and cameras. Their designers never had an inkling of how much they had virtually borrowed from Nature. Indeed, our eye is in no way inferior to a modern photo- or TV camera. It is furnished with special devices to refract light rays and focus them on the inner surface of the posterior wall of the eye, with a diaphragm to control the amount of light entering the eye, and photo-sensitive cells. Stimulation of these cells is transmitted through the optic nerve fibres to the occipital region of the brain, where the signals are scanned as on a TV show, producing visual sensations and a visual image.

In order to see a thing distinctly, its image must be sharply focused on the receptor units. In modern cameras this is done by changing the position of the lens. Nature chose the same design principle for the eyes of the first vertebrates. Fish amphibians have a crystalline lens, the principal refracting unit of the eye, furnished with a special circular muscle enabling it to move along the eye's optical axis.

Reptiles, birds, and mammals have a different device which has not yet been modelled by modern technology. This device focuses light by modifying the curvature and, hence, the refractive index of the crystalline lens. This is done by an annular muscle round the crystalline lens.

Birds and reptiles change the shape of the crystalline lens by contracting the muscle, which presses against the lens and makes it more spherical. The annular muscle in mammals, on the other hand, distends the lens to flatten it. When it relaxes the lens resumes its former curvature. This mostly applies to the curvature of the anterior surface of the lens, the radius of which varies between six and ten millimetres. The radius of the posterior surface never changes more than half a millimetre.

When devising the refracting device for the mammalian eye Nature committed a grave error. She never suspected that the supreme representative of that animal class, man, would invent all kinds of tiny scrawls which he would call letters and use them to exchange messages. He had to become short-sighted enough to be able to decipher his own scribbling. Then man began to experience trouble, for which Nature is to blame. Our crystalline lens becomes less elastic with age. It can still stretch well, but can no longer return to its previous shape. People become long-sighted with age and have to wear glasses.

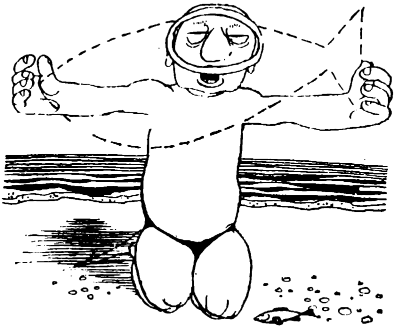
The refracting power of the eye is basically made up of the refracting power of the cornea and the crystalline lens. The refractive indices of the cornea and of the fluid behind it are almost equal to that of water. For this reason our eyesight is seriously disturbed under water. The rays reaching the eye pass through the cornea unrefracted and the lens on its own cannot focus the light on the light-sensitive cells. People become so long-sighted under water that virtually every object, however distant, seams to be too near them. They can only see large objects, and then very vaguely. Divers wearing helmets and aqualungs can see well in clear water, for their eyes are not directly in contact with the water. Their eyes are separated from water by glass and a thin layer of air, so that both the lens and the cornea take part in focusing. The images they see are distinct, but everything seems one-third larger than it really is. One should keep this in mind when listening to aqualung hunters describing their adventures.

The refracting power of the eye not only depends on the curvature of the cornea and the crystalline lens, but also on the materials they are made of. In fish, the cornea can refract light in water no better than that of man. So fish do not even try to use it for this purpose. Their cornea is quite flat, but this is compensated for by the ball-like shape of their lens. A whale's cornea is convex, and its refractive index is high, so that both the cornea and the lens take part in focusing.

Each animal species has developed eyes suited to its environment. Those which have to see both under water and on land had the greatest problem. They were faced with the dilemma of either choosing eyesight fit for one medium only or undertaking a drastic reconstruction of the eye. The mud-skipper has eyes typical of those of a land animal. This small fish is fond of climbing the trees near the shore and it spends hours out of water. It is of no importance that it can see nothing under water, for in the pools, where this fish likes to live, the water is so muddy, that it is impossible to see anything anyway.

The whirligig beetle lives in clear water. It was very hesitant to make a choice and Nature gave it two pairs of eyes, one for being under water and the other for being out of water. She was equally indulgent with the four-eyed fish living in the lakes of Central and South America. This fish feeds on insects, nimbly jumping out of the water and snatching as they fly above the water.

In fact, the four-eyed fish has two ordinary eyes, except that the pupils are stretched vertically and divided into two parts by a special partition. The refracting substances of the upper part of the eye's tran-



sparent media are adapted to see in the air, and those in the lower part to see in water.

Devising eyes for fast-moving animals was another headache for Nature. The cormorant needs long sight on the wing like any other bird, but when catching fish in water it must be able to see at a very close quarters. Therefore, it can change its lens curvature over an unusually wide range. While the refracting power, even of a young man's eye, is no more than fifteen diopters, that of a cormorant is forty or fifty. Thanks to this, it sees a small fish fleeing at top speed to a hedge of marine grass and an eagle hovering high up in the sky over its head equally well.

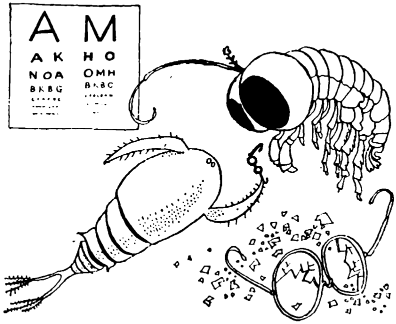
Most seals and many sea snakes see very well, both in water and on land. As for penguins, they become very near-sighted when out of water.

The eyes of contemporary animals greatly differ in light sensitivity. The reason is clear: the lighting on our globe varies a great deal: now there is bright sunshine, now it is cloudy, and now a dark night. Many animals live permanently in darkness, under the ground, in caves and in the depths of the oceans. Many sleep during the day and leave their refuge only after nightfall. All such animals usually have either very big, sensitive eyes, or, on the other hand, their eyes have deteriorated completely and they have to do without their eyesight.

Sometimes, the eyes become really huge. Deep-sea molluscs have eyes up to twenty centimetres in diameter, while the eyes of the small amphipod are equal to one-third of its body length. The eyes of deep-sea fish and molluscs have an elongated telescopic shape with a very large pupil. This serves to gather as many light rays as possible inside the eye and focus them on the highly sensitive receptor cells. To see clearly, an owl needs one-hundredth of the lighting a man would need.

The eyes of deep-sea fish and predatory beasts on land have one more interesting feature. The inner surface of their eyes is covered with a lustrous layer, the so-called tapetum lucidum, which reflects incident light rays well. This is why a cat's eyes shine in the dark. Neither the wolf's, nor the cat's (or crocodile's) eyes emit light; they just reflect the weak rays of the moon and stars, and of far-off lights that get into their eye and are concentrated on the posterior surface. In complete darkness their eyes do not shine.

A traveller, groping his way through the woods late at night, experiences the really awful sensation of being watched by attentive, bright eyes glowing in the dark like live coals. However, the tapetum lucidum of the eye has another job to do, rather than scaring people at night. Its task is to reflect the light rays back on to the light receptors so as to reinforce their action. An eye furnished with this tapetum lucidum makes the fullest use of all the occasional specks of light that reach it. Regrettably enough, we humans have been deprived of this valuable device and our eyes do not

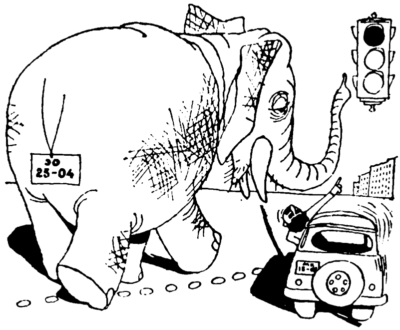


betray the persons that take to ambushing their fellow-men at night.

The receptor units of the eye are cones and rods. The human eye contains about seven million cones. The rods are even more numerous, about 130 million. The light-sensitive cells are distributed unevenly, the cones being denser in the central part of the field of vision. Their concentration is particularly high in the yellow spot which we use for the close scrutiny of the surrounding objects.

Another function of the cones is to detect colour. Not all animals by far can distinguish colours. The higher invertebrates were the first to have a sense of colour. Cephalopods, crustacea and many insects are skilled colour experts. Insects are to a certain extent even superior to all other animals: they can see ultraviolet rays which are invisible to humans. They see a miraculous world which we have only come to know recently from snapshots on special ultraviolet-sensitive film.

Most vertebrates which are active during the day discern colours well. Many fish, amphibians, reptiles and birds are also aware of colour. Nature only stinted mammals of this gift. Perhaps this happened because



their ancestors were nocturnal animals. Even our true friend, the dog, which has learnt so many things from man, has never achieved perception of colour. Hoofed animals are, incidentally, no better off. They, too, do not distinguish colours. Despite the proverbial belief that the bull dislikes the colour red, one is compelled to state the fact that it is completely unable to tell it from the colours green, blue or even black of the same intensity. It seems as though the monkey and man are the only mammal species able to enjoy the rich play of colours.

The capacity of the yellow spot to provide the brain with detailed information about an object is, apparently, due to the high concentration of receptor cells in this spot, and also to the fact that each cone is connected to its own individual neuron. The rods have no such individual neurons and they have to crowd in groups around a single nerve cell.

If the images of two dots fall on two different cones of the yellow spot, we see the two dots as being different. Using the peripheral part of the field of vision, we can distinguish between the two dots only if their images are projected onto two different groups of rods.

If the two dots are focused within a single group, the eye will see them as a single dot. It is no wonder that eagles and griffons which prey on the victims from high up in the sky, have two, or even three, yellow spots.

Apart from the yellow spot, cones also occur in the remaining sections of the central part of the field of vision, but in a much lower concentration. On the periphery of the eye there are only rods and no cones. The rods are more sensitive light receptors. Since several rods send their signals to one and the same nerve cell, the joint efforts of the rods, even slightly stimulated in the twilight, suffice to excite their common neuron and the eye is at least able to see something in conditions where the cones, that have individual neurons, would be of no help.

We resort to the rods in the twilight, when the cones merely become an obstacle to the eyesight. Were it not for the habit of focusing the image on the yellow spot, we would see much better at night. For this reason, in the dark we see the things that are projected against the lateral parts of the retina better. This occurs when we do not look directly at the object we want to see.

A large part of the retina that we so efficiently use in the daylight becomes completely or partly useless at night. Incidentally, even during the day we do not use the whole of the retina. Near the yellow spot there is the so-called blind spot, where the fibres of the optic nerve come to the surface. This area is devoid of any light-sensitive cells and it takes no part either in daytime or night vision.

How strange it is that we never notice this blind spot in our field of vision. To some extent this is because we look at the world with two eyes, so that different parts of the image are omitted by the blind spot of each eye. When scrutinizing an object, the eye never stands still; it glides along the outlines and the essential details of the image and, moreover, quivers slightly all the time. The image of the object quickly moves across the retina allowing us to see it as a whole.

Because of the differing concentrations of light-receptor units we only see the object that we are scrutinizing sufficiently clearly. This is good, for it helps us to concentrate our attention on the main things. It is different in the case of predatory beasts and birds. They need a very broad field of vision when looking out for their prey. Nature has found a way out here as always.

Have you ever dived with your aqualung into a clear sea far off shore? Did you not feel rather lonely there? Whether you looked to the left, to the right, in front, downwards, or upwards, everywhere you see nothing but the same bluish-grey haze spreading out into the distance. The emptiness is complete, boundless! The eye just has nothing to hang upon. Even outer space does not seem so desolate. After all, there is the bright shining sun and the gay glistening of the myriads of stars.

The fish which live in the open sea feel no less lonely. It is no accident that they seek company of their own kind and join shoals. In this boundless void any object rivets attention. One just cannot tear one's eye from it and cannot help coming close to it. One angling technique is based on this principle.

The extremely simple fishing device consists of a long line with a plummet at the end and half a dozen fish hooks attached to it on separate short strings. No bait is needed. The tackle is just thrown into a depth of thirty to fifty metres and given a tug from time to time. Soon the line will start to quiver telling you that a fish has been caught. Now you can carefully pull the tackle up into the boat.

Beginners are usually amazed by the fact that the fish swallow empty hooks and they are extremely sur-

prised when they see that a fish sometimes catches on the hook by its belly, tail or back. There is nothing amazing about this, however. The fish, tormented by the void, cannot help riveting its eyes on the new unknown object; it tastes it, swarms around it in a rolling tangle, and gets caught on the hooks when the angler jerks the line. If a man were doomed to live in the melancholy of the sea depths, perhaps our amazed novice would also swallow a hook.

The fish that wander through the bluish-grey haze all their lives leave no object they come across unnoticed. Indeed, there is so little to attract their attention. So Nature wisely gave some of the carnivores living on land, with its rich, festive colours, a personal desert stretching before their eyes to enable them to notice their prey better.

The light-perception elements in the eye are built so that they can transmit to the brain information not only on the intensity of the light that falls on them, but also on the pattern of the change in the illumination level. The cones and the rods send signals to the brain about every slight change in their illumination and then wait for the next change to send in a new cable. This is the way they work.

This interesting property of the light-perception units of the eye was first discovered in a study of the electrical reactions in response to the illumination of the eye. A theoretical analysis of these experiments suggested the hypothesis that a fixed eye closely looking at a set object can see it for only a very short time. It was not easy to verify this hypothesis for, apart from the continual searching movements of the human eye, it jerks slightly all the time. Scientists invented a clever way to clarify this question experimentally. If we cannot check the eye's movement, let us mount the image directly on the eyeball. The eye may move as it will, but the image will remain fixed and focused on one and the same elements of the retina. The experiment confirmed that the eye really does not see an immobile image!

Vertebrates developed the ability to move their eyes only at recent stages of evolution. The eyes of most fish are immobile, but this does not trouble them, as water is not rigid, and their bodies are never absolutely motionless. Their eyes move with their bodies.

When, long ago, fish turned into amphibians, crept out onto land and found a stable footing for their body, they lost the ability to see the world around them in a continuous manner. This loss had a detrimental effect on amphibians: deprived of a constant inflow of visual information they became very stupid compared with their fish forefathers. When the brain receives no information to digest, it remains idle and does not develop.

An amphibian beholds a very strange world. Just look at a frog or toad basking in the midday sun at the side of a shallow pond. It is looking at the world with such enviable philosophical calm! Well, what has it to worry about? When there is a haze of hot air hanging over the swamp and no breeze to move a grass stem or to twitch a leaf, the toad sees nothing of the flamboyant colours around it. A bluish-grey haze hangs before its eyes like a curtain, as though it were swimming in the depths of the ocean or sitting before a TV set with a broken receiver.

Tedious and monotonous as the amphibian's visual world may be, its eyes are a great help to it. No living creature will ever escape its eye. When a fly buzzes past the frog, its image immediately appears on the void TV screen. Now the fly alights on a stalk, the stalk swings and also appears on the screen just for a short while. And again the frog sees nothing but the crawling fly against the bluish-grey background, alone in the whole world. How could the frog possibly miss it? No prey will ever escape such an attentive eye.

This temporary blindness does not interfere with the normal life and orientation of an amphibian. It never bumps into things, for immediately it budges the world appears on the void TV screen.

However, on the whole, amphibians are not particularly lucky with their analyzers. The conditions for reception of sound and smell information in the air medium are essentially different from those in water. In the amphibians these two sense organs are not too well adapted to the new conditions on land. So an amphibian has to rely on its eyes to find food, and even that is possible only when it is moving.

If you have ever kept a frog or toad at home, you must know that it never takes motionless food. This is a very regrettable peculiarity of the frog. Harmless and enduring, the frog is scientists' favourite choice for all kinds of medical and biological research. Moreover, frogs are cheap, and in winter they can be comfortably kept in a chilly room, never even asking for food, for even in natural conditions they hibernate throughout the winter and never eat during that season.

The frog would be an ideal object for research were it not for the sole defect that, when summer comes, research has to finish. The frogs awaken from hibernation and clamour for a nourishing diet. At that time they need lots of food, and this must be live food or nothing. It is practically impossible to arrange to feed them in a laboratory, keeping hundreds or thousands frogs, to say nothing of the fact that live food costs far more than the frogs themselves. All attempts to teach a frog to eat pieces of meat from a feeding-trough have been futile. This is simply because the frog does not see the food. For a long time this seemed an unsurmountable obstacle, until someone was struck on the idea of making a rotary feeding-trough, a sort of merry-go-round, with pieces of meat nicely riding on its edge. The frogs soon got accustomed to the show and began to snatch at the meat as though nothing were the matter.

It is hardly probable that Nature meant from the very outset that the sensitivity of the eye should be increased as the result of these peculiarities of the immovable eye. This has not occurred in higher animals whose eyes became movable.

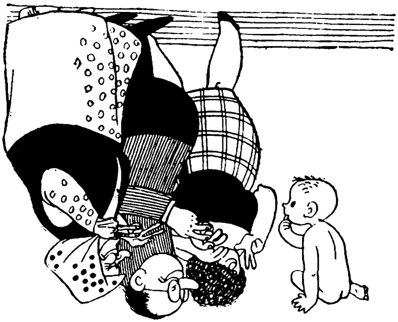
Further improvement of eyesight took the path of raising the sensitivity of light-receptor cells. This posed new problems in the functioning of the eye: highly sensitive receptors that work very well in the twilight cannot stand strong light. Therefore, from the very beginning the optic receptors were fitted with a diaphragm to change the intensity of the light flow.

The diameter of the pupil of a human eye adapted to darkness is eight millimetres, several times larger than in bright sunshine. The contraction of the pupil not only restricts the light flow, but also enhances the sharpness of the image, for the light rays in this case pass through the middle of the cornea and the crystalline lens, that is through the optically more uniform parts of the light-refracting system.

