THE ORIGIN OF LIFE*

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UNTIL one hundred years ago the origin of living organisms was not a major problem in biology. Apart from the biblical creation, the view was frequently held that many at least of the simpler organisms were produced by spontaneous generation. The ease with which this idea was accepted was partly due to imperfect observation and partly to the view that there was a completely graded sequence between the living and the non-living. This found its most complete expression in the detailed 'scale of beings' of the eighteenth century. The disproof of individual cases of abiogenesis did not change this attitude until Pasteur showed that every supposed case of spontaneous generation was, in fact, due to infection by living organisms.

Pasteur's work raised the question of how the first organisms came into being. The publication of the "Origin of Species" made this one of the fundamental questions of biology. It is certain that at one time life, as we know it, could not have existed on earth. It must, therefore, either have arisen spontaneously from lifeless matter or have been conveyed to the earth from elsewhere after it had become inhabitable. The theory that life originated by infection from without has been discussed by Arrhenius and others. Bacterial spores may be conveyed to outer space by being carried to the upper atmosphere and then repelled from the earth by virtue of their electrical charge. Arrhenius showed that light pressure could then distribute such spores throughout the universe at an astonishingly high speed. In this way it would be possible to spread life from planet to planet. But apart from the fact that this hypothesis only shelves the question of how life began, it is rendered impossible by the physical conditions to which any living organism must be exposed in outer space. Spores might survive intense cold or a fair degree of heat. But they could not withstand the intense short-wave radiation from which we are shielded by the oxygen of our atmosphere. A minute spore can have no protection against this radiation, for the individual molecules of which it is composed will be destroyed.

We are thus forced to suppose that life began on this earth, and Pasteur's experiments must be taken to mean that life can only begin under very special conditions and that such special conditions must be sought for in the geological past. We can therefore ask three questions : What were the first organisms like ? When did they arise ? Under what conditions did they arise ?

Evolution has carried life from simple to more complex organisms. Side by side with the complex existing organisms we find others which are far simpler. It was supposed that among these we might find more or less unchanged survivals of the primitive living organisms of an earlier age. There is much to be said for this view, though it involves a very important assumption. Evolutionary trees were made and still are made which are based upon it. Haeckel constructed a phylogeny based on existing organisms. An amœba was not only an existing organism, but its grade of organization also corresponded to that of an actual ancestor. More primitive than amœba was Haeckel's 'monera', structureless protoplasm supposedly without a nucleus. Existing monera disappeared in the light of investigation, but the idea of a 'primordial slime' remained.

'Primordial slime' was an invention of zoologists. It was, therefore, an animal. But animals require food, and their normal food can be traced to plants. Ray Lankester tried to evade this difficulty by supposing that original organisms "fed upon the antecedent products of its own evolution". One must, however, explain the presence of 'albuminoids' in a suitable form for animal consumption, and also how the animals obtained oxygen for respiration. There is good reason for supposing that all our oxygen was produced by plants ; and the physical and chemical requirements of plants for growth are far simpler than those of animals. Church supposed that the first organism was a planktonic flagellate producing its substance by photosynthesis.

It is difficult to suppose that an organism so complex as a flagellate could arise by the spontaneous aggregation of its parts from non-living material. Even the smallest flagellate must contain about 10^{10} organic molecules. But is the aggregation of matter into a simple organism so improbable as it seems ? May their morphological complexity be a natural property like the complexity of crystal structures ? Leduc reproduced some of the obvious features of living organisms by inorganic models such as osmotic growths in silicate solutions. But the correspondence between these models and living organisms was very incomplete, and unquestionably the structure of a flagellate is

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far too complex for us to suppose that it has arisen spontaneously. Nor is there any need for us to suppose this, because there exist much simpler organisms than flagellates.

The smallest known living organisms are the bacteria. These grade into the yet smaller viruses. It is a question of definition whether the latter are considered as living or not. Bacteria are of far simpler organization than flagellates. They are still, however, sufficiently complex to make it difficult to suppose that any bacterium could ever have come into being by the chance aggregation of material. They are saprophytes and require complex organic media which they make use of in very varied ways. Many are anærobic. In the viruses we have still smaller units than bacteria. Their properties as infective agents resemble those of pathogenic bacteria. They possess properties which are associated both with living and non-living systems. Their power of growth and reproduction is a characteristic feature of living organisms. At the same time their extremely small size overlaps the size of large molecules, and they have been obtained in the crystalline state. It seems scarcely possible to make this property agree with our normal ideas of the structure of living matter. Instead of a complex arrangement of different kinds of molecules on a small scale, it seems that some viruses simply consist of nucleo-protein molecules. Whether the virus particle is living or not, it is always associated with living tissue, though we may yet find a non-living medium suited to its requirements.

Our search for the simplest type of existing organism leads us into a rather curious position. We can find bacteria of smaller and smaller size, and still smaller things, the viruses. Whatever view is taken of the nature of the virus, it certainly makes conceivable the existence of living material on an almost molecular scale. From the point of view of finding the simplest organism, this is certainly a great step forward. But from the point of view of conceiving of the first living organism, what has been 'gained on the swings seems to have been lost on the roundabouts'. Compared with plants the chemical environment required by bacteria is very complex and varied. It may even require the absence of oxygen. Viruses even seem to require living tissue itself for their existence. While it is easier to suppose that these minute forms might arise spontaneously, we can only suppose their existence in an environment which is very different from, and much more complicated than, that which exists to-day. The origin of a suitable environment becomes as much a problem as the origin of the organism.

