The Origin of Life*

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Grau, teurer Freund, ist alle Theorie,
Und grün des Lebens goldener Baum.

GOETHE

The Theory of Spontaneous Generation

EVER since he took the first steps towards a conscious life, Man has tried to solve the problems of cosmogony. The most complicated and also the most interesting of these is that of the origin of life. At different times and at different stages of culture different answers have been given. The religious teachings of all ages and peoples have usually attributed the appearance of life to some creative act by a deity. The first students of nature were very naïve in their answers to this question. Even to a man of such outstanding intelligence as Aristotle in ancient times, the idea that animals, including worms, insects and even fish, could develop from mud presented no special difficulty. On the contrary, this philosopher maintained that any dry body becoming moist or, on the other hand, any wet body becoming dry, would give rise to animals.

The authority of Aristotle had an exceptionally strong influence on the outlook of men of learning in the Middle Ages. In their minds the ideas of this philosopher became interwoven with the doctrines of the fathers of the Church, often giving rise to suppositions which, to our eyes, appear stupid or even ridiculous. In the Middle Ages it was held that although the preparation of a living person, or of something like one in the form of a "homunculus", in a retort by the mixing and distillation of various chemical substances was extremely difficult and impious, nevertheless it was undoubtedly something which could be done. The production of animals from non-living materials seemed to the scientists of those times to be so simple and ordinary that the well-known alchemist and doctor, van Helmont, actually gave a receipt according to which it was possible to prepare mice artificially by placing damp grain and dirty rags in a covered vessel.

There are a number of writings from the sixteenth and seventeenth centuries describing the transformation of water, stones and other inanimate objects into reptiles, birds and beasts. Grindel von Ach even gives a picture of frogs formed from May dew, while Aldrovandi gives drawings which show how birds and insects arise from the twigs and fruit of trees.

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The idea that the maggots in rotting meat, fleas in dung and intestinal worms are generated spontaneously from decaying materials was generally accepted as an unalterable truth which was in full accord with Holy Writ. Also, in the writings of those times, we often meet with numerous texts by means of which the authors hope to convince their readers that the theory of spontaneous generation has the full support of the Bible.

However, the further science developed and the more the study of nature came to involve the use of accurate observations and experiments rather than just argument and philosophizing alone, the narrower became the region in which the learned men believed that spontaneous generation could occur.

As early as the middle of the seventeenth century Redi demonstrated by simple experiments that there was no basis for the opinion that spontaneous generation of maggots takes place in rotting meat. He covered the meat with a thin gauze and thus made it inaccessible to those flies from whose eggs the maggots would develop. Under these conditions the meat putrefied but no maggots whatsoever appeared. It was as simple as that to refute the idea of spontaneous generation of insects.

Thus, so far as living things visible to the naked eye were concerned, the theory of spontaneous generation had no support. However, at the end of the seventeenth century Kircher and van Leeuwnhoek discovered a world of tiny creatures, invisible to the naked eye, and only discernible with the microscope. These "tiny living beasties" (as van Leeuwnhoek called the bacteria and infusoria which he had discovered) were to be found wherever decay was taking place; in decoctions and infusions of plants which had been allowed to stand for a long time, in decaying meat and broth, in sour milk, in dung and in the fur on teeth. "There are more of them (microbes)", wrote van Leeuwnhoek, "than there are people in the United Provinces". It was only necessary for a substance which sours quickly and decays easily to stand for some time in a warm place for microscopic living creatures which had not been there before to develop in it immediately. Where did these creatures come from? Had they really arisen from germs which had happened to fall on the decaying material? How many of these germs there would then have to be everywhere. The idea inevitably arose that it was indeed in the rotting decoctions and infusions that the spontaneous generation of living microbes from non-living material took place. This view received strong support in the middle of the eighteenth century from the work of the Scottish clergyman Needham. He used meat broth or decoctions of vegetable material which he placed in completely closed vessels and boiled for a short while. By doing this Needham reckoned that he must have destroyed all the germs which were present and new ones could not get in from outside because the vessels were completely covered. Nevertheless, after a short while microbes appeared in the liquids. From this demonstration Needham drew the conclusion that he was witnessing the phenomenon of spontaneous generation.

However, there was another learned man who opposed this view. He was the Italian, Spallanzani. He repeated Needham's experiments and became convinced that more prolonged heating of the vessels containing the organic liquids sterilized them completely. A bitter quarrel raged between the proponents of the two opposite viewpoints. Spallanzani showed that, in Needham's experiments, the liquids had not been heated enough and that the germs of living things were still present in them. Needham retorted that it was not he who heated his liquids too little, on the contrary, Spallanzani heated his too much and by such rough treatment destroyed the "generative power" of the organic which was very tricky and unstable.

Thus, each of the contestants stuck to this opinion and the question of the spontaneous generation of microbes in putrefying liquids was not solved one way or the other for a whole century. During this time quite a large number of attempts were made to prove or disprove by experiment the occurrence of spontaneous generation, but none of them gave a definitive result. The question became more and more embroiled and it was not until the middle of the nineteenth century that it was finally solved by the studies of a French scientist of genius – Pasteur.

Pasteur first showed the extremely wide distribution of microbes. In a series of experiments he showed that everywhere, but especially near human habitations, the air contains tiny germs. They are so light that they float freely in the air, only falling to the ground ver slowly. On the slightest breeze they fly up again and are carried around us invisibly. The air of large towns is positively swarming with these crumbs of life. A single cubic metre of the air in Paris in summer contains up to 10.000 viable germs. If they encounter favourable conditions they grow, develop and begin to multiply at an extraordinary speed causing the decomposition of liquids which putrefy easily. Thus, it is not the putrescent liquids which give rise to the microbes but the microbes falling from the air which cause the putrefaction of the liquids.

Pasteur explained the mysterious appearance of micro-organisms in the experiments of earlier authors being due to incomplete sterilization of the medium of insufficient protection of the liquids against the access of the germs which might enter it with the air, the, in a hundred per cent of cases, there will be no putrefaction of the liquid and no formation of microbes.

Pasteur used a great variety of devices for sterilizing the air entering his retorts. He sometimes heated it in red-hot tubes of metal or glass; sometimes the neck of the flask was plugged with cotton wool in which all the minute particles carried in the air were trapped; or finally, sometimes the air was passed through a fine glass tube shaped like the letter S, in which case all the germs were trapped mechanically on the damp surfaces of the curves of the tube. Whenever the precautions were sufficiently reliable the appearance of microbes in the liquid was not observed. Maybe, however, the prolonged heating had changed the medium chemically and made it unsuitable for supporting life. Pasteur easily refuted this suggestion. He dropped into the sterilized liquid the cotton-wool plug through which air had passed into the retort and which therefore contained germs. The liquid quickly putrefied. The boiled liquid was, thus, a perfectly suitable soil for the development of bacteria. The only reason why this development did not occur was the absence of seed in the form of germs. As soon as the germs fell in the liquid they began to grow at once and gave a good harvest.

Finally, Pasteur succeeded in showing that it is possible to keep such easily putrefied liquids as blood and wine for long periods even without any heating. It was only necessary to remove them from the animal (where they do not contain bacteria) aseptically, that is, taking precautions against bacteria falling into them from outside.

Thus, Pasteur's experiments showed beyond doubt that the spontaneous generation of microbes in organic infusions does not occur.

All living organisms develop from germs, that is to say, they owe their origins to other living things. But how did the first living things arise? How did life originate on the Earth? In what follows theories will be examined which attempt to solve this problem.

The Theory of Panspermia

Pasteur is rightly considered as the father of the science of the simplest organisms, i.e. microbiology. His work gave the impetus to extensive studies of a world of minute creatures, invisible to the naked eye but inhabiting the earth, water and air. The investigations undertaken were not now, as formerly, directed merely towards describing the form of the micro-organisms; bacteria, yeasts, infusoria, amoebae, etc., were studied from the point of view of the conditions necessary for their life, their nutrition, respiration and multiplication; from the point of view of the changes which they bring about in their environment and finally from the point of view of their internal structure in its finest details. The further these studies proceeded the clearer it became that the simplest organisms were by no means so simply constructed as had once been thought.

The body of any organism, whether it be plant, mollusc, worm, fish, bird, beast or man is made up of very small droplets which are only visible under the microscope. It is built up from these droplets or cells as a house is built of bricks. The various organs of different animals and plants are composed of cells of different sorts. In becoming adapted to the work carried out by a particular organ the cells of which it is composed are changed in one way or another but, essentially and in principle, all the cells of all organisms are alike. Micro-organisms differ only in that their whole bodies consist of a single cell. This similarity in principle between all organisms confirms the idea, now generally accepted in scientific circles, that all living things on the Earth are connected with one another; they form, so to speak, a family of blood relations. The more complicated organisms arose from simpler ones which gradually changed and grew more efficient. Thus, it is only necessary to explain how some very simple organism could have been formed in order to be able to understand the origin of all plants and animals.