A curious feature of all analyzers is that the sensation caused by a certain stimulus does not vanish immediately after its action ceases. This permits us to hear continuous sounds instead of alternating changes in pressure and to perceive frequent flickering of light as continuous. Humans can no longer discriminate separate light flashes after their frequency attains the level of sixteen to eighteen flashes a second. This property of our vision was a premise to the birth of a new art, the cinema. During a film show the separate images are projected onto the screen at a frequency of twenty four a second. Thanks to this, we see a continuous image and have the illusion of real movement.

We humans are sluggish creatures, and this duration of the consecutive sensations does not interfere with our sensations. The case is different with birds and flying insects. If they retained their sensations as long as we do, they would find it hard to see the world on a rapid flight. But they cannot enjoy our films. To give an insect the pleasure of seeing it continuously we would have to run the film at a minimum of two hundred images a second.

The chamber eye in higher animals is a very complex device and every individual has first to learn how to use it. This function is entrusted to the brain. Before using the eyes, one's brain must learn to decode the information they send, for example, to decide which of a pair of objects is the nearest. The images of the two objects on the retina may happen to be equal in size or even the image of the farther object may be larger than that of the nearer one.



In general, the image of an object on the retina as such is not enough to judge the dimensions of that object. To determine its size, information from the light-sensitive cells must be correlated with that from the receptors in the muscles informing the brain about the position of each eye (to be exact, about the angle at which the optical axes intersect), and about the degree of accommodation, that is the degree of the change in the lens curvature. The greater the degree of accommodation, the better we can judge of size and distance when we look at an object with one eye. The same principle is found in many animals such as rabbits, woodcocks, and fish whose facial part of the cranium is so constructed that they cannot see an object with both their eyes.

The ability to decode and correlate information on visual perception and the perception of movement is inherent in the brain, but one must learn to use this ability as one learns to control the movements of one's hands and feet.

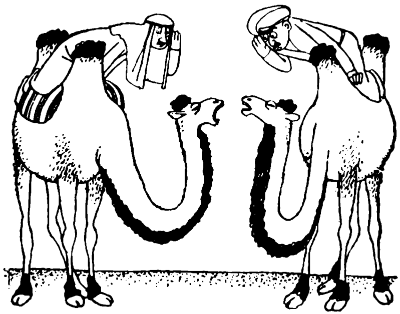
Insects see the world with their complex eyes like a mosaic pattern, but they have the advantage of seeing a direct image of objects. Vertebrates have more problems with their chamber eyes. The light rays entering our eye pass through a tiny biconvex lens which refracts them so that the image focused on the posterior wall of the eye is turned upside down. Why then do we not see the world topsy-turvy? We must be grateful to the brain for this, since from early childhood it learns how to piece together the information it receives from the eye with that from other senses, first and foremost from the skin and muscle receptors.

What if the image on the posterior wall of the eye is oriented correctly? What should we see then?

This has been studied in many experiments. To position the image on the retina in the correct way you must put on special glasses. At first the world will seem upside down. But if you never take off the glasses, in four days your brain will be adapted and you will see the world the right way up again. Visual perception becomes quite normal, so that you can even drive a car. But then, beware if you take off the glasses, for the world becomes topsy-turvy again. Though, in that case, too, the obedient brain will again gradually become accustomed to the old system of processing information. The actual processes that take place in the brain in such cases have not yet been thoroughly understood, but this is connected with a different topic, the functioning of the brain.

WHISPERING PLANET

Optic and acoustic analyzers essentially differ from each other; only a few animals can emit light, but an overwhelming majority of those which can hear have special devices to fill the world with the sounds of life. We cannot reconstruct in detail how the faculty for sound signalization developed in animals. But we can assume that the sound analyzer first appeared because



it was necessary to hear sounds emitted by the enemy or by the prey.

After animals acquired ears they certainly discovered that very important news can be received from their own kith and kin, if they only troubled to listen to the sounds produced by them. These signals not only told the animal how the members of its family or flock were getting on, but also gave it a general idea of how things stood in the world. There remained but one more step to active sending of signals to one's kinsmen.

Animals developed an ability to produce sounds to communicate with one another. To reproduce sounds sufficiently accurately, an animal must be able to hear them well, so the sound-production and sound-perception organs had to develop in parallel.

Indeed, animals are particularly apt to perceive their own sounds and those emitted by other representatives of their species. Naturally, they noticed that the sounds they made produced an echo and that one and the same sound may produce different echoes in different surroundings. When Nature had grasped the reason for these differences it began to stage experiments which culminated in the creation of such sound-production and sound-perception systems as enabled the animals to employ sounds for various purposes of their own.

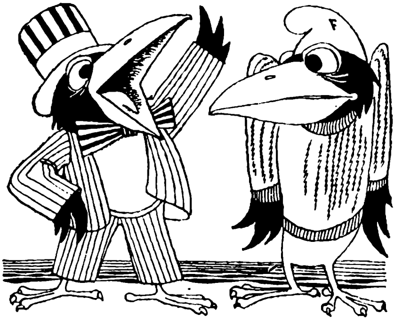
The best sound instruments are those of birds and mammals. Their vocal organs use the movement of the air to produce a wide range of sounds. However, not every species was equally endowed by Nature. With some of them she was not as generous, and created them voiceless. To contribute their share to the sea of sounds and to diversify their musical repertory, these animals had to invent their own ways and to resort to the same auxiliary means of expressing their emotions.

The typical sound of the Hudson owl is a loud clicking of the beak. There are virtuosi of beak clicking which can play whole concertos in this way. The sounds emitted by the stork are very similar to those of castanets. Varying the rhythm and sound intensity, a stork can perform sweet Spanish serenades.

The enamoured woodpecker thinks that his beak alone is not enough to express his feelings. He entertains his lady with long concertos drummed on dry tree trunks. The male partridge beats a drum roll with his wings, making up to forty beats a minute.

Insects have no vocal organs, and they usually resort to friction to make sound. The locust rubs a leg against its stiff wings. The grasshopper rubs certain parts of its wings together. The cricket has about 150 triangular prisms on the rubbing parts of its wings, and four membranes which vibrate and amplify the sound. No wonder that an insect's ears are not in its head. The cricket's ear is on its knee, and that of the locust at the base of the leg.

Fish rub their branchial plates together to make sounds. The carp grits its pharyngeal teeth. The percoids have a very peculiar sound apparatus, which is



especially developed in the singing fish and the sea robin, the gurnard. It makes sounds with its swimming bladder by contracting special muscles that make the walls of the bladder vibrate.

Many animals emit sounds when moving. The cry of the snipe that we hear coming from the sky is due to the vibration of the rectrices, special quills on its tail, during the nuptial flight. The heart-rending singing of the gnat that makes you stand stock-still waiting to be stung is no chivalrous declaration of war on its part. This high-pitched buzzing sound is produced by the motion of the gnat's wings, and sometimes the gnat would prefer to keep silent, but it just cannot do this.

Ever since man came into being he has been intrigued by the language of animals. Priests, scholars, artists, poets turned to this idea over and over again. Volumes have been written on the subject, many by famous authors. For the most part these books have now fallen in oblivion, including the works by great writers.

Numerous studies failed to lead to decoding of the signals that animals use for communication. It was only after the equipment for recording, multiple reproduction and all-round analysis of animal talks appeared that the scientists could get to grips with this fascinating problem.

Signals serve diverse purposes. Some are roll-call signals, others sound the alarm, a third type announces a food find, and the fourth are love-calls appealing to the mate. The mellow charming chirruping of our birds for the most part announces that a nesting area has been taken.

It is very interesting, but as yet unclear, why the songs of birds and frogs that carry very little substantial information are so involved and sometimes also beautiful pieces of music. The ability to sing is innate, but a bird must learn to sing well. A fledgling that has never heard the voices of its fellow birds will never become a good singer. The fact that a bird can learn is not as astonishing as the fact that it is endowed with good taste. A good singer never imitates the style of a bad singer, but usually the bad one will learn from the good one. This explains why, in some localities, only good singers live, while in other places all singers are bad.

The language of animals proved to be much richer than it had formely been believed. It is especially rich in the case of the animals living in large groups. The stupidity of hens is proverbial, but even their language contains about thirty words-signals.

Every species has its own inventory of signals, while the species that are widely scattered over the globe fall into separate nationalities or, to be more exact, linguistic groups. It has been established that crows living in the United States are completely incapable of understanding their French brothers and sisters. The Black Sea dolphins cannot speak the language of their Mediterranean relatives.

On the other hand, even very dissimilar birds and beasts who live together end up by mastering to a certain extent the signals of their neighbours, especially the warning sounds. The alarm signal sounded by magpies is well understood by all the inhabitants of the nearby woods and fields. Even the clumsy master of the taiga, the bear, or the dangerous, striped dandy of the Far-Eastern jungle, the tiger, never risk ignoring it. There are polyglot birds, too. Birds, which live a nomadic life, learn the different dialects of their settled relatives.

The voices of different species are so unlike that sometimes the voice is the best means of identifying its owner. A bird expert unmistakably tells the species of a singing warbler, but he can make a mistake if he holds the bird in his hands. This diversity of voices is very important. Similar as they are, the different species of warblers never bear hybrids, for the sound signals help them recognize their mates. The songs of many insects serve the same function. Gnats recognize their ladies by the typical buzzing made by each species, which depends on the frequency of the flapping of the wings.

Signals emitted by animals differ in duration, amplitude and frequency modulations, the intervals between individual sound messages, spectral band range, steepness of the rising and falling of the signal, and a number of other characteristics. However, a detailed analysis shows that, despite all these differences, the sounds made by animals have certain similarities.

For instance, the air-warning signal of most birds and small animals is a prolonged, slowly rising sound. It is difficult to localize in space such a signal with an insignificant steepness of rising of the sound, but in this case it is of no consequence. When the enemy threatens from above, when there is a hawk or eagle over-head ready to swoop down any instant, it is no use to flee. The air alarm gives an animal no hint as to whether the menace is on the right or on the left, in the front or behind, and does not tell it where to run. The only thing that remains is to stand still with bated breath hoping you will not be noticed, or take refuge nearby. Indeed, these are the only means of escape if the attack is from the air.

The signals of land alarm are quite different. In this case it is important to know where the menace comes from, so one must localize the signal. Land alarm must therefore be a signal affording exact localization. For this purpose hens use packets of short impulses steeply rising at the beginning and slowly falling at the end. The land-alarm signal makes birds take wing and beasts run in the direction opposite to that of the signal.

For all the admirable richness of the animal language, which is not confined to sound signals alone, we are still compelled to brand it as a second-rate language. The fact is that birds and beasts inherit all the 'words' of their language and do not learn them in the way human children do. The signals emitted by animals are involuntary, caused by a definite emotional state. A hen shrieking with terror at the sight of a swooping kite is not trying to tell her hen-friends of the impending danger. The hen's outcry is as instinctive as that of a man who has touched a hot iron. The language of animals is innate and their information exchange involuntary. This is one of the reasons why their language develops so slowly in comparison to human languages.

The longer a group of animals live together, the more information about the environment they learn to get from the spontaneous sound signals of their companions. When one of a pair of dogs living in a house looks out of the window and sees a member of the family, the other dog will know exactly who it is by its mate's sound responses and general behaviour.

Animals can learn to make more active use of sound signals. A dog can easily be taught to yelp when it is thirsty, to bark loudly and frequently when it is hungry, and to whine when it is time to go for a walk. A parrot whose vocal chords are the most similar to those of human beings can be taught to utter words and whole phrases in any language and to use them in keeping with the situation. A jacquot brought to England by a retired boatsman of a merchant ship screamed 'Drink!' when the water in the trough had dried out, and said 'Give me lettuce!' when it wanted some vegetables. The parrot never forgot to say 'Good night!' before it stuck its head under its wing, even if there was no one in the room to answer it.

Compared with the instinctive signalling system mentioned above, such responses are a step forward, although they are inferior to human speech. They are merely conditioned reflexes, like the usual salivation of a dog hearing the jingle of the metal bowl and seeing its master pour the broth into it.

Are there any more sophisticated forms of communication between animals?

American scientists have recently been perplexed by the behaviour of dolphins. Two animals who lived in the same pool were taught to push the left-hand lever when shown a certain pattern, and the right-hand lever when they saw a different pattern. Then a partition was put up in the pool. The dolphin which stayed in the right-hand part of the pool could see the patterns displayed but was unable to reach to the levers. Its companion in the left-hand part of the pool could push the levers to its heart's content, but did not see the pattern that was displayed to stimulate the pushing of the levers.

The first staging of the familiar test after the partitioning of the pool amazed those involved in the experiment. The dolphin in the left part, which did not see the signal patterns, unmistakably pressed the correct lever: the other dolphin communicated to its companion when and which patterns were displayed.

The dolphins used sound signals. These signals have been recorded on magnetic tape. The nature of this acoustic information, however, remains unclear. Does the right-hand dolphin emit its sound responses spontaneously like the dog which sees its master through the window, or do the dolphins actively inform one another about their surroundings? If the latter hypothesis holds, this would mean that the signal responses of dolphins are closer to human speech than those of any other animal.

The diversity and strict specificity of sound signals have naturally given rise to comparisons. The similarities between the voices of different animals are sometimes purely accidental. An unexperienced town-dweller would have the shivers if he happened to be in a wood at night, when the harmless and elegant roe deer are celebrating their wedding. The unexpectedly strong voice of the enamoured male greatly resembles the roar of a large predatory beast. Is this resemblance absolutely accidental? Perhaps, Nature was not all that absent-minded when she made the roe deer's call attractive to the female and deterrent to any other beast. In what other way could she possibly protect these defenceless and at other times extremely shy and inconspicuous creatures that have no means of defending themselves?

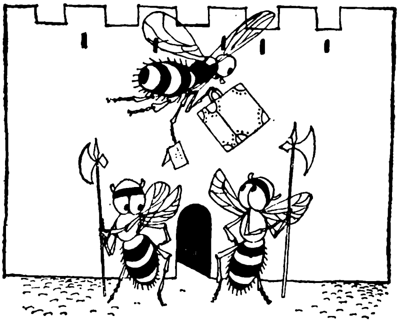
'Purposive' simulation is encountered much more frequently. Wasps are dangerous to attack, so it is good for other creatures to imitate them. Such gifted actors do, indeed, exist. In places where wasps usually live one can often find large flies. A wasp in flight buzzes with its wings, making 150 strokes a second. The flies buzz very much like the wasp, making 147 wing strokes a second. This resemblance is sufficient to confuse their enemies, while the flies have sufficiently keen ears never to take wasp for a fly and approach it with an amorous proposal.

A bee-hive is an unassailable fortress. Even the bear, the only animal that is brave enough to attack the bees in open battle, is often put to flight by their well-knit family.

Day and night guards are on the alert at the entrance to the bee-hive, ready to repulse any intruder. It is almost impossible to sneak unnoticed past these vigilant sentries. The smell of honey is enticing, but the entrance to the bee-hive is closed.

This is why naturalists always wondered how the large sphinx *Acherontia atropes* can get into the bee-hive. The wings and belly of the sphinx are coloured black and yellow, and the back has a pattern of yellowish-white spots resembling a skull and cross-bones. In the bee-hive, the sphinx gorges on huge amounts of honey and gets out unpunished, so drunk and heavy that it can hardly fly home. The sphinx emits peculiar sharp sounds, with which it enchants the sentries in the bee-hive. To a bee's ears these songs sound like the Siren's sweet music did to Ulysses' companions. The secret of this miraculous power was recently disclosed: the sphinx was found to imitate the 'voice' of a young queen bee.

Without a queen, bees feel like orphans. When a part of the swarm leaves its hearth and home together with the old queen, the bee-hive is plunged into despondency. But in a few days the young queen hatches from the cocoon, the spell is broken and everything is changed in the bee family. The young queen almost immedi-



ately sets out on her tour of the bee-hive. Briskly she runs all over the honeycombs and sings, heralding her enthronement to the swarm.

The sphinx imitates the song of the newly-hatched young queen. This sounds like a magic spell to the bees. Taking advantage of the temporary embarassment, the sphinx climbs up on to the honeycomb, sucks as much honey as it can, and hurries from the bee-hive before its bewildered population has time to regain their senses.

Sound imitation is also practised by other animals. These phenomena have still been insufficiently explored. We know that imitation of sounds is more frequently observed in aquatic animals, for whom sounds are, in general, more important than for land dwellers. Predatory beasts practise sound imitation to steal up on their unheedful prey. These, in turn, mimic stronger animals to deter their enemies. Ultrasounds are often used for this purpose which puts additional difficulties in the way of human exploration of this curious phenomenon.

Nocturnal animals make as wide a use of echoes as of any other sound signals. The principle is simple: the sound wave emitted by the animal is reflected by the objects it meets on its way and returns to the animal. The time the sound wave takes to come back tells the animal the distance from the object, and the type of the echo gives it an inkling as to the object's properties.

Almost all higher animals possess a capacity for echo sounding. A blindfold dog learns not to stumble against the walls and larger objects within a few days. Its trained ear easily perceives the sound of its own steps reflected from solid surfaces. Longer training enables it to by-pass even small objects.

Man can also use echo sounding. People born blind have an extremely well-trained ear, and they even learn to avoid slender trees guided by the sound of their steps or cane. Compared with dolphins and bats, this is but a rough type of orientation, but the nature of the sounds a man can use sets a limit to the accuracy of reaction.

Fish employ a similar method of orientation. Their movement produces local compressions which spread into all directions like waves. Their reflections from close objects are detected by a special organ in the lateral line possessed by all fish and urodele amphibians. Such vibrolocation (the waves produced by fish do not give sounds) helps them negotiate underwater obstacles, even at night.