When and under what conditions did life arise ? It is still one of the remarkable facts of palæontology that the fossil record suddenly fails below the beginning of Cambrian times. Unequivocal remains of Pre-Cambrian organisms are few, and none are easy to interpret. Yet the abundant fauna of the Cambrian itself already shows all the main groups of animals, so that there must have been a long period of evolution before this time. Though poor in fossils, Pre-Cambrian rocks offer important information. The oldest rocks dated by radioactive methods are some 1,700 million years old. Before that there is evidence of sedimentary rocks which it has been suggested carry us back to 2,000 million years. Radioactive study of the age of meteorites leads us to conclude that the age of the solar system is not greater than 2,800 million years. Estimates by other methods agree with this. We can therefore examine rocks which cover a substantial portion of the earth history. The occurrence of graphite in the Pre-Cambrian is of particular interest because it suggests the early existence of organic matter and possibly of life. Most of the evidence of the earliest rocks suggests that conditions on the Earth's surface did not differ substantially from those of the present day. The existence of very old sedimentary rocks indicates the existence of exposed land and familiar weather conditions. There is some reason for supposing that the sea has not altered fundamentally in its composition since very early times. The Earth probably only took a matter of thousands of years to cool to approximately its present temperature ; and there appear to have been Pre-Cambrian ice-ages. Whatever factors control the temperature on the earth, they appear to have operated for a very long time.

There is, however, evidence of one important change in the course of Pre-Cambrian times. These ancient rocks have been exposed to great changes, but there is some reason for supposing that before the middle Pre-Cambrian iron was laid down in them in the ferrous form, and not until after this time was it laid down in the fully oxidized ferric form. This is important because it suggests a lack of oxygen in lower Pre-Cambrian times. The idea that the early atmosphere lacked oxygen is an old one. The present oxygen content of the atmosphere certainly depends on plants. Photosynthesis by marine planktonic diatoms alone produces oxygen at a rate which would regenerate the whole oxygen of the air in about 100,000 years—a geologically negligible period. Photosynthesis by plants may have become an important factor in middle Pre-Cambrian times. Before that an atmosphere of carbon dioxide such as that which occurs upon Venus probably predominated on the earth. The geological record thus suggests the existence of organic matter at a very early period under physical conditions not wholly different from those of the present day, except that there may have been a change from anærobic to aerobic conditions during the Pre-Cambrian.

The early presence of an anærobic organic medium finds support from another quarter. We know now that the larger planets have developed enormous atmospheres of hydrocarbons and ammonia from the solar material of which they are composed. The overwhelming reducing character of this material thus leads to the development on a planet of an anærobic organic medium. In a planet such as Venus, there has been further atmospheric evolution through the inability of the gravitational field to retain hydrogen, so that carbon dioxide has been produced. Venus and the Earth are very close in size. A similar condition must once have prevailed on the Earth, and would rapidly do so again if photosynthesis ceased. The reducing character of planetary material leaves no place for free oxygen except through the intervention of photosynthesis or some analogous process.

We do not know how complex would be the organic molecules formed in the original medium. Molecules of kinds utilizable by bacteria would fairly certainly be produced. We have seen that still simpler organisms require a still more complex organic environment, the nature of which we do not yet know. It helps us little to point out in our ignorance that an original planetary organic medium might develop the required environment. But one thing seems certain, an organic environment developed in physical equilibrium on a planet could not of itself develop living organisms. For one of the characteristics of life is that its existence requires a supply of energy, either as radiation or as substances at a higher chemical potential than their surroundings. A system in equilibrium cannot provide this; but solar radiation might have done so, at least before the atmosphere developed oxygen and absorbed its most active components.

The answer to the question "How did life originate?" thus seems to depend on the question "What are the environmental requirements of simple bodies such as the viruses, and could these requirements have been met in the original organic environment?" The answer to these questions will carry with it the answer to many other fundamental questions in biology.

THE SEARCH FOR ECONOMIC PLANTS*

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THE history of the spice plants has been dealt with at some length since they have played so important a part in geographical discovery, territorial acquisitions, and wars between European nations. There are however several plants of great economic importance which have travelled far from their lands of origin, of the wanderings of which we have no certain records. Among these are the coco-nut, sugar cane, banana, cassava, ground nut, and possibly the West African oil palm.

The coco-nut has no doubt been transported partly by ocean currents and partly by natives voyaging from island to island in the remote past when they took the nuts with them for food and planted them in the islands or coastal regions to which they migrated. Of ocean transport we have recent evidence in the germination of coconuts washed up on Anak Krakatau IV in 1932. The original home of the coco-nut seems definitely to have been the East Indian Islands, whence it has travelled to the West Indies and to America.

* *Continued from p.* 16.

Sugar cane, also East Indian, must have been similarly conveyed by natives for food on their voyages and then planted by the settlers in their new homes. In this way it has been distributed throughout the tropics before the existence of historical records. The edible banana, probably native in Thailand and Malaya, must also have been transported in much the same way.

Both the ground nut (*Arachis hypogea*) and the oil palm (*Elœis guineensis*) afford puzzling problems. The ground nut is now the staple product of The Gambia, but all its near allies are natives of Brazil and there is none in Africa. Similarly, the closely related species of Elœis occur in Brazil, but there is an allied species in Madagascar. It is an open question whether either economic plant is truly native in West Africa; if not, then it seems probable that natives voyaging from Brazil to West Africa may have brought over both the ground nut and oil palm, and also the American cassava (*Manihot utilissima*), as food in their