However, as has already been said, even the simplest creatures, consisting of only one cell, are extremely complicated structures. Their main component, called protoplasm, is a semi-liquid, ductile, gelatinous substance, permeated with water but not water soluble. Protoplasm is made up of a large number of extremely complicated chemical substance (mainly proteins and their derivatives) which are never found except in organisms. These substances are not simply mixed but are in a special state which has not yet received much study. Owing to this the protoplasm has an extremely fine structure which is poorly differentiated even under the microscope, but is extraordinarily complicated. The idea that such a complicated structure with a completely determinate fine organization could arise spontaneously in the course of a few hours in structureless solutions such as broths or infusions is a wild as the idea that frogs could be formed from the May dew or mice from corn.

The extreme complexity of the structure of even the simplest organisms struck some scientists so forcibly that they were sure that an impassable abyss existed between the living and the dead. The transition from dead to living or organized seemed impossible, either in the present or in the past. "The impossibility of spontaneous generation at any time whatever", writes the well-known English physicist W.Thomson, "must be considered as firmly established as the law of universal gravitation".

How then did life appear on the Earth? There was a time when, according to the views now generally accepted among scientists, the Earth was a white-hot ball. Astronomy, geology, mineralogy and other exact sciences provide evidence for this and it is beyond doubt. This means that conditions on the Earth are such that it was unthinkable, not to say impossible, for life to exist on it. Only after the Earth had lost a considerable amount of its heat by dissipating it in the cold of interplanetary space, and the cooling had gone so far that the water vapour had formed the first hot seas, did the existence of organisms like those we now see become possible. In order to explain this contradiction a theory was evolved which bore the rather complicated name of "panspermia".

H.e. Richter was the originator of this theory. Starting from the hypothesis that everywhere in space there are small particles of solid material (cosmozoa) which have been cast off by celestial bodies, the author suggested that along with these particles and possibly attached to them, there were the germs of micro-organisms. Thus these germs could be carried from one celestial body which was not yet inhabited by organisms to another which was not yet inhabited. If on this body the conditions of temperature and moisture were suitable for life, then the germs would begin to grow and develop and would be the original parents of all the organic creatures on the planet concerned.

This theory attracted many supporters in the world of science, among them such outstanding minds as those of Helmholtz and W.Thomson. Its proponents were mainly concerned to demonstrate scientifically the possibility of such a transfer of germs from one heavenly body to another with conservation of their viability. In fact, when all was said and done, the main question was whether or not spores could complete such a long and dangerous journey as a flight from one planet to another without being destroyed and while retaining the ability to grow and develop into a new organism. Let us examine closely what dangers the germ would meet on the way.

In the first place there is the cold of interplanetary space, about –220º C. Having been cast off from its home planet the germ would be doomed to spend long years, centuries or even millennia at such an appalling temperature before some lucky change would give it the possibility of arriving in a new world. The question inevitably arises as to whether the germ could survive such an ordeal. To solve this problem experiments were made on the resistance to cold of present-day spores. Experiments along these lines showed that spores tolerate cold excellently. They remain viable even after having been kept at –220º C for six months. Of course, six months is not 1.000 years but, all the same, this experiment give us reason to suppose that at least some spores could stand the severe cold of interplanetary space.

A far more severe danger to germs is presented by their complete lack of protection from light rays. Their path between the planets is penetrated by the rays of the Sun which are destructive to most microbes. Some bacteria are destroyed by the action of direct sunshine after only a few hours while others are more stable, but all, without exception, are unfavourably affected by very strong irradiation. This unfavourable effect is, however, considerably mitigated when there is no oxygen in the atmosphere, and we know that there is no air in space so we have some reason to suppose that germs of life could survive even this ordeal.

But let us assume that a lucky chance has given our germ the opportunity of falling into the gravitational field of some planet on which the conditions of temperature and moisture are favourable for the development of life. It remains only for the wanderer to submit to the gravitational force and to fall on its new land. But here, at once, just as it is reaching its destination in space, a terrible danger awaits it. Before this germ had been in air-free space, but before it can arrive at the surface of the planet it must pass through a fairly thick layer of air which surrounds its planet on every side.

The phenomenon of "falling stars" (or meteorites) must be well known to everyone. Scientist now explain this phenomenon as follows: there are, floating in interplanetary space, lumps of material of greater or lesser size, fragments of planets or comets which have flown into our solar system from distant parts of the Universe. When they pass close to the Earth they are attracted to it, but before they can fall on it they have to pass through the atmosphere. Owing to the friction of the air the quickly falling meteorite becomes heated to white heat and becomes visible against the dark vault of the sky. Only a few of these meteorites reach the Earth in the form of red-hot stones from the sky. Most of them get burnt up by the intense heat long before they reach its surface.

A similar fate must befall the germs. However, various considerations indicate that destruction of this sort need not necessarily occur. There is reason to suppose that at least some of the germs reaching the atmosphere of any planet would reach its surface in a viable state.

Furthermore, there is no need to dwell on colossal, astronomical periods of time during which the Earth could have been sown with germs of life from other worlds. These periods are reckoned in millions of years. If, during this period, even one of the thousands of millions of germs could have reached the surface of the Earth satisfactorily and found there conditions suitable for its development, then this would be enough for the formation of the whole organic world. All the same, in the present state of scientific knowledge, this possibility, though conceivable, seems not to be very probable. [*]In any case we have no facts which would directly contradict it.

However, the theory of panspermia is only the answer to the problem of the origin of earthly life, and not in any way to that of the origin of life in general.

Carus Sterne writes: "If this hypothesis merely pushes the beginning of life backwards to the time of the first appearance in the world of celestial space, then, from the philosophical point of view it is a

[*] Even such an out-and-out defender of the theory under discussion as Helmholtz says in this connection, "I cannot deny it if anyone thinks that this hypothesis is not very probable or even in the highest degree improbable". And he adds further that he is forced to take up the point of view of the theory of panspermia because of the complete impossibility of explaining the origin of life scientifically in any other way.

completely useless labour because whatever could have happened in the first world was also possible in the second and third and would be the act of creation or spontaneous generation".

"There are two possibilities", said Helmholtz, "organic life either began (came into being) at some time or else it has always existed". If we accept the former view, then the theory of panspermia loses all logical point, for, if life could originate at some point in the Universe, there is no reason to suppose that it could not originate on the Earth as well. The partisans of the theory under discussion therefore accept the theory of the eternity of life. They recognize that "life can only change its form, it can never be created from dead material". Thus they put an end once and for all to any further study of the problem of the origin of life. They try to set up an impassable barrier between the living and the dead and to impose a limit on the efforts of the human mind and on the boundless generalizations to which exact science leads it.

But do we have any logical right to accept the fundamental difference between the living and the dead? Are there any facts in the world around us which convince us that life has existed for ever and that it has so little in common with dead matter that it could never, under any circumstances have been formed or derived from it? Can we recognize organisms as formations which are entirely and essentially different from all the rest of the world?

We shall try to give an answer to these questions in the next chapter.

The World of the Living and the World of the Dead

The first and most eye-catching difference between organisms and the rest of the (mineral) world is their chemical composition. The bodies of animals, plants and microbes are composed of very complicated, so-called organic substances. With very few and insignificant exceptions we do not find these substances anywhere in the mineral world. Their main peculiarity consists in the fact that at high temperatures in the presence of air they burn while in the absence of air they carbonize. This shows that they contain carbon. This element is present in all organisms without exception. It forms the basis of all those substances of which protoplasm is made up. At the same time, however, it is no stranger to the mineral world.

The diamond is certainly more or less well known to everyone. It is a precious stone which, in the cut form, is much used as an adornment under the name of brilliant.

As early as 1690 the English scientific genius Newton put forward the idea that diamond, the hardest and brightest body on the Earth, must contain combustible material. This suggestion was quickly confirmed. A diamond was submitted to trial by fire at the focal point of a burning mirror. It did not survive the test but became covered with cracks, glowed and burnt away before everyone's eyes. Later and more accurate experiments showed beyond doubt that the shining diamond is the blood-brother of the unattractive graphite, the substance from which pencils are made. Both consist entirely of carbon. They have no component other than this element.

However, carbon is met with in the mineral world, not only in the pure state, but also in combination with other elements. Chalk, marble, soda, potash and other compounds all contain carbon. In general, one of the most valuable properties of carbon is its tendency to form the most varied compounds with other elements. In the substances which make up the bodies of organisms the carbon is always found combined with hydrogen, oxygen, nitrogen, sulphur and phosphorus and often with several other elements. All these elements are widely distributed in the non-living world. In combination with oxygen, hydrogen forms water; the air around us consists of a mixture of oxygen and nitrogen; sulphur and phosphorus are found in many of the minerals which make up rock formations. Thus we see that all the elements which enter into organic compounds are also found in abundance in mineral world. Even this alone gives reason to doubt the existence of any essential difference between the world of the living and that of the dead.

It may be, however, that this difference concerns not so much the elementary compositions as the actual compounds made up from the elements.