To improve the ability to locate objects, Nature had to reconstruct the sound-producing organs in animals. First, in contrast to acoustic communication with other animals, location does not require that sounds be sent on all sides. It is much more expedient to send a tight bundle of sound waves strictly in one particular direction. Secondly, not every sound is fit for location purposes. To reflect well from an obstacle a sound wave must be one-half or one-third of the size of the obstacle. That is why short waves are as a rule used for location.

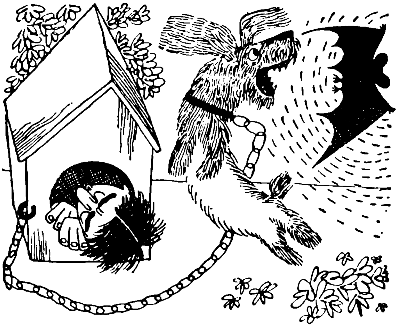
The most famous of all birds which uses echo sounding is the guacharo, or oil, bird living on the islands in the Caribbean sea and in Latin America. It is a large chocolate-coloured bird with white speckles. Its wing-spread reaches almost a metre, and it bears a great resemblance to a large hawk.

The guacharo is a nocturnal bird. All day long it stays deep in dark caverns, where it builds its nest on an inaccessible ledge. After nightfall the bird flies out to feed on fruit of tropical palms and returns home before daybreak. It sweeps safely and swiftly in pitch-darkness trough the meandering underground tunnels, never bumping against a wall or a jutting rock. The bird finds its way by means of echo sounding.

On the flight the guacharo emits frequent short sounds in the frequency range of 7,000 cycles a second, that is perceivable by the human ear. The speed of sounds in air is known to be 340 metres a second, that is twelve to fifteen times the speed of the bird in flight, so that the sound message always has time to reach the obstacle and return to the guacharo. The bird gets timely and exhaustive information about its path in front of it. The salangane and some other nocturnal birds employ echo sounding for the same purpose.

Bats and dolphins use echo sounding not just to avoid obstacles, but also to find food. Therefore, they had to resort to ultra-high sounds with frequencies ranging from 40,000 to 300, 000 per second and wave lengths of one to three millimetres.

The bats that feed on fruit, berries, and larger insects sitting on branches and leaves, and the vampire bats which suck the blood of large animals, locate food with sounds of low intensity and a frequency of up to 150,000 cycles a second. The task of these animals is comparatively easy—they must find small but mostly immobile objects and they therefore use sounds of a constant frequency.



The dolphins and the bats which snatch their prey in flight have a much more difficult task to accomplish. They need information not merely on the whereabouts of the prey, but also on the speed of its movement. Probably, this is why most bats use messages with varying wave frequencies.

For example, the typical insect-eating bats (*Vespertilionidae)* hang from branches with their heads down and, like the flycatcher bird, turn their muzzle in all directions and seek their prey by emitting from ten to twenty signals a second. Each signal consists of roughly fifty acoustic oscillations, beginning with a frequency of 90,000 and ending with 45,000, so that there are no two identical frequencies within a message. Having detected potential prey, the bat brings the frequency of impulses up to 200 per second, reducing the duration of an impulse to 0. 001 second.

It has been suggested that, to establish the direction of the victim's flight, the bat measures the change in the sound wave of the echo in relation to the wave length of the locating signal. If the prey is moving towards the bat, the reflected waves become shorter. They are as though compressed by the flying prey, and the higher its speed the more compressed are the reverse waves and the higher the frequency composition of the echo. If the victim is moving away from the bat, the waves of the echo will be the longer the faster it is flying, and the lower is sound that will reach the persecutor's ear.

The bat's echo sounder is so perfect that it can distinguish between equal pieces of velvet, emery paper and plywood. Every object reflects sounds in its own peculiar way. Smooth surfaces reflect sounds better, while rough and soft surfaces damp them. This explains why bats sometimes get entangled in a woman's hair. They mean no harm to its terrified owner but just occasionally run into her fluffy tresses, because they received no echo from it.

The insects that the bats feed on were wise enough to guess in good time about these specific traits of sound reflection. They understood how they could make themselves invisible. It is not because of the chilly night air that the bodies of most nocturnal moths and even certain bugs are covered with dense and soft fluff. The echo they produce is so feeble and vague that the bat may pass its prey without noticing it. If the moth, moreover, is furnished with a sound receiver tuned into the wave of the noctural pirate's locator, its chances of survival are even greater. The insect need only fold its wings and drop like a stone into the grass.

The bat's miraculous locator permits it not only to find its bearings in the air, but also to 'X-ray' denser media. Some bats like to eat fish. They fly close to the water surface, sending their sound signals dounwards. Receiving the appropriate response, they quickly put their paws into the water and pull out their prey.

Scientists had to contemplate a great deal in order to understand how the bat can do it. First of all, the sound signal is partly reflected from the water surface and the resulting echo is greatly dispersed by the air. Moreover, the acoustic properties of the water and the body of the fish which contains 80 per cent water are so similar that the sounds emitted by the bat can hardly be reflected from the body of the fish. So it is, indeed. The fish is 'invisible' to the bat, but it has a small swim bladder filled with gas. It is this bladder that betrays the fish. The bat sounds the water with its locator and easily detects it.

Polar whales and seals are prodigies in echo sounding. For the greater part of the year they have to get fish from under ice covered with thick snow. Throughout the long polar nights, the underwater world is not even lit by the Aurora Borealis. Naturally, they have to rely on their ears.

Wood mice, shrews and many other animals also make use of echo location, but we cannot hear their sounds.

Have you ever observed a bat in captivity? Did you notice that a bat never flies up all of a sudden. Before taking to wing, it pouts with its lips and moves its snout about in the air, each time making a circle of a greater radius.

Many bats send their locating signal not by the mouth but through their nostrils. Formerly naturalists never supposed that a bat could make sounds. If our ears were at least like those of a dog, we should be able to hear something of them. The vampires that attack man, horses and cattle are seldom lucky enough to relish a dog's blood. Apparently, their locating signals wake up the dog and it stands up for itself.

A Personal Refrigerator

A STRANGE GLAND

When reading the works of the ancient scholars, one cannot help being surprised at the number of scientific discoveries that were made merely as the result of observation and subsequent conjecture. More than two thousand years ago, scholars and physicians possessed quite a profound knowledge of how most of the human organs function. Nevertheless, they did not even suspect the real function performed by the brain. Strange as it may seem, Aristotle, a prominent Greek scholar who lived in the fourth century B. C., considered the brain to be merely a large gland for cooling the blood. Now we know that the brain is by no means a refrigerator. We also know what purpose this so-called 'gland' serves, but the way it operates still remains largely a mystery.

The human brain has developed as the result of long evolution of the nervous system which originated in the primeval oceans, when individual biomolecules finally merged to produce little conglomerates of living matter. Those primary living particles, as well as the subsequent more complex single-celled organisms which settled in large colonies, already possessed two main properties, irritability and conductivity, i.e. the ability to transmit excitation to neighbouring cells.

Later, in many-celled animals there emerged a differentiation between these functions. The coelenterates were the first to develop special nerve cells with a high degree of irritability and conductivity. The function of these cells was to become ever more sensitive to external influences and to transmit the excitation to those cells or organs which could react in a way beneficial to the organism.

The nerve cells in primitive coelenterates are joined together by their processes to form a nerve network, the most primitive type of nervous system. The next improvement was the emergence of separate clusters of nerve cells, with their subsequent development into more organized and more compact nerve strands. These came into existence wherever the co-ordinated action of many contractile elements was required. Such clusters form the nerve rings encircling the umbrella of a jellyfish, and cause the whole umbrella to grow limp or tighten up (i.e. to open or close), thus enabling the creature to move actively in the water.

In flatworms, the descendants of the coelenterates, all the nerve cells are concentrated in the form of strands arranged like braiding around the body in intricate patterns. Numerous constrictions between the strands, as well as the sites where the nerves come into direct contact, ensure the co-ordinated functioning of the entire nervous system. A diffuse network of nerve strands was undoubtedly an improvement compared with the network of randomly scattered nerve cells. However, this barrel-like nervous system proved too cumbersome and intricate to control the functions of the animal's separate parts and organs, and a new organ was required to direct its operation.

Such a central organ first appeared in the higher representatives of flatworms. It consists essentially of nerve strands with numerous nerve cells, aggregated into masses which are known as ganglia. These ganglia not only assumed the most difficult functions but also influenced the work of other parts of the nervous system. Ganglia are primarily to be found near the sense organs, the eyes, the organ of equilibrium, and also near the gullet with which the flatworms catch their prey, hold it and push it into the intestine.

The nervous system of the ganglionated type proved to be very convenient. In segmented worms, which must be descended from the flatworms, all the nerve cells are concentrated in the ganglia, while the nerve strands connecting them hold only the long processes of these cells. Practically every segment of the worm has a pair of ganglia connected to each other. Besides, each ganglion is linked through the nerve strands with the corresponding ganglia of the preceding and following segments. This nervous system bears a close resemblance to a ladder. The anterior pairs of ganglia are the largest. They carry out the most important functions and have command over the rest of the nervous system.

In higher worms, the ganglia come closer together, making up a single, compact formation. Their nervous system has some features characteristic of that of contemporary vertebrates.

We do not know what the brain of the first vertebrates was like. The lancelet, one of the most primitive representatives of the chordates, has only a nerve cord, but as yet no cerebrum. This part of the brain first appears in the cyclostomes (lampreys and hagfish) and in fishes.

In these primitive animals the brain is divided up into the same sections as the brain in human beings. These sections are the same, but their structures and, what is more important, their functions essentially differ. The fore-brain is the main organ controlling the mental processes in a human being. All it does in lampreys and fish is to analyse olfactory stimulations. In amphibians, the functions of the fore-brain are somewhat more complicated.

When amphibians left the water, they had a great many problems to face. In particular, their sense of smell became less acute. Fishes can perceive the odours of substances dissolved in water. In order to differentiate between smells on land, the pioneering amphibian had first to dissolve the odorous substances in some fluid present in its nose. Its olfactory receptors could not immediately adapt to the new conditions and its fore-brain, receiving no information to digest, remained idle, as it were. This is, apparently, the reason why the fore-brain in the amphibians assumed another function. It began to help in analysing visual, auditory and, perhaps, many other stimuli. For the first time a division of the brain appeared which dealt with all sorts of information.

In mammals the brain developed particularly rapidly. First, it developed individual zones, which were not as yet strictly differentiated. Each zone was responsible for the analysis of a certain kind of stimulation—visual, auditory, olfactory, or skin irritation. Higher mammals developed small islands of so-called association cortex, which lay between the analysing zones. These zones continually grew and progressed in the course of the further evolution of the brain. In apes and humans they occupy a large part of the surface of the cerebral hemispheres. It is not difficult to guess that it is these zones that perform the most involved, purely human mental functions.

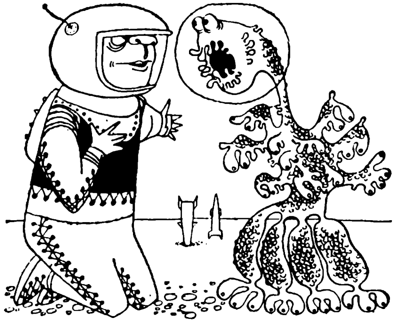
THE FUNCTIONS OF THE BRAIN CONVOLUTIONS

The human brain is the greatest wonder Nature has ever wrought on this planet. Science was unable to cope with its astonishing complexity till the twentieth century. The great Russian physiologist Ivan Pavlov and his numerous disciples were responsible for the first major achievements in the study of the brain. Pavlov's success may be explained by the fact that he fortunately chose to study a phenomenon which, on the one hand, could be regarded as a simple physiological act and investigated by conventional physiological methods of research, but which was, on the other hand, a psychic phenomenon. Moreover, this phenomenon was later found to be the very elementary psychic act which, according to Pavlov, provides the cornerstone of the immense edifice of mental activity and became known as a conditioned reflex.

It would be an exaggeration to say that the theory of conditioned reflexes was generally recognized from the very start. The older generation of scientists have not forgotten the time when very few people believed that it would ever be possible to comprehend the extremely involved functions of the human brain. The situation has changed since then. But even now there are still those who doubt that mental activity is based on any more than systems of conditioned reflexes (or temporary connections), that is on extremely simple reactions in the organism.

Our brain doubtlessly has many mechanisms of mental activity so far obscure to us, but they are all dependent on conditioned reflexes.

Any cell in the body, and, of course, any single-celled organism, is more or less capable of retaining traces of the previous stimulations and modifying its reactions according to past experiences, that is it is



capable of associating one event with another. This function is more pronounced in the nerve cells whose development made it the prerogative of the nervous apparatus.

Associations are established when two events—one important for the organism and the other inessential—coincide in time. If a dog hears the rattle of its bowl each time before it is given food, it will very soon develop a conditioned reflex, and the rattle alone will eventually be sufficient to evoke salivation and the other reactions previously caused only by food.

Conditioned reflexes are a summary of elementary knowledge of the world around the animal. They reflect the basic laws governing the animal's environment. When the feeding process is preceded by the rattle of a bowl, and this happens several times, the dog develops a conditioned reflex which means that the animal has 'noticed' the interconnection of the two events. The conditioned stimulus (the rattle of the bowl) has become something like a signal for the second stimulus, and can now evoke all the responses that were formerly only induced by food.

The signalling activity (the formation of temporary connections) is a universal phenomenon common to all animals on our planet. Moreover, there are grounds for believing that this principle is even more universal and valid for any organism, so that even on other planets we may find animals with temporary connections. There is every reason to assume that the formation of temporary connections is one of the basic and universal laws of Nature, inherent in all forms of highly organized matter. The specific properties of temporary connections can, of course, vary in each particular case.

The animals on our planet possess a marvellous adaptation mechanism which helps them to study their environment and accumulate knowledge throughout their lives. This mechanism partly depends on the functions of the sense organs. Their characteristic feature is that they soon become 'accustomed' to stimuli of continuous action and stop responding to them, but react at the same time very actively to all new stimuli.

This is probably a phenomenon with which everyone is familiar. If you go into premises from outside and smell a pungent or offensive odour, within a few minutes the odour ceases to irritate you. Your nose becomes accustomed to the odour and stops sending messages about it to the brain. But, if you leave the room for a short time, and then come back again, you are immediately aware of the odour again.

Owing to this feature of the sense organs, the brain always receives information on all the new events occurring in the environment. Besides, every new stimulus evokes the orienting reflex, which helps the organism to prepare for any surprise. If a new stimulus, inessential to the animal, is followed by some important events, a conditioned reflex is formed, and the new stimulus becomes a signal announcing the coming of an important event.

Certainly, the formation of simple temporary connections is not the only function performed by the human brain. Feeding, defensive, sexual and other conditioned reflexes in lower animals are but the most important responses of organisms to their environment. At a certain stage in evolution animals developed the ability to form temporary connections, even as a result of stimuli which have no direct significance for the animal. This faculty is already to be found in reptiles, but it is completely developed in birds and mammals. It greatly extended the boundaries of the cognitive activity of the brain because such temporary connections can reflect any stimuli in the environment which occur regularly.

Indeed, by forming numerous temporary connections between the individual stimuli or their complexes, we form mental images of the world about us. Such systems of temporary connections, which are not directly manifested in outward responses, constitute the basic reserve of man's intellectual activity. Any stimulus, which is part of a complex of this sort, can set in action long chains of interrelated temporary connections.

Both man and animals are able to form temporary connections. The difference in this ability, if any, is quantitative rather than qualitative. We became human beings owing to speech. Only direct stimuli—olfactory, taste, thermal, auditory, or visual—can become signals to an animal. It is different with man, who, besides these stimuli, can use word substitutes for them. Words have become signals of these signals (this is why physiologists refer to speech as a 'second signalling system'). The form in which words are perceived is not important: they may be heard, or seen in reading, or even sensed tactually (for example, Braille's alphabet for the blind), and kinesthetically, in the case of internal sub-vocal speech (the sensations in the muscles of the tongue and the throat when we are speaking).

Man enjoys two advantages due to speech. First, it permits information to be processed in an essentially new way.

Even a simple conditioned reflex involves a high level of generalization and abstraction from reality. For instance, when a dog develops the conditioned food reflex in response to the rattle of a bowl, this implies a sort of generalization of the sound by its relation to food. At the same time, there is quite obvious abstraction: the sound can now induce the food reflex, but does not thereby become food.

The stimuli of the second signalling system, i.e. words, provide for a much higher degree of generalization and abstraction than those of the first signalling system. Speech has enabled man to manipulate concepts instead of images and sets of stimuli, and this greatly simplifies and promotes process of cognition.

Secondly, man's speech helps to establish new temporary connections. Moreover, the second signalling system is responsible for the formation of the bulk of man's temporary connections, even without the participation of the usual stimuli. Unlike animals, man does not need to become familiar with this or that phenomenon every time for an association to come to mind. By means of speech, we continually establish associations. This has brought about very favourable conditions for exchanging knowledge with people, thus reducing the time required to learn the basic laws of the world about us. The invention of writing further simplified this process by making personal contacts inessential. It allowed people to store the knowledge accumulated for a long time and hand it over not only from one man to another, but also from one generation to the next.

DELAY SPELLS DEATH

Some thirty centuries ago, on the Peloponnisos peninsula, which is the southermost part of modern Greece, there existed a powerful and militant state, called Sparta. It was ruled, as many other states of that time, by a king. It so happened that once the throne of Sparta was inherited by Charillus, who was still a minor and, quite reasonably, could not enjoy much authority. So the country was ruled by Lycurgus, his uncle, who become regent and guardian of his nephew. In this high post Lycurgus made many enemies and later had to leave Sparta.

His years in exile were not wasted. He had a great deal of time to see things and think about them. Lycurgus travelled about Asia Minor and Egypt. He visited Crete and came back to his country with the draft of a new constitution. According to Lycurgus' constitution, the state was to be headed by two hereditary kings of equal authority. These were to be assisted by a council of elders made up of twenty eight elderly citizens of Sparta. Moreover, the most important problems were to be discussed at the assembly of citizens, and each citizen of thirty and over had the right to vote. Lycurgus' law envisaged the redistribution of property among the country's citizens on the basis of equality and many other democratic innovations.

According to legend, Lycurgus made his countrymen promise not to make any alterations in the laws before his return from a journey. He then left Sparta determined to starve himself to death in voluntary exile. Before death, he ordered his body to be burned and the ashes scattered on the sea. This was to prevent the Spartans from taking his remnants back and, consequently, to keep them bound by their oath to preserve his constitution inviolate forever.

Most of Lycurgus' laws are certainly models of human wisdom. The most essential thing for us is that the laws paid special attention to people's physical development. In this connection they minutely regulated the mode of life in Sparta. By an ordinance of Lycurgus private property was limited and the country's citizens were to pursue a healthy and moderate life. The Spartans' liability to military service continued till their death and they had to take an active part in all the wars waged by the state. They were forbidden to pay much attention to their home life. They were to dine only in sisitias (dining-rooms or clubs). Until their seventh year Spartan children were educated in state schools under the supervision of experienced tutors. The severe system of training in Sparta became proverbial.

Lycurgus seems not only to have been able to create and justify the theory of education but also to propagate his ideas expertly. The legend goes on to say that he once took two puppies from a dog and placed them in a deep pit. No one entered the pit and the dogs' food and water were lowered to them on a piece of rope. Two other puppies from the same dog were left by Lycurgus to grow up in freedom and were allowed to keep company with other animals and people. When the puppies grew up Lycurgus gathered a large crowd of people and staged an interesting experiment. He let a hare free in front of these dogs. According to Lycurgus' expectations the puppy which had grown up in freedom chased the hare, caught and killed it. The other puppy which had grown in the pit behaved quite differently. Instead of helping its brother, it fled from the hare. Can there be any more convincing demonstration of the significance of education in forming the character? If the legend is true, Lycurgus should be considered the founder of experimental pedagogy.

Lycurgus did, of course, have disciples. Scientists and educators long ago paid attention to the significance of the child's early years in the formation of its future personality. Adherents of Lycurgus are also to be found among our contemporaries, too, but, unfortunately, not a single state has run the risk of making education compulsory for very young children.

All parents, of course, love their children, and do everything to guard them against life's difficulties, danger or adversities, all kinds of diseases and fatigue. Can we really expect the parents to act differently? To love one's child is quite natural and understandable, and it is difficult to think of parents treating their children otherwise. However, parents frequently overdo it and in this way do irreparable harm to the one who is most dear to them.

Experiments have shown that rats can endure hunger, thirst and cold more easily if they were subject to mechanical or electrical stimulations, or periodically exposed to cold when they were very young. By influencing the organism of very young farm animals, it is possible to modify some of the functions of the organism. It is not uncommon in agricultural practice to place the newborn calves, lambs and kids in a cold environment. This leads to stable thermoregulation and increases resistance to the cold in adult animals.

Our children would no doubt gain from similar treatment. But far from hardening them up we often prevent them from gaining experience by not allowing them to face even the tiniest difficulties in life. Parents usually guard their children against everything, thinking that they can learn to cope with life's problems later on, when they have grown up and are a little wiser. This is really so awful that it makes one want to shout, 'Good people, grandmothers, grandfathers, parents, what are you doing to your children?

Why do you interfere in their normal development?'

This alarm is not without good reason. Every skill should be developed at the time when it is acquired most readily and more often than not does not form at any other period in life, no matter how hard you try. True, we still know very little about the way in which children develop, but we have sufficient information on animals. All the newborn of both lower and higher animals have very accurate and detailed programmes of behaviour, without which they would not survive. All mammalian young know how to suck. All young birds hatched in broods can open their mouths wide for their parents to feed them. Ducklings, goslings, chickens and the young of many hoofed animals are all able to follow their mothers from the moment they are born. All young know how to seek shelter in moments of danger.

All these complex acts of behaviour do not just occur, but are evoked by quite definite stimuli. The young of all members of the cat family (lion cubs, tiger cubs, kittens) as well as those of the dog family (puppies, wolf cubs, fox cubs) begin to take milk as soon as their little snouts feel their mother's fur. When the young of the hoofed animals sense a shadow, they raise their heads and are ready to suck. In natural conditions this occurs each time the mother stands over her young. The same is observed in birds: the nestlings reflexly open their mouths whenever the approach to the nest is obscured, or the nest is shaken slightly. And if the parents give an alarm call, the young will take cover.

Nature has worked out detailed programmes of behaviour for each animal but has consciously left numerous gaps. For example, the lambs of the Central-Asian sheep *(Ovis ammon)* automatically follow moving objects, but they have no idea whom in particular they should follow. This is not merely by chance, for if the programme of behaviour were rigidly fixed in every detail, further evolution would be impossible.

For instance, if the same sheep were to undergo positive mutations resulting in a change in colour (all over or only in part), length of coat, or size, the new qualities would have no chance of being inherited if the newborn lamb had a fixed idea of its mother's appearance. The lamb would not recognize a mother who had changed even slightly and would refuse to follow her. This of course would mean its losing its mother and would eventually result in death. Consequently, the lamb would not pass on the new trait gained by mixed breeding. To avoid this happening, Nature made sure that lambs could learn to recognize their mothers, which they have to do quickly if they are not going to be left without mother. Indeed, knowledge of this kind is gained in the twinkling of an eye, so to speak, and is preserved for a long time, sometimes for the rest of its life.

This method of learning is known as imprinting. It only occurs at one particular period in life. A newly-hatched duckling will acknowledge as its mother the first moving object it sees and will follow it irrespective of whether it is a duck, a football, a puppy or a mechanical toy. If it follows a moving object for the first five to six hours after hatching, it will develop a marked attachment, whether it be for its own or its adopted mother, but this attachment will not be lasting. The best imprinting takes place between the thirteenth and seventeenth hour after hatching. At a later stage, for example, in a thirty-hour-old duckling, imprinting is impossible and it will be an orphan for the rest of its life, although living side by side with its parents.

The ability to follow somebody or something is a complex reaction. The young do not merely have to run after their parents, but must follow them at a definite distance so as to see their mother at the right angle. This is why a gosling will follow mother that is much larger than a goose at a distance, and will run right behind an adopted mother that is rather tiny.

A quite convincing experiment was carried out by Konrad Lorentz, an Austrian zoologist, who himself pretended to be a 'mother' to some goslings. While Lorentz strolled about the garden, the goslings followed him at a respectful distance, but as soon as he entered the pond and began to immerse gradually they came right up to him and when nothing but his head was showing above the water, they even tried to climb on it.

One can cite many examples to prove that the whole life of an animal can be ruined if it has not been taught, properly at the right time. An adult sheep will never join the flock if orphaned when very young, nor will it be able to conform to the laws of the flock. Neither will the lamb ever make contact with other sheep of its kind or start a family. In fact, it will be a useless animal. Australian sheep-breeders are well aware of this and mercilessly kill lambs which lose their parents.

Another impressive example is that of the dog, the first animal to be tamed by man and his most unselfish and devoted friend. It is not without reason that M. Gorky wrote: 'We know that a dog is often more honest than a dear friend. . . .'

You may think that this friendship gradually developed during the thousands of years that dog has kept company with man, but this is not so. Our friendship with the dog is largely due to that same phenomenon of imprinting. If a puppy grows up without the sounds, images or smells characteristic of man, it will grow to be, at best, a well-tamed wolf. Such a dog will never trust a man completely or become his friend.

The dog, man's closest ally, has played an important part in the formation of the human race, a part which is difficult to overestimate. It would be difficult to imagine how the development of human society would have been retarded had the dog not been endowed with this wonderful characteristic which enables it, even when very young, to establish contact with others of its own species and with animals in general. One cannot but agree with Modest Bogdanov, a Russian zoologist of the 19th century, who was quite right when he said that it was the dog that gave man a start in life.

Many of the habits of animals are cultivated in such intricate ways that we often think them to be inborn. Nobody teaches the bird to build its nest but, if the young grow up in a cage with smooth perches, they will not become good nest-builders. Things are different, however, if the smooth perches in the cage are replaced by rough, crooked or knotted twigs and branches from a tree. The birds will jump about from morning till night training their legs in fine well-coordinated movements which will help them later on when they start to build their nests.

The same can be said about birds learning to sing. The ability to sing is an inborn reaction, but to be a good singer a bird must hear at least once the voice of its own kind. If a bird grows up without the company of its own kind, it will not sing like the rest of its species. Learning to sing also seems to be a matter of imprinting.

Certain species of sea fish are hatched from spawn laid in fresh water, i.e. in rivers and lakes connected to them, and they spend their childhood there. In adolescence they go down to the sea, sometimes swimming thousands of miles away from their native waters. They often spend many years in far-away seas, only to come back to their native rivers when they are fully grown. How they find their way in the ocean is a special problem, which has as yet not been adequately studied, nor is it related to the present chapter. What scientists do know is how the fish can recognize their native river, and why on their way upstream they confidently turn into the tributary where they spent their childhood, and even into the brook where they were born. It turns out that every river has a characteristic odour, depending on the plants and animals which inhabit it. The odour of the plants and animals merge to create a unique aroma peculiar to one river only. The fish remember this aroma for years. This is a striking example of imprinting.

In the lives of our own children, too, some periods are especially opportune for acquiring certain important skills and habits. Scientists believe that imprinting has something to do with the brain mechanisms which provoke a smiling reaction in tiny babies.

Children can only be taught to speak during their first six years. This seems to have been known even to ancient people. At any rate, Herodotus says that Psammetichus, an Egyptian king, founder of the twenty-sixth dynasty, who lived twenty five centuries ago, decided to find out which people was the most ancient. He ordered that two newborn boys of simple peasant stock be given to a shepherd to bring up. The shepherd was strictly instructed not to speak in the presence of the children or allow anyone to see them. The children had to live in an isolated hut all alone. The only person allowed to see them was the shepherd who would come with his goats at definite times to feed the boys with milk and do for them what was absolutely necessary. This cruel experiment was contrived in order to learn in what language the children would speak their very first word. This was to show which people was the most ancient.

Twenty centuries later a similar experiment, but on a somewhat larger scale, was conducted by Jelal ud-din Akbar, a ruler of Hindustan. He had an argument with his courtiers, the subject of which was what language had been spoken by the 'earliest people'. He resorted to the same method as Psammetichus: he ordered his servants to take twelve newborn babies from their mothers and isolate them in a tower. So that they should not die Akbar gave them dumb wet-nurses. For twelve years the children were not to hear a single word.

At the end of this time, Akbar decided to test the children in public. For this purpose he invited experts who spoke different languages: Jews, Persians, Hindus, Arabs, Chaldeans and many others. However, the result anticipated was not achieved: the children did not speak any existing language and were only able to utter inarticulate sounds and communicate with each other by means of gestures.

It is difficult to say whether this legend is based on real facts or not. The results of the cruel experiment tend to make us think that it really took place. At any rate, all cases now known to scientists, where children have grown up isolated from adults and deprived of verbal contact in early life, have resulted in their not being able to speak any language. Of course, this has long ceased to cause surprise that children who had grown up in strict confinement are completely unable to speak. It has long been established that children learn to speak from grown-ups. What is astonishing is that such children never managed to master human speech, even later on, and remained mentally retarded throughout their lives.

Now it is an established fact that children only learn to speak during the first six years, and lose the ability to learn later on. If a human being masters one language in childhood, later on he can acquire knowledge of another one, and then of a third, and sometimes he can, in fact, learn dozens of languages. But if the years which are the best for developing speech are missed, the damage is irreparable and the efforts of even the best tutors will yield very poor results.

There is a widely used aphorism by the French statesman Talleyrand that 'speech was given to man to disguise his thoughts'. This is not, of course, without a certain amount of truth, but actually man has an inborn necessity to exchange ideas. Remember Akbar's experiment with the children who lived in a tower for twelve years and explained themselves with gestures. This is still further proof that the legend is based on actual fact. At any rate, when two or more children were brought up together without verbal contact with humans they invariably worked out their own language which, of course, had nothing to do either with their mother tongue or any other tongue. In most cases it was a language of gestures and primitive sounds.

In one of the cases studied in detail, the language invented by the children comprised twenty-one basic gestures with combinations and variations to allow the children to convey practically all the information they could possess at their age. It is interesting to note that children who have elaborated their own language of gestures are nearly always incapable of learning a spoken language, until they have been separated from one another and cannot communicate with one another in the manner they are used to.

The first few years of life are especially important, because during that period the child's brain is growing. It is the time when the relationship between the brain cells is being finally formed and the brain is, consequently, most subject to changes.

When in the company of adults, the child can master its mother tongue easily and naturally. If the people around him speak several languages, the child will also master them. But if a child does not have such an opportunity, he will have to work hard for years at school and later on at an institution of higher education in order to master a foreign language. But, as a rule, he still does not speak the foreign language fluently. That is why the children should be taught foreign languages as early as possible.

WHEN ONE IS CRAZY ABOUT FRENCHMEN

Elisaveta Drachinskaya was not only a charming woman and a skilful surgeon, but also a brilliant lecturer. She was a keen horsewoman, and also a no less fervent admirer and connoisseur of literature and art. Her extraordinary erudition in all fields of knowledge made her lectures extremely interesting. It is no wonder that they were attended not only by students from all courses, but even by teachers and physicians.

Drachinskaya was especially well versed in the achievements of French science and culture and was a sincere admirer of the talented people of that great country. When lecturing, she never missed an opportunity to mention the achievements of France's greatest scientists, and not only those of scientists. In fact, she mentioned almost every one. For instance, when she was speaking of asepsis, she naturally dwelt on the works of Louis Pasteur and his colleagues; then she logically went on to talk about the Sorbonne; this was followed by a sudden turn which brought her to Jean Paul Sartre or Louis Aragon: she always found surprising links between science and art.

The audience was invariably spell-bound by such lyrical digressions. Neither the lecturer nor the audience seemed to notice the time pass, and it was not until the bell rang that Elisaveta Drachinskaya used to cut herself short, smile timidly and say, 'Oh, I'm mad about Frenchmen'.

Physiologists term this phenomenon which makes our thoughts repeatedly turn to one and the same subject a 'dominant'. To put it simply, for various reasons, a site of highered excitability develops in the brain which, apparently, attracts all the impulses of excitability from the rest of the brain sections and thus intensifies its own activity.

Everybody has more than once experienced the action of a dominant. When one is engaged in interesting and important work, such as preparing for an examination or rehearsing a part for a new theatre performance, it is quite often difficult, or even impossible, to switch over to something else. This is an important feature of the brain's activity that allows us to concentrate our resources on the task which has to be given priority at a particular period in life.

There are many reasons why a person may be overcome by a dominant. It may be due to lofty patriotic feelings, a burning interest in one's work, love for one's sweetheart, or a maternal instinct. Producing a dominant state, these emotions enable people to use their gifts to the full, to surmount every difficulty and obstacle. Love for the people, evoking the corresponding dominant, helped the Russian revolutionaries not to give up hope in the prisons and hard labour colonies and at first opportunity to resume the struggle against tsarism. A similar dominant state helped soldiers during the World War to suppress their fear, staunchly endure cold, heat, thirst and hunger, wrestle with fatigue and to put all their efforts into defending their country.

But a dominant state is not always useful. If the reason for the dominant is insignificant, and yet it occupies the entire activity of the brain, it may interfere with more important functions.

A person may often become very biased due to a dominant state. It is sometimes rather boring to hear a young mother talk of nothing else but her baby, even in the theatre, a lecture hall, or at dinner. On the other hand, she may often draw extremely clever comparisons and parallels with regard to the baby which might never have occurred to you.

This occurs as a result of a thorough selection of information. A person does not extract much, only what is most important to him, only the wheat from the chaff, so to speak. Unfortunately, it makes no use whatsoever from the remaining information.

A dominant which persists for months or years greatly limits one's interests and makes one's development very uneven. This might be useful for your job, but, to quote a witty phrase: a specialist is like a gumboil; he is one-sided. On the other hand, a dominant focus that subjugates all weaker dominant points enables an erudite to extract from the depths of his brain immense amounts of useful information. Every routine lecture delivered by such a specialist can become a really memorable event.

The dominant is a regular occurrence in normal brain activity. Even very primitive animals are subject to dominant states, although in them it arises as a result of simpler causes, the instincts of hunger and thirst, self-preservation, or reproduction. The force of a dominant may change to correspond to the organism's needs. A strong focus of dominant excitation can subdue or subjugate all weaker dominants.

A hungry dog rushes towards its feeding bowl at every movement made by its master. The dog has a food dominant. But, if you place this dog into a new, strange environment, it will put its tail between its legs and forget its hunger. Now any sound, any new smell and the like will make it growl or bare its teeth. Finally, twice a year, when the bitch's organism is flooded by sexual hormones secreted by the endocrine glands to prepare it for bearing offspring, the dog will forget its fears, its hunger, and its master, and its entire behaviour will be concentrated on the task of reproduction.

Apart from the normal brain processes, any pathogenic process, particularly if it is localized in the cortex of the cerebral hemispheres, can produce a stable focus of pathological dominant excitation. Such a focus attracts excitation arising in other regions of the brain until its activity exceeds a certain upper level. Then the excitation starts to spread in the opposite direction, affecting the neighbouring areas. A pathological focus of overexcitation located in the anterior sections of the cortex can produce an epileptic fit.