It has been considered that the substances of the organic and inorganic (mineral) world are so unlike one another that the former could not be obtained from the latter by artificial means under any circumstances. Some chemists of that time even maintained that it was impossible to obtain organic bodies simply because these substances could only be formed within the living organism by the action of a special "vital force". However, as early as 1828 the chemist Wöhler succeeded in preparing an organic substance artificially and so to cast doubt on the importance of the famous "vital force".

Since then the study of organic compounds has been advancing with rapid strides, and the further it has gone the clearer has become the falsity of the idea that there is a fundamental difference between these substances and inorganic bodies. Starting from the simplest inorganic substances, chemists can now prepare artificially almost all the substances which are encountered in organisms. Although some of these substances have not yet been obtained there is no doubt that they can be obtained in the near future. The structure of these substances has been studied in extreme detail. No special means of combination of the individual elements has been found in them. They obey the same physico-chemical laws with the same constancy as inorganic compounds.

The essential similarity between organic and inorganic substances has now become so obvious that not a single serious natural scientist would deny it and the protagonists of the view that there is a fundamental difference between the living and the dead have already stopped. They assert that organic compounds whether prepared artificially or isolated from organisms are just as dead as minerals. Life may be recognized only in bodies which have particular special characteristics. These characteristics are peculiar to living things and are not seen in the world of the dead.

What are these characteristics? In the first place there is the definite structure or organization. Then there is the ability of organisms to metabolize to reproduce others like themselves and also their response to stimulation.

Let us go over each of these characteristics and see whether it is really present only in the living organism or whether it is not, in some form or another, also found in the mineral world.

The most important and essential characteristic of organisms is, as is demonstrated by their very name, their organization, their particular form or structure. The bodies of all living things, beginning with the smallest bacteria and algae and ending with man, are constructed according to a definite plan in which the greatest importance attaches, not to the external visible organization but to the fine structure of the protoplasm of the cells which make up the organism. This structure is the same in general for all members of the animal and vegetable kingdoms. Unfortunately it has still not been studied very much. Various investigators have seen different structural formations in the semi-liquid protoplasm in the form of fibres, networks and alveoli. However, as these formations are so extremely small it is very hard to see them, even with the best microscopes now available. All the same it is certain that protoplasm has a definite structure and is not a homogeneous lump of slime. This structure holds the secret of life. Destroy it and there will remain in your hands a lifeless mixture of organic compounds.

Some scientists believe that this structure itself, this organization, could not haven been formed spontaneously from structureless and, according to them, lifeless substances. Following the ancient Greek philosopher Empedocles, they repeat, in one form or another, the idea that the organization is closely bound up with the spirit which both constructs the body and is destroyed or flies away when the particular form is annihilated. However, if we adopt this position we must agree with another philosopher, Thales, in ascribing a spirit to a magnet since this extremely simple spirit which expresses itself in the attraction which iron holds for the magnet, depends on the structure of the magnet, that is to say on the arrangement of the particles in it. This structure has only to be disturbed, as when a magnetic stone is ground up in a mortar, and it will lose its spirit just like an organism which has been cut into pieces.

The world of the dead or mineral world is certainly not lacking in definite forms, it is not structureless. It is a property of most chemical substances that they try to take up particular forms, that is to form crystals. We now know that the finest particles of the substance forming the crystals are not just arranged anyhow in them, but are arranged according to a definite plan depending on the chemical composition and the conditions under which the crystals are formed by separation from a solution or from the molten state. It is here that a transition takes place from the hitherto formless, structureless substance to the organized body. In a solution the smallest particles of the substance are in disorder; the same is true even when a substance is melted. However, when a crystal separates out, the particles arrange themselves relative to one another in a strict order, like soldiers forming straight ranks on the command "Attention!" The form of the crystal and the whole range of its other properties depend upon this arrangement. If the crystal is destroyed by disturbing the arrangement of the particles all these properties disappear.

There is thus no doubt that even the simplest crystals have a definite arrangement. At first glance this arrangement seems to be extremely simple. However, we shall immediately put this idea aside if we remember those marvellous "ice flowers" which appear on the panes of our windows on a frosty day. In their delicacy, complexity, beauty and variety these "ice flowers" may even look like tropical vegetation while all the time being nothing at all but water, the simplest compound we know. In small droplets of it the particles were scattered in disorder but they were cooled, the wind blew, the temperature fell below zero and these particles, complying with the eternal laws of nature, which are the same for both the living and the dead, arranged themselves in a definitive order and, on the simple window pane, they produce pictures of fabulous gardens, glistening in the sunshine with all the colours of the rainbow.

If we leave the simplest compounds aside and go on to look at those forms which produce more complicated substances an even more varied and involved picture will be presented to our gaze which, in its complexity, is in no way inferior to the most detailed picture of the structures of organisms. However, before we enter on this review we must make a small excursion which, though perhaps rather tedious, is necessary for our further discussion into the realms of the comparatively young science of colloid chemistry which has already acquired great importance.

As early as 1861, the English scientist, Graham, divided all the chemical bodies known at that time into two main classes, crystalloids and colloids. To the first class belonged such substances as various salts, sugar, organic acids and so forth. The substances in this group formed crystals easily and, when dissolved, gave clear and completely transparent solutions. If such a solution is poured into a bag made of vegetable parchment or the bladder of an animal and the bag is placed in pure water, the dissolved substance will pass through the walls of the bag and be washed out of it by the water.

Colloids present a completely contrary picture. They very seldom crystallize and then only with great difficulty. Their solutions are usually cloudy and they cannot pass through vegetable or animal membranes. Graham assigned such substances as starch, proteins, gums and mucus to this group.

It turned out later that such an assignment of all substances between two groups was not altogether correct since the same chemical compound could turn up both as a colloid and as a crystalloid according to the conditions of the solution. Thus "colloidness" was not a property of a particular substance but of its particular state.

There was, however, a considerable element of truth in the classification made by Graham since substances which have very large and complicated particles very often and easily give rise to colloidal solutions. The study of the colloidal state is therefore of special importance since the vast majority, if not all, of the substances of which protoplasm is made up have very large and complicated particles and therefore must give colloidal solutions.

As we have already said, colloidal substances do not give crystals, but still they are fairly easily precipitated as clots or lumps of mucus or jelly. We may take as our example of such formations the protein of eggs which is precipitated on boiling and the gelatin which sets on cooling (well known to everyone as a jelly). The separating out of such coagulates or precipitates from previously uniform solutions sometimes takes place amazingly easily for apparently insignificant reasons.

The coagulates or gels obtained by precipitating colloids are, at first sight, quite structureless. If we examine a lump of jelly under the microscope, even at a high magnification, it appears to us quite uniform. However, scientists have now invented very effective instruments with which they have succeeded in revealing the complicated structure of coagulates. Here it is not a question of straight lines and planes such as we meet in crystals, for here we have a whole network, a whole skein of fine threads which are interlaced, separating from one another and coming together again in a definite, complicated order. Sometimes these threads are very fine, on the other hand, sometimes they are thickened, fusing with one another to form small enclosed bubbles or alveoli.

The structure of coagulates is strikingly reminiscent of that of protoplasm. Unfortunately this structures has not yet been sufficiently well studied for us to be able to say anything conclusive about this resemblance. However, there can be no doubt that we are dealing here with phenomena of the same order. There is no essential difference between the structure of coagula and that of protoplasm.

It may be, however, that the difference between living and dead does not lie in the organization which, as we have seen, is present in both worlds, but in the other features which we mentioned, the ability of living organisms to metabolize to reproduce themselves and to respond to stimuli.

The shapes of crystals are unalterable, they are formed once and for all, while an organism may be compared with a waterfall which keeps its general shape constant although its composition is changing all the time and new particles of water are continually passing trough it. The composition of the living body changes in just the same way. The organism takes in different substances from its environment; after a number of chemical changes it assimilates these substances, transforming what had been foreign compounds into parts of its own body. The organism grows and develops at the expense of these substances. However, just a factory requires a certain amount of fuel to carry on its work, so, if the organism is to carry on its unceasing activities it should consume, that is to say break down, at least part of the material which it has assimilated, and this is what actually happens. In the process of respiration or fermentation the organism breaks down substances which it has already taken in and the products of their degradation or decomposition are given off into the environment. Thus life consists of continual absorption, construction and destruction.

However, if we make a detailed analysis and simply contemplate the phenomenon of metabolism which has been described, we shall not find, even here, anything specifically characteristic of the living world. In fact, the phenomenon of feeling, the assimilation of substances from the environment, is, of course, found in its simplest form even in crystals. Thus, a crystal of common salt, which is well known to everyone, will, if it is immersed in a supersaturated solution of the same substance, increase its size and grow by absorbing individual particles of substance from its environment (the solution) and making them part of its body. Even here, in this simple phenomenon, we have before us all the characteristic features of the phenomenon of nutrition. There is even more similarity between this phenomenon and the processes which occur in colloidal coagula. A lump of such material has the ability to extract from solution and absorb the most varied substances such as dyes. These latter do not just remain on the surface of the lump but penetrate deeply into it, some of them simply adhering to the tangled threads which constitute the lump while others enter into chemical reactions with these threads and combine firmly with them, forming component parts of the whole lump.

Study of the process of feeding of living protoplasm shows that this process too takes place in exactly the same way as has just been described. Solutions of different chemical substances penetrate into the protoplasm as a result of the action of comparatively simple and thoroughly studied physical forces, just the same forces which operate in colloidal coagula. Having entered into the protoplasm, one substance will quickly pass out of it while others will enter into a chemical reaction with it, combine with it and become parts of it. And here, all in wall, we have a simple chemical reaction and not anything mysterious such as could only be accomplished by a "vital force".

Thus, when various chemicals are absorbed by lifeless coagula we are dealing with processes which take place in a way which is completely analogous with the first stage of metabolism, that is to say, feeding.

The following example shows that, even in the world of the dead, we can find processes which are essentially just the same as metabolism as a whole. If we take a small piece of so-called spongy platinum (platinum is one of the "noble" metals which can be obtained by special methods not as sheets or solid lumps, but as a very delicate sponge with very fine holes and delicate walls) and throw it into a solution of hydrogen peroxide in water* then bubbles of oxygen will immediately begin to form on the surface of the lump. They are formed by the breakdown of the hydrogen peroxide and the process goes on quite rapidly and only stops when all the hydrogen peroxide has been broken down to oxygen and water. If we then remove, dry and weigh our piece of platinum we shall find its weight has remained just as it was before. The same piece may again be thrown into a new amount of hydrogen peroxide and will again decompose it quickly while itself remaining unaffected. Thus, a comparatively small piece of spongy platinum can decompose an unlimited quantity of hydrogen peroxide.

Chemist have been interested in the mechanism of this process for a long time, and as a result of many investigations we now know for certain that the decomposition of hydrogen peroxide by platinum takes place in the following way. First the peroxide is adsorbed on the platinum. As the peroxide cannot penetrate into the metal this adsorption only takes place on its surface. That is why it is important to use spongy platinum for this experiment as it has a very large surface at which the metal is in contact with the liquid. The particles of peroxide do not simply adhere to the surface of the platinum but form a chemical compound with it, namely the hydrate of platinum peroxide. Thus the piece of metal, like the living organism, extracts particles of hydrogen peroxide from water and assimilates them into its body. However, it does not end at that. After a short time the hydrate of platinum peroxide on the surface of the metal breaks down to platinum, water and oxygen, the last being given off in the form of bubbles of gas. The reduced platinum can combine with a new portion of hydrogen peroxide and again break it down, the products of the decomposition being oxygen and water. The process is repeated until there is no hydrogen peroxide left in the solution surrounding the metal.

In the example given we have the simplest but still complete prototype of metabolism. It contains all the important elements of this process. The absorption of substances from the surrounding medium, their assimilation and breakdown and the giving off of the products of

* Hydrogen peroxide is a chemical compound which, like water, is composed of hydrogen and oxygen only but there is twice as much oxygen in it as in water. This compound is fairly stable and can usually stand for a very long time without breaking down. When it breaks down for any reason it gives rise to oxygen and water.

their decomposition. Just the same process takes place in any living organism, for example in any bacteria cultivated in a solution of nutritive substances. The bacteria absorb the substances from the solution, assimilate them and then break them down, giving off to the outside the products of their decomposition. Thus, a simple piece of metal behaves in just the same way as a living organism.

In this connection it must be pointed out that both phenomena (the metabolism of organisms and the decomposition of hydrogen peroxide by platinum) are not only similar, in their external form, but the actual mechanism of the process is similar in both cases. In all organisms, without exception, metabolism is brought about by means of so-called enzymes. This name is given to substances, the chemical nature of which is still only poorly understood, but which can comparatively easily be isolated from any animal or plant in solution in water or as a powder which is easily dissolved in water. All enzymes now known have the power to act on substances forming part of the living body in a very remarkable way. They alter these substances in one way or another (either by breaking them down or by causing them to combine with one another) while themselves remaining completely intact. A detailed study of this phenomenon has shown that enzymes act on the different organic compounds of the living body in just the same way as does platinum on a solution of hydrogen peroxide. In fact metabolism, in its most important aspects, does not consist of anything but a long series of successive enzymic processes following one another and related to one another like the links of an unbroken chain.

At present one of the most extensive sections of physiology, the science which studies the functioning of living organisms, is devoted exclusively to the problem of metabolism. The further the study of tins complicated process goes on, the more closely and accurately we got to know the essential features of the processes which are carried out in the living cell, the more strongly we become convinced that there is nothing peculiar or mysterious about them, nothing that cannot be explained in terms of the general laws of physics and chemistry.

Thus, even the ability to metabolize cannot be taken as a special characteristic peculiar to living organisms.

We still have two "peculiarities of life" left to discuss, namely, the capacity for self-reproduction and response to stimuli.

In what does the capacity of organisms for self-reproduction consist? In the simplest case it amounts to this: the elementary organisms, the cell, divides itself into two halves each of which then grows into a new daughter cell in which the structure of the mother cell is reproduced down to the finest detail. This property, however does not belong only to organisms, but to all bodies possessing a definitive structure, without exception. Let us take the simplest case as our example. If we take a crystal of any substance such as alum, break it into two halves and place them in a supersaturated solution of the same substance what will happen will be that the halves of the crystal which had been placed in the solutions will quite quickly replace their missing faces, angles and edges at the expense of particles which had previously been floating freely in the solution. Before growing larger they take a form which reproduces in the finest details that of their mother, the original crystal.

The question may, however, arise that in the example which we have given we forcibly broke the crystal whereas the division of the cell apparently takes place spontaneously. Is that not the fundamental difference between the two phenomena? The fact is, however, that it only seems to us that the division of cells takes place spontaneously, it really takes place under the influence of definite physical forces (capillary attraction, surface tension) which, though they certainly have not yet received much study, still are of just the same kind, in principle, as all the other physical forces.

An even more interesting phenomenon is that of the "seeding" of supersaturated solutions. It occurs as follows. In some case it is possible to concentrate a solution of a particular substance very strongly without that substance separating out in the solid form. However, if the most minute crystals will immediately begin to separate out of the solution, sometimes in such quantities that the whole mass becomes crystalline.

This shows that a crystal can cause the formation of bodies like itself which would otherwise not have been formed. If the particles which are scattered at random throughout the solution are to arrange themselves according to a definite plan to give a definite organization or form, that form must already be present.

Here we have the occurrence of the most amazing phenomena which may serve as a key to the understanding of other extremely complicated phenomena of the same order. "Let us take the example of sulphur" as Carus Sterne says, "this is known to be a simples substance yet it depends on the temperature at which it changes from the liquid to the solid state which of two very different forms it will take, octahedral or prismatic*. If we place two such crystals on fine the platinum wires in a supersaturated solution of sulphur in benzine then, in the neighborhood of the prismatic crystal new prisms will be formed while octahedra will be formed near the octahedral crystal. When the two armies of crystals approach one another, the latter form is victorious at the first clash. Here is an example of the struggle for existence in the realm of crystals!".

Let us now go on to take a look at the last of the peculiarities of living things which we mentioned, that is, at responsiveness to stimuli. In all living things without exception we meet with a property which in its most general form may be described as follows. In an organism external and internal stimuli will cause something of the nature of a discharge and will induce the performance by it of some definite action (e.g. movement, etc.) which will carry out in a particular way according to its structure and the means at its disposal. It is a very characteristic feature of responsiveness that there should be a quantitative disparity between the energy, that is to say the forces, required to excite or bring about the response, and the work which is the response of the organism to the stimulus in question. Thus, for example, a relatively slight touch can be enough to induce the organism to move from one place to another or to carry out some other work requiring the expenditure of much force. The organism draws from within itself the forces (energy) required for this work.

Some scientists believe that responsiveness is a specially characteristic feature of organisms. However, if we take this view we shall have to regard a railway locomotive with the steam up as a living

* On crystallizing, different substances take on regular geometrical shapes. The crystals are characterized by these forms. Some substances may crystallize in different forms under different conditions. In particular, sulphur can give crystals in the form of octahedra (two four-sided pyramids joined together by their bases) or hexagonal prisms.

thing. In fact it is only necessary to apply a slight stimulus by shifting a lever and the locomotive will start to move, carrying out a very considerable amount of work at the expense of the fuel which is burnt in its boiler. This work is many times greater than that expended in moving the lever and is carried out in complete accordance with the structure of the locomotive.

Responsiveness is to be found, not only in organisms, but also in any physical body which has any noteworthy store of hidden (potential) energy. Comparatively insignificant causes may lead to the discharge of this energy which will lead to the carrying out of some particular work. A landslide caused by a comparatively slight movement of the air, the explosion of a powder magazine caused by a spark which happened to fall in it –these are very simple cases of the phenomenon of responsiveness.