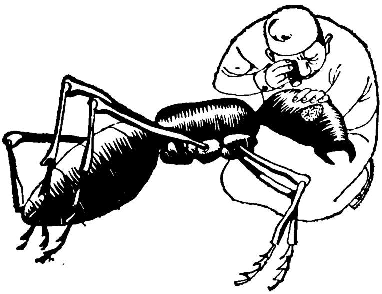
We know very little about the reason for a pathological focus of excitation, and still less about the effects of its overexcitation, even as far as the human brain is concerned. *Kuru* is a horrible disease which rages in the jungles of New Guinea. The disease only afflicts women and children. The English for *kuru* is 'laughing death'. The disease begins with a progressive weakening of the body, followed by paralysis, and then cramps of the facial muscles after which death ensues. A stiff mask of laughter remains on the face of the dead person. The cause of the disease and the brain region where its focus is localized are unknown.

We know even less about the functioning of the nervous system of animals, to say nothing of the lowest animal forms. However, it is in this terra incognita that the most interesting discoveries are to be expected.

Cows and sheep are molested by a nasty parasite, the lancet-shaped fluke, which is also dangerous for man. The parasite lives in the liver of farm animals, but its larvae can live only in the body of ants. Cows and sheep eat the ants when they are grazing and become infected with fluke. For a long time it remained a mystery how such agile creatures as ants could allow themselves to be eaten alive. Moreover, the number of infected ants may be very small, perhaps one in ten thousands, but the disease is wide-spread in cattle. How many ants must a cow eat to swallow at least one infected ant? One gets the impression that in the areas infected by the disease the cattle feed solely on ants.

The lancet-shaped fluke is hard to fight. It is difficult even to detect the infected pastures, for in order to know whether an ant carries the larvae of the pestilent parasite in its body a great deal of time has to be spent dissecting the ant, extracting the stomach, preparing it and examining it under a microscope to find the small black dots, traces of the channels which the cercariae (the name given to the fluke's larvae at a certain stage in its development) gnaw through the wall of the ant's stomach on their way out.

Recently, scientists who wished to find out what the cercariae do after they leave the ant's stomach were surprised to discover that most of them simply stay in the ant's abdomen, but at least one cercaria always penetrates into the subpharyngeal ganglion, the most important division of the insect's nervous system. The cercaria settles down there in the anterior part of the nervous ganglion between the roots of the nerves leading to the ant's jaws; there it develops into the metacercaria, which is the last stage in the larva's metamorphosis. So far, we do not know which of the cercariae goes into the ganglion, why only one of them occupies the ganglion, and how the rest of the cercariae know



about it. But, as you will immediately see, they do need to have their emissary at the headquarters of the ant's nervous system.

Naturally, scientists were eager to find out about the fate of the infected ants: the intrusion of a living being into the insect's brain must certainly affect its behaviour. For a long time no change in its behaviour was observed, until it was established that as long as the temperature of the air is sufficiently warm, the infected ants behave quite normally. They run to and fro along their favourite, traditional tracks, fetch food and building materials to their native ant-hill; in short, they take an active part in all the affairs of the ant community. But at nightfall, when it gets cooler, a cercaria-infected ant climbs up to the top of a blade of grass and clutches it with its jaws so hard that you can hardly pull it off. It remains motionless in this position until the next morning when the rising sun warms up the ground. During the morning and evening grazing the cattle eat such ants. The colder the weather the longer the torpid state of the ant and the greater the chance of the cattle becoming infected.

This discovery is as interesting as it is useful. Now, if the ants are put into a refrigerator, it is possible to detect from their behaviour whether there are any infected ones among them.

This will help in detecting the infected pastures as early as possible, so that timely measures can be taken to disinfect them, or, at least, to make sure that they are not used in cold weather when the diseased ants cannot leave their positions at the tops of the blades of grass and are eaten by the cattle.

In general, the study of the diseases of the brain in lower animals has not yet been undertaken, although all scientists agree that it is high time that this problem was dealt with.

THE SPECULATIONS AND DOUBTS OF SCIENTISTS

Modern biology is faced with the tremendous task of solving the mystery of memory. This problem is being tackled by hundreds of scientists all over the world. At present, we know next to nothing of what memory is, and what parts of the brain are involved in storing our recollections and the vast amount of knowledge that we have collected bit by bit throughout our lives; above all, we need to find out how all this information is coded in the brain. In other words, scientists must find out what paper, ink and alphabet our brain makes use of to imprint on the mind the information it receives.

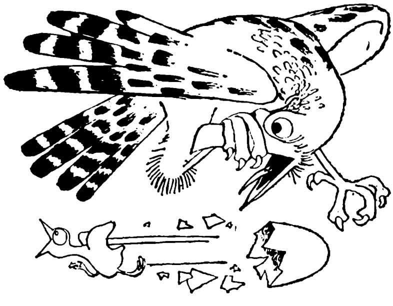
These are just a few of the numerous problems pertaining to the memory. It would, for instance, be useful to know how the information the brain needs is sorted, selected, and extracted from the stores of our memory. There is every reason to suppose that the human brain firmly retains all the information acquired, and that it is only the imperfect mechanism of extraction which is responsible for the fact that we use only a negligible part of the knowledge stored.

All existing theories on the memory fall into two categories. The first is the biochemical theory of memory, which suggests that the information in the brain is coded on molecules of ribonucleic acid (RNA), or on some other macromolecules. The first argument in favour of this theory is that biochemical coding allows practically unlimited amounts of information to be retained. The second argument, which is even more forcible, is that this method of storing information dates back to the very first moments of life and that Nature still employs it for handing on information from one generation to the next.

By this is meant the so-called genetic information, a set of very rigid rules and demands that defines what every individual belonging to a given species is to be like. This not only governs the appearance of an animal and the specific functions of its internal organs, but also determines the pattern of its behaviour. No one teaches ant lions how to build traps, lie in wait, and catch their prey; no one shows the spider how to spin its web; the female cabbage white butterfly tells automatically males of its own species from other admirers. This innate knowledge with which the animal is endowed is as permanent as other features of its organism. It was not without reason that Wagner, a Russian zoologist, suggested classifying spiders according to their behaviour instead of morphologically (which is perhaps more sensible since some species are very similar in their appearance).

The pattern of behaviour in the higher animals and even in man is partly inherited. Nobody teaches a newborn baby to suck; it is an innate reaction of its organism. There seem to be very many reactions of this sort, though relatively little is known about them.

Scientists were recently very surprised to find that newly-hatched chicks, even those hatched from eggs laid by a hen which has never seen a bird of prey, can



easily tell a predatory bird from a harmless one. When the newborn chicks were shown a moving silhouette of a flying kite (a small head drawn into the shoulders, large widely-spread wings, a long, thin body and a tail) they were panic-stricken. If the silhouette was moved in the opposite direction it looked like a duck or goose on the wing (the tail became a head on a long neck stretched forward, and the small head a short tail) the chicks were now no longer afraid of it.

This means that the image of a predatory bird is imprinted on the mind of a tiny chick, and this information is inherited from its parents with the help of a biochemical code. If the inherited image is coded biochemically, why should an image resulting from actual experience not be coded in the same way? We have noted repeatedly that Nature seldom neglects good finds. Why should it act differently this time?

According to the second theory, the process of remembering involves the formation of a new system and the building of new links between the nerve cells. Can these potential nerve contacts last man throughout his life? Can the fading of memory in old age (the ability to remember new events diminishes) be accounted for by the fact that the reserves of the nervous system are exhausted by that time? Mathematicians cannot throw any light on the subject. However, taking into consideration that the body of any nerve cell receives several thousand nerve endings, it is very likely that the nerve network of man's brain is capable of storing all the information required.

An argument in favour of this theory is that the nerve cells themselves have changed very little in the course of evolution. The biochemical processes occurring in the neurons of lower animals and man are very similar. Progress has mainly been made in the increase in the number of nerve cells and the improved organization of the nervous system.

Not everything that we know about memory at present corroborates this theory. If the larva of an insect, for example, the larva of a flour beetle, is trained to turn only to the right when moving in a labyrinth, the adult beetle will retain this habit. Hence, its memory has not been disturbed, in spite of the fact that, when the larva changes into the pupa, its body structure changes, and all the nerve contacts and 90 per cent of nerve cells are destroyed. It remains a mystery how its memory is preserved.

At present, it is difficult to say which of the two theories is correct. But, as to a conditioned-reflex memory, there is a unanimous opinion that temporary connections exist between the nerve centres, which retain recollections caused by a conditioned stimulus and a command point governing the responses to it. However, this still leaves a lot to be explained. How this connection is formed is obscure. Some scientists claim that this bond is purely functional and merely transmits excitation more efficiently through certain synapses. Others consider that the formation of conditioned reflexes is accompanied by the appearance of new contacts between the neurons due either to the growth of their processes or of new synaptic formations on these processes.

In any case, the function of the brain, or the higher nervous activity, is linked with the activity of the nerve cells. This is universally recognized and beyond doubt. This is why an article published some years ago by the well-known, American professor R. Galambos caused a great deal of controversy. The scientist argued that perception of the outer world, the formation of conditioned reflexes, memory, all the main functions of the brain, have nothing to do with the nerve cells but are associated with the glia, the tiniest cells which surround the neuron bodies and fill the gaps between their processes.

Improbable ideas are not a rare occurrence in biology, but they are usually forgotten before they gain popularity. Galambos' ideas became known even in the Soviet Union which is traditionally concerned with research on the nervous system. At that time scientists were, however, not prepared to discuss the functions of the glia elements, as they could not support their arguments with proven facts. Almost nothing was known about glia, in spite of the fact that glia cells are much more numerous than nerve cells. It was previously thought that they only supported the neurons and provided them with all they need, as the blood capillaries never come directly into contact with the nerve cells.

The idea advanced by Galambos seemed to be too groundless to last for long. It did, however, attract followers in different countries, including the Soviet Union. For example, certain Georgian physiologists have voiced the assumption that the role performed by the glia was much more important than that previously ascribed to it. Unlike Galambos, however, they do not ascribe to the glia the function of consciousness or memory, but claim that the glia elements ensure the function of closing the temporary connections when conditioned reflexes are set up.

For a long time now histologists have known that many endings of the nerve processes in the central nervous system are bare, that is they are not covered with a myelin sheath. Calculations show that the electric current coming from these bare nerve endings has to be dispersed and that they are bad transmitters of excitation to the adjacent fibres. The Georgian scientists surmised that the closure mechanism consists in that a previously bare nerve ending acquires a myelin sheath and becomes more active. The insulation is made up of glia cells whose processes entwine around the nerve fibre forming a multi-layer myelin sheath.

As yet, it is difficult to say whether these suggestions will prove correct as the study of glia is only just beginning. It is beyond doubt, however, that the investigations will result in a new approach to the physiological mechanisms underlying the basic functions of the central nervous system.

A COURAGEOUS DECEIVER

Many comparisons have been made between animals and man, and many curious names result from such comparisons: the surgeon-fish owes its name to the sharp spines on its tail which resemble surgeons' scalpels; the monk-seal is so-called because when it sits on rocks by the sea it reminds one of a monk bowing to the ground in prayer; soldier-crabs received their name from their habit of marching like soldiers. . . .

But people, too, are often compared with animals. If I call my little daughter a fox she knows that I think she is a little rogue. When she looks angry because she has been punished for naughtiness, I say 'Put down your spines, little hedgehog', meaning you have only your-

self to blame, so you need not be angry with your father.

It is a pity that comparisons with animals often cause offence. People sometimes refer to other people as snakes in the grass, little pigs, and even swine. People everywhere make comparisons with animals. In the United States of America you can hear a popular expression 'to play possum'. What is its origin? And what does it mean? Does it give offence?

The opossum is a small animal, from 40 to 45 centimetres long, rather like a rat in appearance. It has a long, pointed snout, large whiskers and a very long tail. The mother opossum carries her young about on her back, and they hold on by curling their tails around her tail.

The opossum is only to be found in America. In Europe they are only known to scientists, who are interested in marsupials or pouched mammals, for the mother opossum, like the Australian kangaroo, carries her young in a special pouch, until they are big enough to move around by themselves. But for this, the young would not survive.

In its native land the opossum is very popular and 'to play possum' is an everyday expression. If a young footballer, knocked down on the field, remains lying on the grass longer than expected, his mates shout, 'Stop playing possum', meaning, 'Stop pretending to be dead'. The boy does not feel offended, for his friends have guessed that he has hurt himself slightly and is simply joking.

It is a different matter when a class stays behind after school and tells one of its members that he is playing possum. In this case the child has every reason to feel hurt, as he knows that his mates consider him to be a cheat.

The opossum's reputation for shameless deception stems from its somewhat strange behaviour. When in danger, taken unawares by a predator, or having failed to escape its pursuer, the opossum pretends to be dead. This method of protection is not as absurd as it may seem; otherwise, the opossum would have become extinct long ago.

This undoubtedly 'psychological' method of self-defence is based on the fact that the unfamiliar causes fear or, as scientists say, an orienting-defensive reaction, in all animals. The horrified predator forgets its hunger and immediately gives up the chase.

No beast of prey, no matter how dangerous, fox, wolf, lion or tiger, ever approaches a freshly killed animal immediately, if it comes across one. The fact that the prey does not move and that its pose is unnatural frightens the beast. It goes round and round the 'dead' animal, till it is sure that there is no danger, that is till its orienting-defensive reaction has weakened. It is only then that the beast of prey risks approaching its find.

Often fear gets the better of hunger, and the tasty food remains untouched. By this means, the opossum can bide its time and escape at the right moment. It is usually not pursued, as the change from absolute immobility to rapid movement is also an unnatural phenomenon and scares the predator. The 'psychological' method of defence practised by the opossum is so effective that it sometimes helps it to escape even from the predator's teeth. Only old and very experienced beasts of prey are not deceived. The opossum then has little chance of saving himself from certain death.

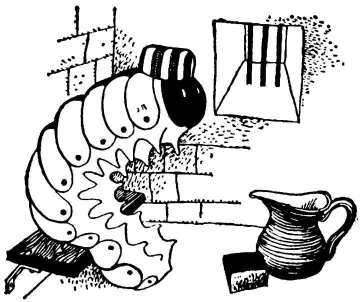
The opossum has been notorious as a cheat for centuries; but scientists have always remained doubtful of the genuineness of this deception. It was not clear whether the opossum does, in fact, feign death, or whether it merely faints of fright.

However, electrophysiologists have recently solved this puzzle. It is a well-known fact, that electrical impulses constantly originate in the brain cells. Scientists call these impulses biocurrents and they can tell by the nature of them, whether the animal is merely sleeping, or has been drugged, or is in a faint, or whether its brain is functioning normally. Biocurrents recorded at different moments in the opossum's life have shown that when it is feigning death the activity of its brain is not in the least inhibited as it is when the animal is asleep or in a state of narcosis. On the contrary, the opossum's brain is then working most efficiently. The opossum is, in fact, a deceiver and well deserves its ill repute.

THE BLUES

Can animals suffer from depression?

It has long been known that man is not the only one to suffer from depression. For example, the cob-swan laments over his dead pen and a dog frets when her puppies have been taken away from her. Pets get so attached to people that they pine when their masters



are away from home. A dog in Milan went to the railway sheds every day for twelve years to meet its master who had long been dead; it was not until the engine had arrived, the steam had been let out and the crew had left the engine that it dragged itself home with hanging head and tail between its legs. So, there can be no reasonable doubt that animals do suffer from melancholy.

This is certainly true of the higher animals, but what about more primitive creatures? Do they feel anything of the kind? How can one know the mood of a butterfly fluttering about the meadow? It is no use asking the butterfly and so the only way is to study the behaviour of different animals under similar conditions; for example, to find out how they bear solitude or behave when deprived of contact with others of their kind.

For man solitude is a dreadful ordeal. Many are the stories of the so-called Robinson Crusoes, people who, for one reason or another, have had to live on desert islands in complete solitude. Many have suffered from grave mental disorders. This is not surprising, for man is a social being.

As for the animals, those living in herds or flocks, primitive as they may be, bear solitude worst of all. Primitive creatures suffer most when isolated from other members of the 'collective'. Higher animals are somehow able to adjust themselves to solitude. Many animals find consolation in man's company. Such animals as monkeys are likely to take us, humans, for their brothers, who are a little eccentric, and get on well enough with us, managing quite easily without their own kind.

It is much more difficult for the lower creatures. We cannot keep them company. Small birds, such as kinglets and long-tailed tits, pine away in captivity and inevitably perish after a short time when kept in solitude. But, if you put a little flock of them in the cage, they are much happier.

Many fish are also sociable. A herring placed alone in an aquarium dies of depression in a few days, yet it is not a yearning for the blue sea, as was once thought, but for the company of other herrings.

Some insects, too, cannot live without company. The caterpillars of a certain type of silkworm moth, a scourge in our woods, always grow up in groups. They creep from branch to branch and from tree to tree, keeping close together in a column, eating up every green leaf on their way. But the caterpillar that falls behind and loses its way is doomed. It becomes downcast, its appetite vanishes, and its metabolism is at its lowest. It will never grow into an adult insect. But if one such 'melancholy' caterpillar is shown some of its friends, or even a dummy, through a glass, its spirits rise and its metabolism improves.

Such social insects as bees, ants and termites cannot stand solitude at all. When in solitude, or sometimes even in a small group, they stop eating and soon die. Only if the company is sufficiently large, do they begin to bring some order into their lives. With ants and bees this minimum is about twenty five individuals. In smaller numbers, being normally accustomed to their crowded communal abodes, they get really depressed.