With this we will finish our short review of the main feature of living organisms. We have seen that not one of these can be held to be inherent only in living things. But if this is so we have no reason to think of life as being something which is completely different in principle from the rest of the world. If life had always existed and had not arisen by generation bodily from the rest of the world, if it had not separated itself or, crystallized out at some time from this world, then it would inevitably have had characteristics peculiar to itself. But this is not so. The specific peculiarity of living organisms is only that in them there have been collected and integrated an extremely complicated combination of a large number of properties and characteristics which are present in isolation in various dead, inorganic bodies. Life is not characterized by any special properties but by a definite, specific combination of these properties.

In course of the colossal length of time during which our planet, the Earth, has existed, the appropriate conditions must certainly have arisen in which there could have been the conjunction of properties which were formerly disjoined to form the combination which is characteristic of living organisms. To discover these conditions would be to explain the origin of life.

From Uncombined Elements to Organic Compounds

Astronomers tell us that very, very long ago, millions, perhaps even thousands of millions of years ago, the Earth existed in the form of an enormous cloud of incandescent gas. We cannot yet form any accurate idea of the extreme heat which prevailed in that cloud which represented the Earth of the future. In any case it was considerably higher than the highest which we can yet obtain artificially, temperatures at which metals such as iron boil, turning into vapour like water when it falls on a red-hot stove. Under these conditions there could be no question of the occurrence of any chemical compounds. Even at lower temperatures all the compounds we know breakdown into their simplest components, the elements. These elements exist as very small particles of matter (atoms) which were distributed freely and haphazardly in space and constituted the earliest cloud from which the Earth was later to arise. This was the primaeval chaos in which, it seems, everything was in disorderly, unrelated and irrational movement.

We can form some idea of such a state of matter from a study of the gases or vapours obtained by raising a great variety of materials to white heat. In the puffs or clouds of these vapours the individual particles of matter are also in constant motion, just as were the particles in the original cloud.

A study of matter in the vapour state had led scientists to the belief that even in the primaeval cloud there was not absolute chaos, but even there, affected by the eternally acting forces of physics, a certain order slowly but surely began to establish itself. In the firs place the particles of the different elements of which the cloud was composed began to distribute themselves within it in some sort of order. Under the influence of that same force of gravity which attracts the falling stone towards the centre of the Earth, the heavier atoms in the cloud began to sink towards its centre while the lighter ones remained at its surface. Thus, the gases forming the cloud were more or less separated out into layers in it, the heavier ones being below, at the centre, while the lighter ones were on the surface.

As the cloud cooled, the material in it became denser and at a particular moment it went over from the vapour to the liquid state. In the centre of the cloud a red-hot liquid nucleus was formed, surrounded on all sides by an immense envelope of incandescent gas. It is quite reasonable that the nucleus should have been composed for the most part of the heaviest elements while the lighter ones remained in the gaseous atmosphere enclosing this nucleus.

According to the views of D.I.Mendeleev, the first nucleus of the Earth must have been composed of heavy metals, mainly iron, while further from the centre there were the alkali and the alkaline earth metals[*], the metalloids and, finally, the outermost part of the atmosphere was composed of the lightest gases, mainly hydrogen. Carbon, the element which interests us most, should, by this scheme, be present in the primaeval nucleus of the Earth in very close association with iron.

The idea is not the result of some theoretical speculations, but is firmly based on facts. It is easy to convince ourselves of this by going back to a study of present-day conditions. In fact, if the heaviest elements were at some time in the centre of the Earth they should still be there. That is to say, if the idea put forward above were true the heaviest elements should be found in the depths of the Earth even today.

Unfortunately, only a thin skin on the surface of the Earth is accessible to study by Man. We can only penetrate a few thousand feet into the depths of the Earth and this means that we cannot see with our own eyes what exist in its interior. However, scientists have succeeded in obtaining a very clear picture of it in other ways. They have managed, though this may seem strange at first sight, to weigh the Earth as a whole. Of course its weight is extremely great. In round figures it is 4 quadrillion Kg. By direct measurements of the surface they have also determined its volume. What they found was that the weight was nearly six times that of an equal volume of water. We know, of course, that the

[*] The commonest alkali metals are potassium and sodium. Calcium, magnesium, barium and strontium are alkaline earth metals. The vapour density of these metals is considerably less than that of the heavy metals iron, copper, lead, mercury, silver, etc.

crust of the Earth does not consist of water alone, but even in its densest parts it does not have a mean specific gravity as great as five to six times that of water. The specific gravity of the crust does not exceed two and a half. Thus, the Earth as a whole has a far higher specific gravity than has the outer part of it which is accessible for us to study. It is so heavy that its weight can only be explained on the supposition that it has a nucleus of heavy metal inside it.

This view is also supported by study of the masses of lava which are extruded from the depths on to the surface of the Earth by volcanoes. The older the mass and the deeper the region from which it poured on to the surface, the greater the amount of heavy metals it contains, especially iron.

Thus, the evidence which we can obtain by studying the state of affairs on the Earth now provides very definite confirmation of the ideas which we have put forward above. The results of studying the heavenly bodies are even more instructive.

Scientists now believe that each of the stars which we see originated, in the same way as we described for the Earth, from a gaseous cloud, by gradual cooling and increasing density of the vapours of which it was formed.

Depending on a number of factors (mainly on the size of the cloud) the process of solidification might occur quickly or slowly. The different heavenly bodies are now, therefore, at different stages of development. Some of these stars shine with a white or bluish light and are in the earliest stage of development, others, which have developed further, are yellowish and our Sun is one of these. Finally, the stars which have cooled most and are already going out shine with a red light. A further stage of cooling is represented by the planets which can no longer shine with their own light. Our Earth is one of these. Thus, a study of the different heavenly bodies gives us an idea of the different stages of cooling of our own planet.

This study has made great strides forward since Kirchhoff developed what is called the spectral method of analysis. The essence of the method is as follows. If a ray of white light is passed through a glass prism it is divided into its component part parts and gives rise to a strip consisting of all the colours of the rainbow (spectrum). If we use the Sun (daylight passing through an opening in a shutter) or an electric light or any solid or liquid body heated to white heat as the source of light for our experiments, we shall obtain a continuous strip like a rainbow in which one colour gradually merges into the next. A different picture is obtained by passing light from incandescent gases through the prism. In this case the spectrum will not consist of a continuous but of individual lines, coloured by a particular colour and separated from one another by black spaces. In this connection it is especially interesting that each element has its own particular, completely characteristic distribution of bands in the spectrum. Thus, if we have an incandescent gas consisting of a mixture of elements we can, by studying the spectrum, find out just what elements are present in it. It is thus possible to analyse the mixture in this way.

This method of spectral analysis is so convenient and accurate that it has found wide application in the study and differentiation of many substances on the Earth, but its most important use has certainly been in astronomy as a method for studying the chemical composition of heavenly bodies.

From the furthest end of the Universe innumerable heavenly bodies send their light to the Earth. By studying this light with a spectroscope we can determine with accuracy which elements are present in the incandescent gaseous envelope of the star in question.

Specially interesting information is obtained by spectral analysis of the gaseous envelope of the Sun. The Sun, as we have already said, is one of the yellow stars. In the centre of it there is a huge, red-hot liquid nucleus, the spectrum of which takes the form of a continuous, rainbow-coulored strip. This nucleus is surrounded on all sides by an envelope of incandescent gas, the atmosphere. Spectroscopic studies of the lowest layers of this atmosphere have shown that it is composed of the incandescent vapours of heavy metals. Here the spectroscope reveals the presence of iron, nickel, cobalt, calcium and manganese, and Roland has even succeeded in finding carbon here. A little higher, further from the centre of the Sun, there is a layer of the atmosphere in which it is easy to demonstrate the presence of the vapours of the lighter alkaline metals, potassium and sodium. Even higher, helium is predominant: this is an element which was first discovered on the Sun*. Helium is a very light gas. Of all the materials known on the Earth hydrogen is the only one which is lighter.

Hydrogen, too, is found in the solar atmosphere. It lies just above the helium. Finally, above the hydrogen there is a layer of what must be an even lighter gas, coronia, which has not yet been found on the Earth.

Thus, the idea which we put forward about the arrangement of the elements in gaseous masses by layers and which was based on purely theoretical considerations has been completely vindicated by observations on the arrangement of the elements in the atmosphere of the Sun.

There was a time when the Earth, too, was passing through the same stage of development as the Sun, namely that of being a yellow star. Later, as it gradually radiated its heat outwards into the cold interplanetary space, it became cooler and cooler. It turned from a yellow star into a red one, its light became dimmer and dimmer and finally went out altogether. The Earth became a dark planet.

What was happening during these changes to the carbon and other elements which now enter into the composition of living organisms?

We have seen that, at the time when the Earth was a yellow star the carbon was present partly in the form of incandescent vapours in the lowest layer of the atmosphere and partly in the molten state in the hot, liquid, central nucleus. In both places it was mixed with heavy metals, mainly iron. The temperature prevailing on the Earth at that time was still too high for any chemical compounds to be formed. The elements, through mixed with one another, remained free and did not combine with one another.