If you were to talk to a group of North Americans who support the fight for Negroes' rights, would you not be surprised to learn that even they often regard Negroes as second-rate humans? Nowadays, everybody knows that there are no essential differences in the functioning of the muscles and internal organs. So the proponents of racist doctrine allege that the main difference lies in the mental sphere, i.e. in the functioning of the brain.

Such views stem from the great difference in the level of cultural development that existed between different nations some three or four centuries ago in the epoch of great geographical discoveries and which even nowadays have not yet been completely smoothed out. Many outstanding personalities have come from Asia, Africa, North and South America, and Australia, but the overall contribution of many nations to the progress of human civilization still remains negligible. The living conditions of these nations are certainly responsible rather than any innate inferiority. The racialists, however, claim that the different levels of cultural development prove the inferiority of non-Europeans.

Are there any real differences in the work of the brain in different human races?

The basic difference between the activity of the brain in man and animals is the use of speech, which Ivan Pavlov called the second signalling system. Speech is a purely human phenomenon and racial differences, if any, will be manifested in the brain mechanisms of speech.

Physicians have an especially vast knowledge of the activity of the human brain, for they have always observed changes in psychic responses in patients with different afflictions of the brain. They have long since noticed that if certain areas of the cerebral hemispheres are injured, paralysis occurs, and when others, eyesight or hearing is affected. A lesion of certain brain regions affects the speech most of all. When the temporal lobe of the left cerebral hemisphere is injured, a patient continues to hear speech, but cannot understand it. Injury to the frontal lobe of the same hemisphere mainly disturbs the articulation of sounds, while occipital-sincipital injuries (that is injuries to the forehead and back part of the head) affect the ability to count. Some brain afflictions interfere with the ability to write or read.

When sufficient observations had been accumulated, it was noticed that the lesions of the temporal lobes that made a European unable to cope with written speech had less grave consequences for a Japanese, and none for a Chinese. On the other hand, an affliction of the sincipital area of the brain never greatly interfered with a European's faculty to write coherently, but greatly disturbed that of a Japanese, while a Chinese became absolutely incapable of writing comprehensively.

Does this mean that there are racial differences in the activity of the brain? Before we answer this question let us discuss the organization of speech function.

Human speech consists of complex sounds of an involved pattern. To be able to speak it is not enough to have good hearing. To a baby in its first months speech is nothing more than a kind of a noise. To master speech, a child must learn to single out from a flow of sounds the essential features, or the phonemes. What one needs to perceive speech is not so much a keen ear as an ear trained to the system of a particular language.

If you do not know a foreign language, you will not be able to distinguish the individual elements of that language in the flow of sounds. You will not be able to repeat the words and phrases you hear, let alone understand them.

It is an interesting and important fact that this process is performed not merely by the acoustic regions of the brain, but also by the articulatory organs, which take part in the utterance of speech sounds, and by the corresponding motor regions of the brain. Even adults, although they usually do not realize it, do not perceive speech either by sounds or visual appearance (written text) but by so-called kinesthetic perception, a vague, inner sensation arising in the muscles and tendons of the articulatory organs during speech.

Acoustic information is analysed in the temporal lobes of the cerebral cortex. Like all the other analyzers in the human brain, the temporal lobes of the cortex consist of primary or projection zones, to which the nerve fibres from each ear come, and secondary zones which receive information from the periphery already processed by the primary zones.

If the primary zones have been affected by disease the patient will have hearing trouble. It is quite a different matter if the secondary zone of the left hemisphere is damaged. The hearing is practically intact, but speech hearing is gravely affected. They cannot distinguish *d* from *t, b* from *p,* and *z* from *s.* Obviously, they fail to identify phonemes and consequently have difficulties in understanding words.

To such patients 'dot' sounds like 'tot', 'lot' or 'cot'. The patient can neither distinguish these words when he hears them nor pronounce them correctly, and he has difficulty whenever he has to say these words in a conversation. Failing to find the appropriate word, he tries to find a substitute, for example, 'the thing you do your hair with' for 'comb', or 'land without water' for 'desert'. In the most serious cases, patients have so many 'difficult' words and make so many mistakes in pronouncing them, that their speech becomes quite incomprehensible.

Naturally, if one cannot sense the differences between the words 'dot', 'tot' and 'cot' one's faculty to understand speech is generally affected. A curious but so far unaccountable fact is that such patients find it especially hard to identify nouns, and their speech mostly consists of link words, prepositions, adverbs, verbs and all kinds of words expressing relationship.

Another curious fact is that when speech hearing is affected, people do not become tone-deaf. Several cases have been recorded where gifted composers have lost their speech hearing and the faculty to speak as a result of a serious illness, but have still been able to write music and have successfully continued their creative work. On the other hand, a lesion of the corresponding zones in the right cerebral hemisphere does not affect the patient's speech, but may make him tone-deaf.

Written speech is also affected in the case of injury to the secondary zones of the acoustic analyzer. The patients can copy or write such familiar words as 'mother' or 'moon', sign their name, and reproduce such common letter codes as O.K. or I.O.U., but they become completely incapable of writing a note or even a few lines of dictation coherently. Their ability to read is also affected. They can recognize and understand some very familiar words or phrases, but become incapable of reading separate letters, syllables or less familiar words.

Obviously, the disturbance in the phonemic hearing faculty prevents the patient from reading or writing, and not the affliction of the visual function. This explains why these lesions do not affect the written speech of a Chinese patient. The Chinese system of writing is hieroglyphic, and is not directly related to phonetic hearing. A Chinese patient can write and understand a written text, but he is unable to read it aloud. If the same patient is a speaker of some European language, he becomes unable to read or write in that language.

Conversely, a European patient who was a fluent speaker of Chinese, can no longer read or write in his own language, but can still understand the Chinese characters.

Japanese writing combines hieroglyphics and phonemic mode of speech and this explains why the written speech of a Japanese patient is affected by similar brain lesions to a lesser extent than that of Europeans.

The perception of hieroglyphs is connected with the functioning of the occipital and sincipital sections of the brain. An injury to these parts of the brain usually affects eyesight. Patients can see a drawing with their eyes but do not identify it. Looking at a portrait, a patient finds the nose, mouth, eyes, but cannot put these details together. The drawing as a whole remains unclear and he is not sure whether it is a picture of a man. If the man in the picture has a moustache, the patient may come to the conclusion that it is a cat.

It is not surprising that such patients are completely unable to understand hieroglyphic writing. If the recognition of letters, which are symbols of a less complex pattern, has been retained, the patient is still able to read and write in other languages. This has of course no connection with nationality or race: the Chinese patients who were speakers of European languages can still read and write in them, while Europeans who could read hieroglyphs can no longer do so.

The peculiarities of the mental processes are not, therefore, connected with a person's race, but depend solely on upbringing and education, that is on the formation of a complex system of conditioned-reflex connections.

Storks and Cabbages

WHY DOES IT ALWAYS TAKE TWO?

Our planet is inhabited by several millions of different animal species which vary enormously. Some live in water, others on land; some like the cold, while others prefer the warmth; some cannot do without high pressure, whereas many others can live in a near vacuum. For all these differences, they have one thing in common: they are divided into males and females. Only the most primitive creatures have no sex.

Why did Nature need to divide all living things into two opposed groups? What task was too difficult for one organism to cope with?

The existence of two directly opposed sexes is usually explained as answering the needs of the reproductive process itself. This, however, should by no means be regarded as the main cause which gave rise to opposed sexes. Primitive organisms that have not developed such differentiation of sex can multiply perfectly well, and many creatures with sex differentiation have still retained an asexual method of reproduction.

Asexual reproduction is fairly widespread. The simplest method, fission, is adopted by amoebae, infusoria, and many other single-celled organisms. In this process, the body of the cell, the nucleus, and all the chromosomes comprising the nucleus, divide into two halves; one cell generates two identical organisms which are in no way different from the original, maternal cell.

Sometimes it is necesary to try other techniques. It is interesting to watch how the thecamoebae, which live in a minute shell, divide. To begin with, the maternal cell comes out through an opening in the shell and builds another home, a shell just like the first one. The two shells continue to be connected to each other. Having completed its new house, the thecamoeba crawls backwards and forwards from one to the other several times, as though checking that everything is in order. Its body then splits into two independent organisms; the new cells part company and go into their respective shells, after which the two break away. From this moment on, the two organisms exist independently.

Another method of asexual reproduction, in which a small part detaches from the parental organism, is known as budding. In single-celled organisms the part detached has a tiny nucleus. A many-celled organism detaches a group of cells each of which later gives rise to a new individual. Yeasts reproduce by this method, and among the many-celled organisms, the fresh-water polyp.

The third method of asexual reproduction is sporulation, or the formation of spores. The nucleus of the parental organism splits into several, and sometimes even many, small nuclei. The cell itself then divides into the same number of parts.

The newly-formed cells, or spores, bear no resemblance to the parental organism. They are very small and, unlike fully-grown organisms, have a strong envelope to protect them in unfavourable surroundings. This is why spores can survive the vicissitudes of life such as desiccation, overheating and cooling.

Reproduction by means of spores is widespread among plasmodia, a causative agent of malaria living parasitically in man's red blood corpuscles. Once in a blood cell, every plasmodium splits into twelve or twenty-four spores. When all the spores in man's blood, numerous as they may be, abandon the red blood corpuscles all at once, the latter are broken down, resulting in an attack of malaria. Plasmodia not only reproduce asexually: when taken together with infected human blood into the digestive tract of the mosquito they reproduce sexually.

Nature has invented numerous methods of asexual reproduction. From this it follows that two sexes exist not merely for the sake of reproduction. What then is the reason?

It has been suggested that long-term asexual reproduction may bring about degeneration due to the disturbance in the genetic code, as has been observed in marriages between close relations. But suggestions alone were not enough, so scientists decided to carry out experiments on an organism which reproduces both asexually and sexually, in order to obtain accurate data.

An infusorian slipper animalcule, a rather large single-celled organism with a fairly complex structure, was chosen for the purpose. The experiment was conducted in such a way that as soon as the infusorian slipper animalcule living by itself divided into two independent organisms, these were immediately separated to prevent sexual reproduction. During the experiment the slippers usualy divided twice a day. The research workers continued their experiment for twently-two years, observing the reproduction of one and the same infusorian. During this period there were 13,500 generations. None of the pre-assumed degeneration or loss of posterity occurred.

Thus, even organisms which employ both methods of reproduction can reproduce asexually for tens of thousands of generations without detriment to themselves. Obviously, the existence of two sexes is essential for some other reason.

Analysis of the role played by both sexes in the reproductive process should throw some light on the problem.

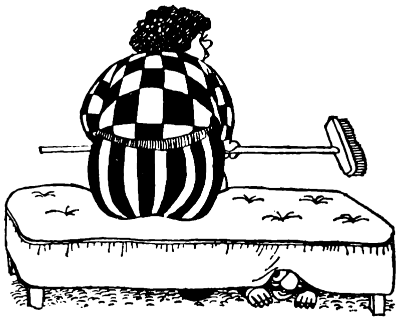
To ensure the continuity of life all animal species must reproduce sufficient young well-prepared for life. With few exceptions, the number of young depends principally on the number of adult females as any male can mate with several females.

What is the function performed by males? It would seem that males are responsible for quality. Not all are able to start a family, and competition for females is keen. A family is started, in the first place, by those males which are better adapted to life.

It is not just a question of physical fitness, although this is indispensible for acquiring and retaining a home territory and for the fighting that takes place between the males of many species. Children invariably take after their parents, and, consequently, males better suited to life will create better offspring.

For the males to do their duty of controlling the quality of the young, they need to be aware of all the changes that occur in their surroundings. For this they must, for one thing, be less adapted to life than the females; they must be able to sense the slightest impairment in living conditions; moreover, there must also be strict differentiation between them, so that some could observe the climatic conditions, others procure supplies of food, and still others oppose natural enemies.

Contrary to popular belief, it is males and not fema-



les that are the weaker sex. The same is true of human beings. An analysis of the longevity shows that old women outnumber old men in all nations. Among all centenarians roughly 60 per cent are women. The champions of longevity, however, are mostly men. Though, when considered as a mass, they are fairly weak, men are so unlike one another that there are always one or two who will become champions.

Bearing this in mind, one can easily see that arguments about the different levels of intelligence of men and women, which were once fashionable, are quite groundless. The fact is that women are more uniform, more like one another and have, apparently, given the world fewer outstanding personalities. But to make up for this, there are far fewer idiots among women than among men.

It thus follows that the main reason for having two sexes is the need to ensure a subsequent generation of the right quality in sufficient numbers. This can only be accomplished in this manner.

The second reason for the two sexes is that it has allowed evolution to develop more rapidly. With sexless reproduction the 'baby' and its mother are as alike as two peas in a pod; the 'baby' very seldom differs from its mother, and then quite by chance. Therefore, with asexual reproduction new characteristics seldom emerge and are slow to develop.

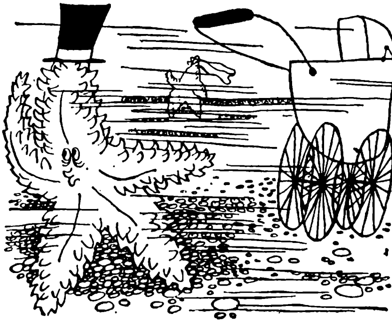
But things are quite different when there is a father and a mother. The offspring inherit some traits from the one parent and some from the other. This is not mass production, as every progeny is created according to an individual pattern, so to speak, which, if it proves successful, will soon result in new positive characteristics becoming wide-spread among the species in question.

MARRIACE AND THE FAMILY

Most animals on our planet reproduce sexually. In single-celled organisms the sexual process consists mainly of the exchange of a nuclear substance between the two cells in the conjugal state.

With the infusorian slipper animalcule, for example, the two organisms which are about to engage in the sexual act press their abdominal parts close together so that their oral openings coincide. The nuclei of the two contacting organisms then divide repeatedly; at the same time they undergo certain transformations, after which each slipper animalcule is left with only two nuclei, a stationary female and a wandering male, the number of chromosomes being halved in the process. The infusoria exchange wandering nuclei, one of which fuses with the stationary nucleus of the hostess so that in each slipper a new nucleus forms with a complete set of chromosomes.

The sexual union of single-celled creatures may involve either two organisms very similar in appearance, as in the case of the infusorian slipper animalcule, or two creatures bearing no obvious resemblance to each other. With regard to the malaria plasmodium, which



we have already mentioned, after a number of sexless generations of absolutely identical spores developing into identical amoeboid creatures, on the tenth or eleventh day there emerges a sexed generation consisting of smaller male and larger female individuals which reproduce sexually.

Many-celled organisms have special sex cells, or gametes, the union, or to be more exact, fertilization of which results in the formation of a new organism. This greatly complicated the process of reproduction and Nature had to invent a great many different devices to ensure the union between the male and female sex cells.

In the majority of lower organisms this union occurs outside the body of the parent and the parents are spared the effort of ensuring that their sex cells are brought together. To produce offspring, the carefree parents simply build up colossal reserves of sex cells, only to cast them to the wind as plants do with their pollen. In animals such processes only occur in water in very limited areas.

Sex cells do not rely on chance meetings. Sperms, the male gametes, can usually move independently, and sometimes quite quickly. Yet to ensure fertilization of most female germ cells, the male cells must considerably outnumber those of the female. This method of reproduction is employed by the slow-moving starfish, the barbed sea-urchin and many other inhabitants of the sea.

It is easier for the germ cells of creatures living in colonies to seek out one another, but to do so they must be in the water at the same time. But how can animals arrange this?

The language of chemistry is the only one which can be understood at this level of development in organisms. Substances, either contained in the germ cells, or together with them, are discharged into the water. These substances are capable of stimulating the secretion of sexual products by animals of the same or opposite sex. Having received a sign, the whole colony begins reproduction, and, within a fixed area, vast numbers of both male and female germ cells accumulate almost simultaneously. This is enough to ensure successful fertilization.

This simple language has long been known to specialists engaged in oyster fishing and they 'prompt' the oysters to start reproducing. At the right time of year, the sexual products obtained from hundreds and even thousands of oysters are put into the water in the oyster beds. This stimulates mass spawning in the free-living oysters and subsequent fertilization of the spawn discharged. Artificially stimulated spawning greatly increases the yield from oyster farms.

During the mating season animals whose mode of life is motile either pair off or collect in groups or even large flocks or herds. In vagile fish the behaviour pattern of the male serves one purpose—to make the female spawn, whereupon he immediately sheds his milt over the newly-laid spawn.

In amphibians contact between the male and female is still closer. As soon as the spawning time begins, the male frog finds a mate, tightly clasps her by the waist with the front legs and does not let go until she has discharged her spawn. Sometimes the male and female meet on dry land, a long way from water, and then the females leap clumsily and comically down to the water, carrying the fathers of their future children on their backs. The male remains on the female's back until spawning has been completed. This is very convenient as his sperm is released over the spawn of the female as it is discharged from her body.

In the higher animals the germ cells meet inside the mother's body and both sexes are specially equipped with external genital organs. To ensure that the germ cells meet, the male and female enter into close contact known as copulation.

Most animals mate during a special season peculiar to their own species. This is because only then do the females have ripe germ cells, and during other periods of their life the organism is not ready for reproduction and cannot ensure development of an embryo. The males of warm-blooded animals can mate all the year round, apart from a few species (deer, for example), whose males have ripe germ cells only during the mating season. It is undoubtedly expedient that reproduction is restricted to a particular season, as young born at any other period, that is when conditions are unfavourable for their development, are doomed to death.

Some species can mate all the year round but mating is only fruitful if both the male and female happen to have ripe germ cells. With human beings there are thirteen such periods per year since the whole sexual cycle is completed within 28 days, but each cycle lasts no longer than twenty-four hours. A woman can, therefore, only conceive during these thirteen days. Many insects, as well as ambystomas (tritons), axolotls, salamanders and others, do not mate in the proper sense of the word. The male lays a spermatophore (a minute sac containing sperm); this done, either he or the female places it into her sexual aperture. Very often, only the neck of the spermatophore is introduced and the spermatozoids enter the genital tract of the female through an opening in the sac. Special appendages exist to prevent the spermatophore from falling away. With the help of these appendages or a sticky secretion produced by special glands of the male, the spermatophore is securely attached to the body of the female. In many insects the females eat the empty spermatophore.

In some insects the process is even simpler: after the sperm has been ejected the male collects it with appendages in his mouth and places it in the genital tract of the female.

The sexual organ of the male and the genital opening of the female may be found in different parts of the body, on the feet, the head, or in other places. The garden spider uses the sharp end of a tentacle on his jaw for a copulative organ. Before mating, the spider spins a web and emits sperm into it. Then, with a special part of the tentacle, he collects a drop of this sperm, as though with a pipette. He is then ready for copulation.

The genital opening of the snail is on its head. In the octopus sperm is contained in one of its eight tentacles, which it introduces into the genital opening of the female when mating. The most curious thing is that the tentacle containing sperm can detach itself from the octopus' body and live independently. Formerly this tentacle was regarded as a specific animal known as a heterocotyle. No one suspected that it was merely one of the organs of a cephalopod mollusc. When it comes across a female octopus, the heterocotyle crawls into the genital tract of the female and squeezes out the sperm.

Some female insects have no special genital opening. The male inserts its sharp copulative organ into any part of the female's body and injects the sperm into it. The sperm travels then through the internal cavities until it encounters an egg. Rotifers and leeches also use this method: they force the spermatophore into the body of the female.

The process of mating may last a few seconds or for several days. The previously mentioned sham mating of frogs may last up to three days. In butterflies, where mating lasts for several hours, the male secretes a special sticky substance, which soon hardens in the air, and attaches himself securely to the female.

Sometimes mating is fraught with danger. For instance, the male spider approaches the female very stealthily. Should she notice him, she is sure to attack and devour him. But after mating only a few manage to escape the fate of being eaten by the female.

The male's life is in danger even during mating, and so some spiders tightly close the mouth of the female with special hooks on their forelegs. It is not surprising that the males of some species of southern spider outnumber the females by tens or even hundreds to one. Only when there are such large numbers are there enough sufficiently reckless males to risk mating.

In some creatures, mating invariably results in the death of one of the partners. The male bee which is lucky enough to leave behind his rivals during the marriage flight and overtake the female, dies as soon as mating is over. The female praying mantis starts devouring the male during mating, beginning with its head.

The marriage habits of one species of the ringed worms of the Polychaeta class are even more tragic. They do not really mate. The male discharges the sperm directly into the mouth of the female. Then he tears her to pieces, enabling the sperm to fertilize the eggs which fall out from the pieces of her body.

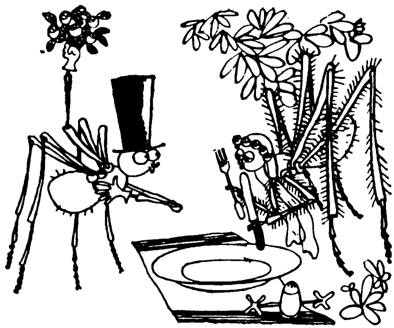
There are some creatures which, though reproducing sexually, do not start a real family. Indeed, family exists only because it is necessary to protect, rear, and instruct the young, and it is the young which mainly determine the nature of the family.

Sometimes, the parents share their duties, and the share of each is so strictly defined that they can only cope together with the task of feeding the young. After the young of the sparrow-hawk hatch out, the mother does not leave the nest, but continues to protect and keep her young warm. The father is responsible for feeding the mother and her offspring. He hunts all day, bringing the food home to his wife. (Many creatures do not even allow the father to enter the house). He does not know how to pluck, tear the prey to pieces, or feed the young.

If the family loses its father, an experienced female, can raise the young, although she is not accustomed to bring her quarry home. But if the family is left without a mother, the unfortunate nestlings will starve to death. The father will continue to bring the food to the edge of the nest, but will not attempt to feed the young.

Marriages between thoughtful parents are stable and very often last for life. This does not mean that husband and wife never part. Such couples are very rare among animals. They usually live together when it is time for them to think about children. This often happens with our birds of passage. In their winter habitat the males and females live apart; they also keep apart during the migration flight and only meet at their home nest.

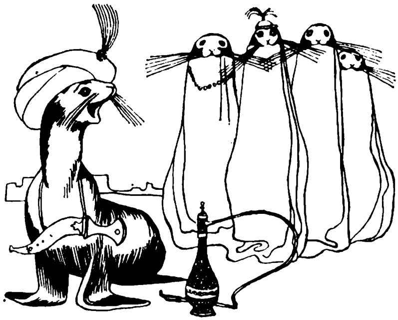
Scientists believe that animals which marry for life do so not because of any mutual attachment, but because of their attraction to the nest. Even storks, who are proverbially good 'family men', readily take another wife.



The male is the first to return to the nest in spring and, if it happens that a young female joins him at this time, he readily accepts her. When, a little later, the real mistress of the house returns the male will watch the ensuing conflict between the two females with indifference. The winner will become his wife.

The pattern of family life is different if the offspring are born strong and independent. In this case there is no need for both parents to care for the young and family life takes on strange forms. One early spring morning a shoal of male perch (zander) may return to their native spawning place where they were born some time previously. The shoal disperses and each fish selects a place on the bottom, clears it and builds a nest, using the roots of water plants. Not all fish simply cast out their ova; many of them build quite intricate nests.

Having built their nests, the males wait for the females. These arrive, spawn, and then go wandering off as if nothing had happened. It is the male who stays behind to protect the spawn, but, when the young have hatched out, he leaves the nest, and the only reason he does not eat his own offspring is because they are too small to be worth his trouble.



With fish it is often the male who looks after the family. Such unusual families are found among birds too. The tiny female of phalaropes just lays the eggs. It entrusts the father with hatching them and looking after the young.

Still more curious is the family of the *Turnix hemipodes* found in the Far East of the Soviet Union. In spring, during the breeding season, the female, like all self-respecting birds, builds a nest, lays four eggs in it, and leaves them to be looked after by the male. Then she builds another nest, finds another cock, lays some more eggs and goes off again. She does this several times.

Polyandry (that is a form of marriage in which a female has two or more husbands) is not very common but polygamy (that is when a male has two or more females) is fairly widespread. Strong mature male fur-seals and sea lions have large harems with scores of females. Polygamy is known among monkeys and birds, especially in poultry.

Sometimes, parents do not look after their own children. The mother finds a nurse, or to be more exact, foster-parents, and leaves her children to their care. There are many cunning birds; fifty species of cuckoo lay their eggs in the nests of other birds; ten species of honey-guides and four species of weaver finches in Africa and the ox-pecker in America, do the same.

All nest parasites (this is the term given to this heterogenous group of birds) want to enjoy the exclusive attention of their foster-parents. So, after the young cuckoos have grown a little, they throw their stepbrothers and sisters out of the nest. Having laid their eggs in somebody else's nests, the ox-pecker parents damage all the other eggs they find there in order to spare their young undesirable competition.

Nest parasitism is more widespread than is popularly believed. Apparently, when places suitable for nests become scarce, some birds start laying eggs in the nests of close relatives. Birds living in the north of the Soviet Union, such as the millards, golden-eyes, and the sheldrake found on the shores of Lake Sivash, often do this. The black-headed duck of South America never builds a nest, but scatters her eggs about the nests of other large birds; she cares little whether the foster-parents will be able to bring up her young. This duck is only saved from extinction because it lays so many eggs that some of its young are sure to survive.

There are some species which rear their children collectively. The emperor penguins of the Antarctic take their children to a kindergarten where they spend whole days in the company of other young penguins of the same age, while their parents are fishing. The young are brought up together but given food separately. Parents easily recognize their own child among the dozens of similar little balls and, when they have found it, they carefully feed it.

The families of social insects are the most complex and numerous. A family of bees may comprise tens of thousands of members, and those of ants and termites may number as many as a million individuals.

Such families are heterogenous and fall into various orders; the queen and the male who are the parents of the large family, and the workers and soldiers—long-winged, short-winged, and many intermediate forms. All the members of the family are interdependent. If one is isolated from the rest, it is sure to perish, even if it has enough food and water. The individuals which provide food and water for the whole family are not even able to provide for themselves.

Rearing the young is a very complicated process in social insects. The larvae cannot survive without the help of careful nurses, as the parents take no part in bringing up their children. The task of the queen bee is to lay eggs. The parent couples of ants and termites which found a new colony, look after their children only until they are old and numerous enough to be entrusted with the care of the family. Then the parents do nothing but eat and breed.

An interesting feature of social insects is that they are capable of contracting a collective marriage. Normally, when it is time for swarming the ants and termites who have left their nests cast off their wings, split into pairs and set out looking for a suitable hole. When they find such a hole, they block themselves in with the purpose of starting a family. It is not unusual for several males and females to find themselves in the same hole. It is to their advantage, because a large group has more chance of overcoming difficulties and starting a family. Once a family has been started, only one mature male and one mature female remain in it.

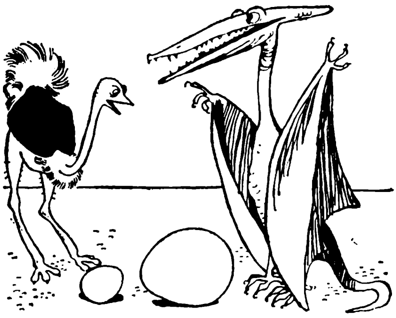
A family of social insects possesses many strange characteristics. For example, they mate for life. Their marriages are never dissolved, but this is not due to the mutual attraction of husband and wife; the clue to the fidelity lies in the peculiar mode of life in the family of such insects.

In higher beings reproduction entails male and female germ cells, or gametes. They are very different from each other and from other cells of the organism.

The female germ cell, called the ovum egg, is a large spherical or globular cell containing a vast amount of deuteroplasm (yolk), the building material providing nutrition for the newly-developing form—in mammals (with the exception of the egg-laying echidna and duck-bill) in the period immediately after fertilization, and, in other animals, until the embryo is mature. In the latter case, therefore, the cells are real giants as cells go.

The largest among egg cells of the animals inhabiting our planet (all the membranes included, and in the case of birds, also the egg-shell and the white too, which are classified as membranes) are the eggs of the ostrich. The weight of this cell varies from two to three kilograms. Still larger in size is the 'roe-corn' of the whale shark which may be up to 60-70 centimetres long and 40 centimetres wide. The contents of such an egg would fill five to six buckets. The eggs of the now extinct prehistoric reptiles and those of the dodo which lived on the Earth not so very long ago were as large as a bucket. The human egg cell is among the smallest, being from 0.2 to 0.5 millimetre in diameter. Among invertebrates there are still smaller eggs, scarcely 0.04 millimetre in diameter.

The eggs mature within the female genital organs called the ovaries. In the case of humans, they develop when the girl is very young, about two and a half years old, and do not undergo any subsequent changes. It has been estimated that there are 30,000 eggs in each ovary of a girl of that age. At an earlier stage, the eggs are even more numerous, but, beginning with the sixth month of their intrauterine life, some of them begin to develop



in the ovary of the embryo, but do not mature completely.

When mature, the egg divides twice and is left with half the number of chromosomes. It is only after the girl's puberty that the egg cell matures and ovulation occurs, i.e. an egg is shed from the ovary. A little over four hundred egg cells mature during the lifetime of a woman, thirteen every year.

The male germ cells, spermatozoa, or sperm, are original in form and unlike other body cells. They differ in shape in different animals. But all of them have one thing in common: they are mobile and invariably smaller than the egg cells.

In mammals, a spermatozoon consists of a small head and a long tail, by means of which it can propel itself. The human spermatozoon is from 50 to 70 microns in length, the head being only four to five microns long. The construction of the spermatozoon is extremely complex even in the lowest of animals. The spermatozoon often has a perforator in the form of an awl, drill, chisel or corkscrew, for breaking the egg membrane, and also blades, fins and other devices.

The spermatozoa develop in the male germ glands, the testes. In vertebrates these are paired and are located within the body cavity. Only in the human beings and in some mammals are they contained in special sacs, immediately under the skin. During the life of the foetus, the testes migrate from their place of origin to the scrotum. If, for some reason, this fails to happen, sperm will not be formed in such testes. It has been suggested that this is due to the high temperature in the abdominal cavity. Anyway, elephants, whose testes are within their body cavity and whose temperature is quite high, go high up into the mountains where it is cold during the mating season. Otherwise, conception will not occur. When these giants are brought to the cold north of our country, they often produce offspring in the very first years, although elephants breed very seldom when in captivity, even in their native land.

A male testis consists of about one thousand small coiled tubes (called convoluted tubules) whose walls contain large oval cells, which, when dividing, are transformed into spermatozoa. Similar to the female gametes, they are left after dividing with one-half the number of chromosomes; having undergone a complex process of morphological reconstruction, an ordinary oval cell develops to become a mature spermatozoon.

The spermatozoa which are unable to move, are pushed along the tubules into the epididymis, an extremely coiled tube where the sperm is stored in the seminal fluid containing the nutrients indispensible to them, glucose and fructose.

Regardless of whether the union of the sperm and the egg occurs within the female genital tract or externally, not every individual spermatozoon has a chance to reach the egg. The human spermatozoon has a long way to go in the female genital tract, moving at a rate of from 1.5 to 3 millimetres per minute.

To ensure the meeting of the gametes, there has to be a great many spermatozoa, even when there is only one egg to be fertilized. Thus, during the sex act, at least two hundred million spermatozoa are discharged into the female genital tract where there is only one mature egg cell, if any.

The situation is aggravated by the fact that both the spermatozoon and the egg cells have a very limited life-span. The female egg cell dies twenty four hours after ovulation. The viability of the spermatozoon in the female genital duct is a little longer, from twenty four to forty eight hours.

Not only the life-span of the sexual elements is of paramount importance, but also the length of their fertilizing capacity. The egg follicle of the salmon, soon after contact with water, becomes too hard for the spermatozoon to penetrate. The spermatozoon, moreover, can only move in the water a very short time: those of the salmon—for 45 seconds, and those of the brook trout only 23 seconds. The two gametes must meet in this very short time. Therefore, fish farms producing trout artificially put the spawn (ova) into the water only after they have been mixed with the spermatozoa.

The life-span of spermatozoa and their mobility can be prolonged by storing them out of the water. When kept 'dry', the spermatozoa of some fish can survive for a week or two, and sometimes for even longer periods.

In some animals, the spermatozoa are preserved in the female genital tract for very long periods. Bats copulate in the winter, but fertilization occurs much later. The sperm introduced into the female body is preserved in her genital tract until the spring. In the case of snails, sperm can be stored for years. Bees copulate once in a lifetime. Sperm is stored in a special sac connected with the genital tract. When laying eggs the queen bee opens the sphincter of the sac at will and allows the sperm to fertilize the eggs she is laying. If the sphincter happens to be closed when the eggs are being laid, they will remain unfertilized.

We still know very little about how the gametes meet. As large amounts of sperm are produced, a spermatozoon may encounter the egg by chance. But there are also special devices provided for this purpose. In some animals the eggs contain special substances which are secreted into the surrounding medium in very minute quantities and either prolong the life-span of the spermatozoa or attract them.

Sperm need not be produced in large quantities. In species, whose reproductive system facilitates the meeting of the spermatozoon and the egg, animals manage with a small number of male germ cells. Thus in some lower crustacea, for instance, in the water-flea (Daphnia), two egg cells are stored in a small brood case. During copulation the spermatozoon penetrates the brood case through an opening. The opening then closes. The spermatozoa in water-fleas are very large, slow-moving, and peculiarly few in number. During copulation five spermatozoa, at the most, get into the brood case, the male having no more than twenty spermatozoa in all.

Fertilization begins when the spermatozoon attaches itself to the egg membrane. It has to penetrate the egg, but the egg membrane prevents it from doing this. In some animals, for example, in the echinoderms, or spine-skinned, and amphibians the membrane is very thick. Sometimes the spermatozoon cannot penetrate the membrane at all, except through a narrow canal called the 'micropyle'. This requires a great deal of effort on the part of the spermatozoon. The size of the spermatozoa is negligible compared with that of the eggs of large marine animals, yet the latter begin moving or rotating when attacked and encircled by armies of many thousands of spermatozoa.

Besides the membrane proper, the human egg is enveloped in a layer of cells called radiating crown, or the corona radiata, and is inaccessible to an individual spermatozoon. Only several hundred thousand spermatozoa, combining their efforts, can break through the barrier, destroying it with the help of a special enzyme, hyaluronidase, which is contained in minute quantities in their heads. The substance solders the cells of the corona radiata together. It is not until this is accomplished that one of the spermatozoa can enter the egg.

When the spermatozoon penetrates the egg, a number of changes occur; for example, a new membrane, known as the fertilization membrane, is formed, which is so dense that no more spermatozoa can enter the egg. This prevents the egg from being fertilized by more than one spermatozoon.

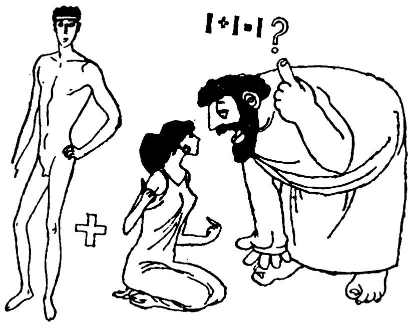
The nucleus of the female sex cell fuses with the nucleus of the spermatozoon which has entered the egg. Thus, the nucleus of the newly-formed cell, resulting from the union of the male and female gametes, is provided with a complete set of chromosomes. Then the first division takes place.