However, the Earth gradually cooled and the time must certainly have come when combination took place between the free elements which were mixed with one another. Spectroscopic studies of the red stars lead us to the conclusion that this must first have taken place

* It was considerably later that the well-known British chemist Ramsay succeeded in isolating this element from an extremely rare mineral. Thus it was possible to confirm, by chemical methods, that helium had the properties which had for a long time been assigned to it on the basis of spectral analyses.

when the Earth passed from the stage of being a yellow star to that of being a red one.

The first compounds to exist on the Earth must have been extremely stable to high temperatures because only compounds of this sort could have existed for long in the heat which then prevailed. The most thermostable compounds of carbon now known are its compounds with heavy metals, known as "carbides". The commonly known representative of this class of compounds is iron carbide.

As the period of existence of the Earth which we are considering carbon vapour was, as we have seen, mixed with the vapours of metals. There is, therefore, good reason to suppose that carbides themselves were the first compounds to arise on the Earth. The existence of other compounds at this time was unthinkable simply because of the temperature.

Only when the Earth had dissipated some of its heat and cooled still further did there arise the possibility of the formation of other compounds and they bean to come into being, gradually clothing the central nucleus in a more or less thick envelope. This envelope, consisting of the substances which later gave rise to the rock formations, thus separated the carbides lying beneath them from the atmosphere of that time. However, the envelope was not very stable and in many places there must have been eruption of the internal material on to the surface of the Earth. At the same time, of course, the Earth was gradually cooling. The central nucleus shrank while its outer layers were forming a solid envelope. The latter could not follow the contraction of the underlying material and this gave rise to folds and cracks through which the red-hot carbides of metal poured out and erupted on to the surface of the Earth.

Such phenomena may be seen even now though, of course, on a much smaller scale. The eruption of volcanoes and the processes by which mountains are formed are explained by geologists in terms of just the same causes as we have given, namely the contraction of the Earth which is still continuing. It is true that the cracks which are formed now are, comparatively speaking, not very deep and the lava which erupts from volcanoes comes from a layer a long way above the central core, but it could not be otherwise, because the crust of the Earth has increased in thickness many times over since the time of the formation of the first envelope. Studies of volcanoes and masses of lava which have arisen at different periods of the existence of the Earth show that the most ancient volcanoes derived the products which they erupted from the deepest layers of the Earth.

Thus, at the period of existence of the Earth which we are considering, when it was a red star about to become extinguished, masses of carbides of iron and other metals which had formerly been concealed in its depths were being extruded on to its surface through cracks formed in its crust. Here, on the surface, they encountered the atmosphere of that time which differed in many respects from that of today. Water vapour was specially abundant in it. All the water in all the seas and oceans now on the Earth then existed in the form of superheated steam in the atmosphere. The carbides which flowed out on to the surface encountered this steam.

If we treat carbides of metals with superheated steam we obtain what are known as hydrocarbons, that is to say compounds consisting of carbon and hydrogen. These compounds must also have arisen when the carbides an steam met on the surface of the Earth. Of course some of these must immediately have been burnt, being oxidized by the oxygen of the air. However, under the conditions then prevailing this combustion must have been far from complete. Only a certain part (and a comparatively small one) of the hydrocarbons were fully oxidized, being converted to carbonic acid and water. A further part, owing to incomplete oxidation, gave rise to carbon monoxide and oxygen derivatives of hydrocarbons, while, finally, a certain proportion of the hydrocarbons completely escaped oxidation and was given off into the upper, cooler layers of the atmosphere without any alteration. The more the Earth cooled the lower became the temperature at which the interaction between the carbides and the water vapour took place, and less carbonic acid and more unoxidized hydrocarbons were formed.

Thus, the theoretical considerations put forward above lead us to the belief that at a particular time in the existence of the Earth compounds of carbon with hydrogen and oxygen were formed in its atmosphere. Let us see whether there are not facts in our natural surroundings supporting tins idea.

Since the period under discussion is that during which the Earth passed through the stage of being a red star it would be quite appropriate to consider first what we know about these stars. Spectroscopic studies of the darkest red stars which are about to go out, carried out by the astronomer Vogel, led him to the conclusion that the atmospheres of these stars contain hydrocarbons. This fact was soon confirmed by several other workers.

Hydrocarbon lines have also been found in the spectra of comets, those heavenly bodies which from time to time pass through our solar system from interplanetary space. Furthermore, thanks to the studies of several scientists it has been found that cyan[*] (a compound of carbon and nitrogen) and carbon monoxide are present in the gases which form the tails of comets.

By origin comets are related to a further class of heavenly bodies, the meteorites. We have already discussed these in an earlier chapter. Meteorites are specially interesting because, in falling, some of them reach the surface of our Earth in a more or less undamaged state in the form of red-hot stones from the sky. Thus they are accessible to direct chemical examination. They are, so to speak, lumps of matter, samples reaching us from the boundless region of interstellar space. Analysis of meteorites and study of their composition gives us the opportunity of getting a direct knowledge of some of the materials of which the stars are made. Most meteorites consist of native iron, partly combined with carbon and sometimes containing carbon in such quantities that it has been possible to isolate it from certain falling stars in the form of diamond dust. This composition of the meteorites is an extra confirmation of the correctness of the view that carbon exists on heavenly bodies in the form of mixtures or chemical compounds with metals.

In meteorites, however, other carbon compounds have also been found. By causing samples from meteorites to incandesce by means of an electric spark, scientists have managed to show that the hydrocarbon lines are certainly present in their spectra. It has even proved possible

[*] An obsolete term for nitrogen carbide, CN, now known to correspond to the gas $C_2 N_2$ (J.D.B.).

to isolate from some meteorites a considerable amount of hydrocarbons and to establish their nature by chemical studies.

Thus, we can demonstrate beyond doubt the presence of hydrocarbons on a number of heavenly bodies. This fact gives full support to the conclusions we had already drawn. There came a time in the life of the Earth at which the carbon which had been set free from its combination with metal and had combined with hydrogen formed a number of hydrocarbons. These were the firs "organic" compounds on the Earth.

Although only two elements, carbon and hydrogen, enter into the composition of these compounds these elements can join together in the most varied combinations and give rise to the most varied hydrocarbons. Organic chemists can now list a very large number of such compounds.

As the properties of hydrocarbons have been studied in great detail, a study of the conditions prevailing on the Earth when these compounds came into being makes it possible to put forward some suggestions as to which hydrocarbons were in fact formed. Without going into details we can only say that everything point to the view that it was the "unsaturated" (free radical) hydrocarbons which were formed first, that is to say the most unstable members of the class we are discussing, having very large stores of chemical energy and great potentialities, compounds which combine very easily both with one another and with other elements.

If these compounds could avoid oxidation at the time of their formation, then, during their stay in the hot, wet atmosphere of the Earth, they must certainly have combined with oxygen and given rise to the most varied substances composed of carbon, hydrogen and oxygen in various proportions (alcohols, aldehydes, ketones and organic acids).

Thus, all the considerations and facts which we have put forward above convince us that, even if not all the carbon, at least a great part of it, first appeared on the surface of the Earth, not in the form of the chemically inert carbon dioxide as had been thought, but in the form of unstable organic compounds capable of further transformation.

Let us leave these compounds for a while and take a look at what happened, during the period in the existence of the Earth which we are discussing, to the fourth element which enters into the composition of living things, namely nitrogen. At high temperatures nitrogen can form compounds with oxygen (the technical production of nitric acid depends on this). We are therefore justified in expecting the appearance of these compounds in the atmosphere of the Earth where the two elements involved were mixed. However, oxides of nitrogen are somewhat unstable. At temperatures of about 1.000º C these compounds break down and give off free nitrogen. Compounds of nitrogen with metals obtained industrially under conditions of white heat are far more stable. Such compounds must also have been formed in the atmosphere of the Earth by interaction between nitrogen and the incandescent vapour of the lighter metals. Later these compounds of metals with nitrogen, of a similar nature to carbides, were submitted to the action of superheated steam and formed ammonia[*], which is a compound of nitrogen and hydrogen. Ammonia could also have been formed primarily at a far

[*] As everyone knows, spirits of hartshorn is a solution of ammonia in water.

earlier stage in the existence of the Earth by the condensation of hydrogen and nitrogen in the upper layers of the atmosphere.

Furthermore, we cannot exclude the possibility of the formation of compounds of nitrogen and carbon. In this case the material obtained would be cyan, a substance with which we have already become acquainted when we were discussing the spectra of comets. Its presence in the gases surrounding these heavenly bodies confirms the possibility that it might also have been formed on the Earth. Thus, the atmosphere of the Earth at a certain period of its existence must have contained compounds of nitrogen in the form of ammonia and cyan as well as oxygen derivatives of hydrocarbons.