In some cases the fertilization membrane is not formed immediately so that several spermatozoa enter the egg. The fusion of their nuclei with the nucleus of the egg results in the total number of chromosomes greatly exceeding the usual number. In some species, however, this often occurs. Yet, in this case, too, only the nucleus of one spermatozoon fuses with the egg nucleus; others degenerate not far from the surface of the nucleus and are only used as nourishment for the egg. Very rarely does more than one spermatozoon participate in the fusion. Ordinarily, such an egg cell develops abnormally and dies after a short time. However, specimens of certain insects, birds and other animals obtained by the fusion of the egg cell with several spermatozoa can be reared experimentally to a full-grown state.

Polyploid animals, i.e. animals possessing more than one set of chromosomes, can also result from fertilization of the egg by one spermatozoon, if the subsequent process of egg division is interrupted. Polyploidy is especially widespread in plants. The cells of polyploid plants are larger than those of ordinary ones; thus, the plants themselves are also considerably larger. All cultivated plants are polyploid plants. In animals polyploidy occurs less frequently, perhaps because of the confusion that is observed when sex is determined. The normal division of chromosomes does not take place in this case, the division of the egg cell is interrupted, and it dies. It is only in unisexual animals that polyploidy occurs readily.

Fertilization is a specific reaction. It means that only germ cells of animals belonging to the same or allied species can take part in the union. Fertilization of the egg by a spermatozoon of dissimilar species hardly ever occurs.

Another peculiarity of fertilization is that it is irreversible. Should the spermatozoon which has entered the egg perish for some reason, the egg cell can continue developing and dividing as if nothing has happened. This development will continue even if the spermatozoon is carefully removed from the egg. No other spermatozoon can enter the egg. The embryo developing from defectively fertilized eggs perishes at an early stage in its development, and only very seldom does it become full-grown. The capacity of the egg to continue developing after the spermatozoon which has entered it degenerates or is removed is a very important characteristic. Thanks to this ability, the egg may develop in a curious manner.



THE REQUEST OF THE ENAMOURED SALMACIS

According to a Greek legend, there lived in a fountain in Caria a beautiful nymph, Salmacis, who fell madly in love with an extremely handsome youth, Hermaphroditus, the son of Hermes and Aphrodite. She entreated the gods to let her be united with him forever. The gods answered her prayer by joining them together in one body. This creature was, of course, bisexual.

Not only the Greek Gods were fond of a joke, but Nature is, too. True hermaphrodites, or bisexual creatures, are often to be found on Earth.

Hermaphroditism is encountered in two forms: one form is natural and the other is pathological, considered as an inborn abnormality. What are hermaphroditic creatures like?

True hermaphroditic individuals possess both sex gonads, the first producing male germ cells, and the other female ones. However, the reproductive organs of these hermaphrodites are underdeveloped and they cannot create a new living being using the eggs and sperm produced by their organism. But there are creatures, although they are very few, that can do it. In the majority of hermaphroditic animals, however, similar to normal, or dioecious, creatures, reproduction requires two individuals.

Self-fertilization is most commonly encountered in parasites. Otherwise, a parasite, dwelling in the body of the host and isolated from the outside world, would not be able to produce offspring.

Self-fertilization often follows the pattern of mating. To ensure the meeting of gametes, one kind of the ciliated worm has to introduce a copulatory organ into a specific opening in its own body.

Some species can do without self-copulation, as the structure of their sexual organs ensures the meeting of the germ cells. In one of the flatworm, which parasitizes in the intestine of the shark, the ducts of the male and female sex glands open into the same cloaca where the gametes meet.

Some hermaphrodites are able to reproduce by self-fertilization but do not make use of it, preferring to have a partner for the process of reproduction. In the many-mouthed flukes, parasites living in the urinary bladder of the frog, copulation between two individuals is normal. They only resort to self-fertilization when no partner is available.

Many hermaphroditic organisms cannot reproduce by self-fertilization for various reasons. Usually, the eggs and the spermatozoa do not mature at the same time. Sometimes, the female germ cells cannot be fertilized by sperm produced by the same organism. This has been observed in the ascidians, but the mechanism of the phenomenon remains a mystery.

The majority of hermaphrodites which are unable to propagate by self-fertilization perform the functions of both male and female during the breeding season, or play the part of males at some periods and females at other periods in their lives.

To the first group belongs the common earthworm. Each worm has two genital openings on its fifteenth segment; one opening is for releasing sperm and the other for receiving it.

During copulation two worms press themselves against each other in such a way that the opening which releases the sperm of one worm coincides with the opening for receiving sperm of the other. The sticky mucus secreted during the process holds them together in this position for a long time.

Another representative of this group of hermaphrodites is the form which lives in the gills of the black-headed minnow. Before puberty, these parasites live separately, but then they pair off and grow together crosswise, staying in this position for the rest of their lives. These worms are hermaphroditic and their insemination is mutual. The parasites which live in the throats of birds, spend the whole of their lives in a state of copulation, the pair resembling in shape the letter V.

The group of hermaphrodites which change their sex, depending on what germ cells are mature at the moment, is also numerous. The round worm, found in the lungs of the frog, belongs to this group. There are also isopod crabs and certain molluscs which behave like males when young but, as they grow older, change their sex to become females.

Highly developed dioecious organisms also change their sex. In the aquariums of fish enthusiasts one can often see the sword-tailed minnow, a common viviparous fish. It quite often happens that, having produced offspring, a young female will change into a fully-fledged male. The same can occur in frogs.

Here it is appropriate to mention a phenomenon which has often been observed in Nature and which appears to be like hermaphroditism, but is actually the parasitic existence of one sex on the body of the other.

Several males may dwell in the genital ducts of certain female worms. They are very unlike the female in appearance and could be classified with other species. In fact, for a long time certain confusion did exist on account of this. It is quite natural that males, dwelling in the genital ducts of females, have more chance to fertilize their eggs.

Females living on the bodies of males are also known. The male of a parasite living in the human blood has a deep fold in its body, which holds the female as though in a tube, only the fore and hind parts protruding from the tube. The male angler, which lives like a parasite on the body of the female, has already been described in a previous chapter.

In lower animals hermaphroditism often occurs, but in higher animals it is rare and abnormal. Such anomalies in development have also been observed in man. The more common pattern is that of the individual who develops features of the opposite sex. The man has no beard or moustache, develops breasts too large for his sex, and his hips and other parts become plump and rounded. Women, on the other hand, develop a hair growth on the face, legs and other parts of the body; their breasts are very small and their voice is deep.

Instances of the external genital organs changing to look like the genitals of the opposite sex are less common. Sometimes they are underdeveloped and not very pronounced, so that it is difficult to tell the sex of the person.

Phenomena of this kind are known as pseudohermaphroditism, as the changes only involve outward features. The sex glands of these individuals are characteristic of one sex, although they are sometimes underdeveloped.

True hermaphroditism, when both kinds of sexual organs are present, is very rare in man. Only a few genuine cases are known; in the majority of these, only the glands of one sex acquired complete functional development.

Since it is very difficult to correctly establish the sex of an hermaphroditic baby at birth (and not only then), as the doctor is expected to do so when he registers the newborn baby, some errors may creep in. Subsequent wrong tendencies in upbringing may result in the patient's cast of mind and sexual inclinations not corresponding to his sex glands. The mental make-up and sexual inclinations of a true hermaphrodite may change in the course of his life.

Nowadays, highly developed operative techniques have made it possible to eliminate this developmental defect without great risk to the patient. When deciding which sex glands are to be removed the surgeon, first and foremost, takes into account the psychological make-up of the patient and not the functional capacity of the sex glands, and performs the operation accordingly. It is only when the patient's cast of mind is in some doubt that the surgeon is guided by the state of the patient's sex glands.

INNOCENT CONCEPTION

We are accustomed to think that in the living beings provided with germ cells the formation of an embryo is accomplished by the fusion of an egg and a spermatozoon. But this is not always the case. In some species the eggs can develop by themselves without the male germ cells. This phenomenon was first discovered by Leeuwenhoek, a Dutch naturalist, in the early XVIIIth century and is known as virgin reproduction or parthenogenesis.

No matter what the method of reproduction, a certain number of egg cells always remains unfertilized,

but they all perish after a short period. There are, however, numerous exceptions. In the echinoderms, some worms, and the arthropods the unfertilized eggs can start dividing just the same as the fertilized ones, but they never develop completely. At a certain stage their development discontinues and the embryo perishes. In these species new, fully-developed creatures seldom emerge from an unfertilized egg.

There are, however, some species of grasshoppers and other insects whose unfertilized eggs develop properly, and the larvae emerging from them develop to become fully-grown individuals. Thus, propagation can be accomplished other than by the ordinary method.

In the animals previously mentioned, parthenogenesis is an unusual occurrence and of no fundamental importance for the species. On the other hand, there are some species which could not survive but for this method, and either propagate parthenogenetically or alternate parthenogenetic reproduction with the ordinary method. This method is known as seasonal parthenogenesis. It is characteristic of the aphids and many other insects.

The eggs laid in the autumn by the vine pest, phylloxera, only produce females the next spring. These lay fifty eggs each, which develop parthenogenetically into similar females that, in turn, lay unfertilized eggs, too. During the summer, several generations follow one another with no males in their ranks. When autumn sets in, two kinds of winged females, markedly different from one another, hatch from the unfertilized eggs. Some of these lay larger eggs, from which females hatch, while the others lay smaller eggs, from which males will hatch. These eggs, too, develop parthenogenetically. It is only when the males make their appearance that sexual reproduction becomes possible.

What sex are the creatures originating from parthenogenetically developed eggs? Judging from the phylloxera they are both males and females. But it is more common for parthenogenesis to produce males only. Having used up all the supply of sperm obtained during mating, the ageing queen bee lays eggs which only develop into drones. This is, no doubt, expedient as it serves to preserve the species. The drones appearing at this period ensure fertilization of the young queen bee.

Many animals can get along without sexual reproduction. One variety of small dotted cymatoa has been observed for twenty eight years. During this period a hundred and twenty four generations were obtained, but there was not a single male among them. All these generations developed parthenogenetically. The same constant parthenogenesis has been found in some ants, sawflies, gall-wasps and other insects. All generations without exception are female. They have no males, and should some occasionally appear, they are defective, and take no part in propagation.

One should not think that parthenogenesis is characteristic of the most primitive animals. In Armenia there are six subspecies of rock-dwelling lizards. In three of the subspecies, males are completely unknown. The females lay unfertilized eggs which can develop parthenogenetically.

The most curious form of parthenogenesis is pedogenesis. The 'affectionate' larvae of gall-flies which eat up their own mother have already been mentioned. Another extraordinary example of pedogenesis are the flukes which live parasitically on fish. The mother fluke's body contains only one egg which develops into an embryo; this embryo, in turn, develops parthenogenetically another embryo; the latter gives rise to the embryo of the third generation and so on. Five generations develop simultaneously, one inside the other, very much like the Russian Matryoshka. It is only the sixth generation that develops into sexually mature individuals.

The question arises as to whether it is only the female germ cell that can develop parthenogenetically. It turns out that spermatozoa also possess this property to a certain extent. But spermatozoa are not provided with a store of the nutrients essential for parhenogenetic development. Therefore, much better results can be obtained if nucleus-free fragments of an egg are fertilized with normal sperm. These provide the spermatozoon with a large amount of food which ensures its development. During experiments with sea-urchins, small embryos resulted from the fertilization of nucleus-free fragments equal to one thirty-seventh part of an egg.

As parthenogenesis is such an ordinary phenomenon, attempts have been made to bring it about artificially. Heat and cold, ultra-violet and radio-active radiation have been used for the purpose; acids and alkalis, hypo- and hypertonic solutions, fat solvents, alkaloids and other substances have all been used; desiccation, rubbing, and injections have also been tried. The development of the egg was stimulated by using the above methods. Complete development was not always attained, as it is very difficult to provide the conditions necessary for the proper development of eggs and embryos in the laboratory.

Sometimes, the eggs developed by artificial stimulation are, for various reasons, defective. One reason is that the symmetry of the future embryo is disturbed. In most organisms the place where the spermatozoon enters the egg is determined by the direction of the plane of bilateral symmetry of the embryo. None of the methods so far employed could replace the spermatozoon in this respect, or stimulate a strictly limited portion of an egg. Even the prick made by a needle cannot imitate the action of a spermatozoon absolutely, as it, apparently, takes the spermatozoon much longer to penetrate the membrane of the egg. Still, in many animals, including lampreys, fish, frogs and even mammals, completely normal fully-grown individuals have been developed.

The many different methods of stimulating the activation of eggs make it possible to explain certain cases of spontaneous parthenogenesis. Various harmful effects, inflammatory and, especially, degenerative processes are responsible. There are very few known cases of spontaneous parthenogenetic development in mammals. But it is difficult to get a true picture, because the developing eggs perish at early stages of division.

The human female germ cells are also able to develop parthenogenetically. Only a fortunate coincidence of favourable circumstances, which is extremely improbable, can result in the birth of a child. The parthenogenetic development of a woman's germ cells can be stimulated artificially. The initial stages of the division of an unfertilized human ovum placed in the blood serum have been observed under experimental conditions. The ova degenerated both due to developmental defects and the fact that scientists were unable to provide the appropriate conditions for their normal development. Successful experiments conducted by the Italian scientist Petrucci give us hope that the parthenogenetic development of a human embryo will be traced to much later stages.

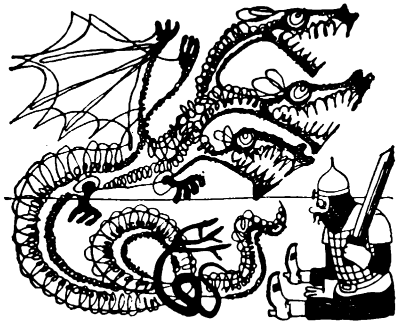
HOW MANY CHICKS CAN HATCH FROM ONE EGG?

When a woman puts a hen on fifteen eggs she does not expect to get thirty chicks. She counts on getting one chick from each egg. In fact, in the majority of living creatures each fertilized egg develops into one and only one embryo.

However, abnormal development, the causes of which are still obscure, sometimes results in two cells, known as blastomeres, forming during primary division; these later develop entirely independently and give rise to two embryos, growing into uniovular twins, that is twins developing in one ovum. The division may also take place at some later stage when the embryo contains several dozens or even hundreds of cells.

Uniovular twins are known to occur in various animals and in man. They are very rarely found in poultry. There was a case when two tiny chicks, weighing as little as eleven and sixteen grams, hatched from a single hen's egg. Thorough studies have revealed that in birds the egg may also divide into two halves, but the resulting embryos invariably perish.

Apart from animals in which uniovular twins develop by chance, there are many animals which regularly and normally give birth to such twins. Among these are highly developed creatures like the American mammal, the armadillo. A fertilized egg of the Texas



variety of these peculiar animals (and the armadillo has only one mature egg to be inseminated before each pregnancy) always develops four embryos. The number of young of the southern species varies, but normally is never more than nine. All the young in a litter are of the same sex.

The development of several embryos from one egg is most commonly encountered in parasites. This is essential for them, as it helps to preserve the species, especially of those parasites which have the greatest difficulty in penetrating the body of the future host. One such parasite lays its eggs on the eggs of the hessian fly. The egg of the parasite divides into sixteen cells, each of which, after its further division, may grow into one or two embryos. Thus, thirty two new organisms may develop from one egg. However, under normal circumstances, the number of young does not exceed eight.

Each egg of some species of ichneumon fly may give as many as 1000 to 1500 individuals. Of course, one egg cannot provide sufficient nutrition for such a large number of embryos which have to develop only at the expense of the victim. Practically, no food is stored in the eggs of this species of ichneumon flies, since it is not necessary.

Not all the young hatched from the same egg are true uniovular twins. In the guitar-fish, the double-eyed ray, and the saw-fish, the number of young is three to five, and even eight, and in some sting rays as many as twelve. But they do not originate from one egg. This is a case of false uniovularity. Each capsule contains several completely independent eggs each of which develops into one young creature.

Uniovular twins may also result from incomplete division of the egg, but in this case the young are joined together at some point. If the egg has divided only to a very small extent abnormalities occur; cases are known of four-legged chicks, two-headed calves, two-tailed donkeys and fishes and two-headed larks. Once a two-headed dolphin was caught. Abnormalities are most common among reptiles; two- and even three-headed snakes have been repeatedly found. It was such finds that probably suggested the many-headed dragons of mythology and that are responsible for the two-headed eagle in the state emblem of the Byzantine empire, later borrowed by the Russian tzar Ivan III.

Can several organisms be experimentally produced from one egg?

If the two halves of the egg are carefully separated immediately after division, each can develop into an integral individual. Even after the second division, independent and quite normal animals can be grown from each of the four cells. After the third and fourth division the resulting eight or sixteen cells may begin to develop normally, but the embryos usually perish in the early stages of their growth. Artificial division of the egg into separate cells (blastomeres) at later stages of its development has not yet produced any results.

Hence, more than one chick can hatch from one egg.

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Our planet, the Earth, is the home of hundreds of thousands of living creatures. Life has permeated everywhere. It has ascended to the tops of the highest mountains, where there is hardly any air, and has hidden beneath the expanses of the oceans, reconciling itself to the tremendous pressures exerted by the waters. Life has come to the hot, arid deserts and to the eternal ice of the Arctic. Living creatures have adapted themselves to an absence of oxygen, to everlasting gloom, and to silence. But, wherever living organisms have settled, they need food which has to be distributed throughout their bodies, and they have to carry out the processes of metabolism. They also need to feel at home in their environment and start families to ensure the survival of the species.

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