Although, from our point of view, cyan can hardly have played any important part in the further transformations of organic substances, we mention it because it is interesting to us in another way. It forms the starting-point of the extremely far-reaching and well-thought-out theory of the origin of life put forward by the well-known German physiologist Pflüger. We shall try to summarize it here. Pflüger says that there is an essential difference between dead protein, such as we find in the whites of hen's eggs, and the living protein of which living material, protoplasm, is made. This consists in the presence of cyan groups in the particles of living protein. However, cyan is only formed at red heat, when nitrogen-containing compounds react with incandescent carbon. "For this reason nothing can be more clear than the possibility of the formation of cyan compounds at the time when the Earth, as a whole or in part, was in a red-hot or white-hot state". Only then was it possible for cyan to be formed that "compound in which the beginning of life resides". "Therefore life arises from fire and its basis is derived from the time when the world was still a white-hot, incandescent globe".

Pflüger also refers to the immeasurable length of the time during which the cooling of the Earth was taking place. "Cyan and other organic compounds therefore had enough time and opportunities to indulge their great tendency to transformation and the formation of polymers". [*]As a result of these transformations they gave rise to "that self-transforming protein which constitutes living matter".

The most recent studies do not confirm Pflüger's ideas as to the predominant part played by cyan. The occurrence of cyan groups in "living proteins" has now come under grave doubt and even the concept of "living protein' itself has become rather out of date. Protein does not form protoplasm, it only enters as a component part into this chemically and physically complicated formation. The "self-transforming protein" as Pflüger described it, certainly does no exist. The ability of protoplasm to transform itself is inherent, not only in the chemical substances of which it is composed, but also in its physical structure or organization.

Nevertheless, Pflüger's theory has retained its importance until now. The fundamental proposition that "life arose from fire" remains unshaken. Only in fire, only in incandescent heat could the substances which later gave rise to life have been formed. Whether it was cyan or whether it was hydrocarbons is not, in the last analysis, very important.

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[*] Polymers is a name for substances having the same elementary composition but a different weight of their particles. Polymers with large particles are usually formed by the combination of two or more smaller particles.

What is important is that these substances had a colossal reserve of chemical energy which gave them the possibility of developing further and increasing their complexity. They contain, hidden within themselves, particles of that fire, that heat, that energy which the Earth so generously and prodigally scattered into the cold region of interstellar space. The hidden fire, this energy, served as the basis for the life that was to come.

From the Organic Substance to the Living Thing

In the last section we left off our discussion of the Earth at the time when it was gradually cooling and going over from being a red star to being a dark planet. Finally the time came when the temperature of the surface layers of the Earth fell to 100º C. It became possible for water to exist in the form of liquid drops. Continuous down pours of rain fell upon the surface of the Earth from the moist atmosphere. They inundated it and formed a cover of water in the form of the original boiling ocean.

The first organic substances which had hitherto remained in the atmosphere were now dissolved in the water and fell to the ground with it. What were these substances?

We have already remarked on their main property at the end of the last section. They were substances having a large store of chemical energy and possessing great chemical potentialities. While still in the terrestrial atmosphere they had begun to combine with one another to give rise to very complicated compounds. In addition, they combined with oxygen and ammonia to give hydroxy and amino-derivatives of hydrocarbons (i.e. compounds of hydrocarbons with oxygen and nitrogen respectively).

When these substances fell from the atmosphere into the primaeval ocean they did not stop interacting with one another. Individual components of organic substance floating in the water met and combined with one another. Thus ever larger and more complicated particles were formed.

We can easily crate a fairly accurate picture for ourselves of this process of aggregation (polymerization) of organic substances on the Earth by studying in it our chemical laboratories. In fact, the conditions in which organic substances existed in the stage of development of the Earth which we are dealing with can be achieved comparatively easily in our present-day laboratories. If we submit such substances as hydrocarbon radicals to the conditions described above and leave them to themselves we shall find the whole chain of reactions set out above taking place. The hydrocarbon radicals will be oxidized at the expense of the oxygen in the water and air to give the greatest variety of derivatives (alcohols, aldehydes, acids, etc.). This process takes place specially quickly at high temperatures and in the presence of iron and other metals.

Oxidized hydrocarbons readily combine with one another to form more complicated compounds. Many of these substances can also combine with ammonia and give rise to the development of the most varied nitrogen derivatives.

The process of aggregation of organic substances usually occurs rather slowly it is true. However, this is not very important. Whether it takes several months or several years, we still get, as a result of these processes, a mixture of various substances having a very complicated structure.

In these mixtures we may even find, among others, compounds of the nature of carbohydrates* and proteins. Both of these types of compounds play an important part in the structure of living material. We find them in all animals and plants without exception. In combination with other and yet more complicated substances they are, as it were, the foundation of life.

Of course, the substances which we produce artificially are not exactly the ones which can be isolated from living organisms. However, they are, if we may express it so, related to these compounds. The elementary composition, the structure of the particles and the chemical properties are almost the same in the one as in the other. The difference is only in detail.

The substances obtained by the method described above can serve as good nutrient material. They are specially nutritious for micro-organisms such as bacteria and moulds. This fact is specially important and we shall give a little more time to it.

One of the main objections brought against the possibility of the spontaneous generation of life in the distant past has been put in its general aspects as follows:

"If we assume", says W.Preyer, one of the opponents of the theory of spontaneous generation, "that at some time during the development of the Earth living material arose by primary generation from non-living material then we must suppose that this is still possible. However, the failure of numerous attempts directed towards finding out how to do this has shown that it is unlikely to the highest degree. If, on the other hand, those studying the first emergence of life assume that it was only possible at some time in the distant past, but now cannot take place; this is also improbable since the conditions required for pursuing life exist now and in fact must also have existed at the time when it is presumed that living material originated from inorganic substances, otherwise the product of the first origin could not have remained alive for long. It is therefore hard to see exactly what is lacking at the present time when primary generation is impossible".

We have already seen in the last section, that at present what are lacking above all are those substances containing much chemical energy which are the only things from which life could develop and which, themselves, could only be formed at extremely high temperatures. However, even if such substances were formed now in some place on the Earth, they could not proceed far in their development. At a certain stage of that development they would be eaten, one after the other. Destroyed by the ubiquitous bacteria which inhabit our soil, water and air.

Matters were different in that distant period of the existence of the Earth when organic substances first arose, when, as we believe, the Earth was barren and sterile. There were no bacteria nor any other micro-organisms on it, and the organic substances were perfectly free to

* Carbohydrates are organic substances composed of carbon, hydrogen and oxygen, the hydrogen and oxygen being present in the same proportions as in water. The various sugars such as glucose, sucrose and fructose as well as starch and cellulose are typical examples of carbohydrates.

indulge their tendency to undergo transformations for many, many thousands of years.

It is, of course, hard to say what these transformations were and what sort of substances resulted from them. The only thing that is certain is that these transformations were mainly directed towards an aggregation of material and the formation of more and more complicated and larger and larger particles.

However, we have seen in one of the preceding sections that substances with large and complicated particles have a great tendency to form colloidal solutions in water. Sooner or later such colloidal solutions of organic substances must have come into being in the watery covering of the Earth and once they had arisen they continued to exist, their molecules becoming more complicated and larger as time went on.

The state of colloidal solution is not, however, stable. For various, sometimes extremely slight causes, the dissolved substances come out of the colloidal solution in the form of precipitates, coagula or gels. It is impossible, incredible, to suppose that in the course of many hundreds or even thousands of years during which the terrestrial globe existed, the conditions did not arise "by chance" somewhere which would lead to the formation of a gel in a colloidal solution. Such formation of aggregated pieces of organic material floating freely in the boundless watery spaces of the ocean which gave rise to them must certainly have occurred at some time in the existence of the Earth.

The moment when the gel was precipitated or the first coagulum formed, marked an extremely important stage in the process of the spontaneous generation of life. At this moment material which had formerly been structureless first acquired a structure and the transformation of organic compounds into an organic body took place. Not only this, but at the same time the body became an individual. Before this it had been inseparably fused with all the rest of the world, dissolved in it. Now, however, it separated itself out, though still very imperfectly, from that world and set itself apart from the environment surrounding it.

With certain reservations we can even consider that first piece of organic slime which came into being on the Earth as being the first organism. In fact it must have had many of those features which we now consider characteristic of life. It was composed of organic substances, it had a definite and complicated structure which was completely characteristic of it. It had a considerable store of chemical energy enabling it to undergo further transformations. Finally, even if it could not metabolize in the full sense of the word, it must certainly have had the ability to nourish itself, to absorb and assimilate substances from its environment, for this is present in every organic gel.

It is hard to say precisely how the further development of this first organisms went on, but still it is quite possible to establish the general direction of that development. Let us assume that in one of the corners of the Earth, in the turbulent waves of the ocean, there were formed, either at the same time or one after the other, two bits of gel. Even if they separated out from the same solution they could not have been exactly alike. In one way or another they must have differed, for absolute identity does not exist on the Earth. Both bits were formed and floated in something that was not just water. They were immersed, so to speak, in a nutrient mixture, in a solution, though a very weak one, of different substances, among which there were various organic compounds. And each of these bits of slime absorbed these substances from the medium which surrounded it. Each grew at the expense of these substances, but as each bit had a different structure from the other they assimilated the material from the environment at different rates, one faster, the other slower. The one with the physico-chemical organization which made it possible to carry out the process of assimilation of hitherto foreign substances from the environment more quickly also grew faster than its weaker, less well-organized comrade. The more it grew and the larger its surface became the wider became this difference in the rate of growth.

As this went on the danger of the piece losing its wholeness by breaking or being broken up into larger or smaller parts also increased. This must have happened to different pieces in quite different ways for purely mechanical reasons, such as the breaking of waves or surf, or it may have been due to surface tension. All the same, in one way or another, sooner or later it must have happened. The bit of gel could not go on growing for ever as a continuous mass. It must have broken down and given rise to new pieces, new "primitive organisms". These latter were constructed parts of its body, and therefore their structure was inherited by them from the gel from which they were formed.

This structure, however, was not something immutable or constant. Naturally it depended to some extent on the chemical composition of the gel, but this was changing all the time. New substances were continually entering it from the external medium, new compounds were always being incorporated into its body and its physical and chemical structure was continually changing.

The bits which were formed by the breaking up of the original gel were, of course, similar to one another at first, but after division each followed its own path. Each began to grow independently and the structure of each began to undergo changes which were peculiar to itself. This meant that even after quite a short time the sister fragments must have differed from one another in their structure. The old story must have been repeated. The more efficiently constructed ones began to grow faster and the less efficient lagged behind in their growth.

This was repeated for many, many years. The structure of one gel with all the changes which had arisen in it was acquired and inherited by all the bits which owed their origin to the break up of that gel. The newly formed bits grew more, their structure again underwent changes in one way or another and the changes were once more transmitted to their offspring.

However, in the course of this process of change, selection of the better organized bits of gel was always going on. It is true that the less well organized could grow alongside the more efficient but they must have soon stopped growing. Even when there was enough of the dissolved nutrient substance for all, the leading part was always played by the qualitatively better organized entities. The growth in mass of the gels followed a geometrical progression and therefore bodies which had even a relatively slight superiority soon outstripped their less efficient comrades in regard to their growth and development. Thus, slowly but surely, from generation to generation, over many thousands of years, there took place an improvement of the physico-chemical structure of the gels, an improvement mainly directed towards increasing the efficiency of the apparatus for absorption and assimilation of nutrient compounds. On this basis a whole series of new properties must have arisen which had been absent from the original gel, among others the ability to metabolize.

Present-day organisms burn up in their bodies a part of the material which they absorb from their environment. This is inevitable as it is only by means of the energy obtained by this burning that the further growth of their protoplasm and further assimilation of nutrients can take place. In just the same way, too, the original organisms, when they had used up a considerable amount of the energy concealed in them, had to resort to a process of respiration or fermentation to acquire the energy they needed for their further growth and development. Only those among them which, during the preceding transformations, had developed within themselves an apparatus enabling them to burn or ferment, more or less quickly, a part of the nutrient substances absorbed by them, could grow and develop further. The rest must have halted in their development.

However, there arose among those fortunate ones which had developed this power of metabolism, a fierce struggle for existence, a fight to the death. The amount of nutrient organic material in the surrounding medium was getting less. Part of it had already been absorbed by the organisms, while part was broken down, burnt up in the process of respiration or fermentation. Only the most complicated and efficient could grow and develop, all the rest either ceased to develop or perished. The further life progressed the less nutrient substances were available to the organisms and the more strongly and bitterly the struggle for existence was waged and the stricter and stricter became "natural selection", rejecting all that was weak or backward and allowing only the most efficient to live.

At last the time came when all, or almost all, of the organic substances which had hitherto served as the only food of the original living things had disappeared. Now only those organisms which could adapt themselves to the new conditions of life were able to maintain and prolong their existence. For this purpose there were only two paths open to them: either they could continue to use their old means of nutrition, acquiring the organic substances which they needed for their nutrition by eating their weaker comrades, or they could turn in a new direction and develop, create within themselves, an apparatus which would enable them to nourish themselves on very simple inorganic compounds.

Only those living things which followed one of these courses could preserve themselves for further life. Having developed and perfected themselves further they finally gave rise to all the forms of organisms which we can now observe.

If we turn to the study of these modern forms, investigating their internal structure and getting to know their means of nutrition, we shall see that the few facts which we have in this field are in complete accord with the hypothesis as to the origin of life. The internal structure of the cells of moderns organisms is always changing, becoming more efficient and more complicated, It is only because of the imperfection of our methods of study that we cannot observe this directly and that this structure appears to us as something constant, cast in a definite and final form. This is not, in fact, true. If we compared the internal structure of the cells of higher and lower organisms we shall find a considerable difference between them. The cells of bacteria or blue-green algae have a considerably simpler internal organization than those of higher animals and plants. This is because these micro-organisms which stand on the lowest step of the systematic ladder, are the direct descendants of the most ancient classes of organisms. They have halted their development and retained unchanged all the features of the structure of their distant ancestors while all other living things, by continually altering and improving themselves, have attained a more complicated form of cell-structure.

Thus, the direct study of modern organisms convinces us that those forms which have a very complicated internal organization of their cells have arisen from simpler forms by successive changes and improvements. If this is so, then we have no reason to deny that these comparatively simple forms arose, in their turn, from beings which had an even simpler organization, one which even approached that of a colloidal gel. It is true that no trace of these primitive living things now remains on the Earth, but this is no proof that they never existed. It should not be forgotten that at a certain period of the existence of the Earth they must have been completely wiped out by their more highly organized comrades.

We obtain even more interesting evidence from the study of the means of nutrition of our modern organisms. A considerable proportion of organisms –bacteria, fungi and animals- can only feed on organic substance. It must be pointed out that this is the method of nutrition used by the least highly organized living things such as the rhizomastigina and protomastigina which are regarded by all present-day systematists as representatives of the kinds of organisms which were the ancestors of all the living things on the Earth. This fact fully supports the idea that the method of consuming organic substances is the most ancient means of nutrition. The power of independent, "autotrophic" feeding could only develop later as a result of a number of internal transformations and changes in their physico-chemical structure. It could not, however, develop all at once. Our knowledge of the means of nutrition of moderns lower and higher organisms leads us to the conclusion that living things underwent many changes and tried out many possibilities before they could achieve the best form of independent nourishment or inorganic substances. Among the lowest organisms, the bacteria, we find alongside forms which are nourished solely on organic materials, other forms which have set up within themselves an apparatus which enables them to feed in another way. Here we can observe an amazing variety of modes of nutrition, means by which organisms try to extract the energy they need for life from the inorganic medium surrounding them. One of them obtains this energy by converting hydrogen sulphide dissolved in the water into sulphuric acid. For the same purpose another converts ammonia into nitrous and nitric acids while a third transforms reduced iron salts into oxidized ones. Whether we like it or not, we get the impression that all these various forms of nutrition have been devised because the organisms were forced to find some way out, something which would enable them to exist in the absence of dissolved organic materials.

However, not one of these forms of independent nutrition became widely used among organisms. All these methods of obtaining the energy required for life from terrestrial sources were found to be inefficient. A far more efficient method was one based on the absorption and use of the energy which the Sun sends to us on the Earth in the form of rays of light. All present-day green plants, from the tiny single-celled algae of our ponds to the mighty giant trees of the tropical forests use just this means of nutrition. By means of a very complicated apparatus, in which the green pigment chlorophyll plays an essential part, these organisms trap the energy of the Sun's rays which fall on them and, with its help, break down the abundant carbon dioxide in the air. As a result of this breakdown the plants acquire the possibility of using the carbon in the carbon dioxide to build up new organic substances which also serve as nourishment for them. The form of nutrition described is very efficient but also very complicated. There can be no doubt that the extremely complicated physico-chemical apparatus needed for it could only have been created as a result of a long series of transformations and alterations of the living cell. We must therefore regard it as the latest and newest form of nutrition.

With this we end our discussion of the origin of life. In our minds we have followed a long path from the incandescent atoms of carbon of the earliest nebula to the living things of our times. We have seen how it is possible to explain the origin of life while basing our ideas all the time on scientificially established facts. Of course, the explanation given here is only one of those possible. We still have very few facts available to enable us to maintain with complete certainty that the process under discussion took place in just this way and not somehow else. We still know very, very little about the structure of colloidal gels and even less about the physicochemical structure of protoplasm. But this ignorance of ours is certainly only temporal. What we do not know today we shall know tomorrow. A whole army of biologists is studying the structure and organization of living matter, while a no less number of physicists and chemists are daily revealing to us new properties of dead things. Like two parties of workers boring from the two opposite ends of a tunnel, they are working towards the same goal. The work has already gone a long way and very, very soon the last barriers between the living and the dead will crumble under the attack of patient work and powerful scientific thought.