Life’s coming into being

Description

This remarkable book was translated by me about fifteen years ago because I felt keenly that Oparin’s contribution had such great importance for scientists and non-scientists alike that it should be available to all English-reading people. It is a tribute to its true merits that the book should be reprinted after a lapse of so many years and I gladly yield to the request of the publishers to write a preface for this edition.

If I were to change the name of this book, I would suggest *Life’s coming into being* instead of the less cumbersome title *The origin of life.* This is not out of sheer caprice but in order to escape some connotations of the latter title which tend to obfuscate essential basic assumptions and to that extent put the wrong slant upon the problems to be formulated. To begin with, the title conceals two significant misconceptions. One concerns the duration of the process. *Origin,* especially to those brought up in the biblical tradition, implies a finite and sharply delineated event of creation, not a process extending over infinite time. Modern palaeontologists tell us that evolution of living things, which has blossomed out with a profusion of plant and animal species of almost endless variety, has occupied a period of something like a billion years. Thee Earth has retained an unmistakable record of this for nearly half a billion years. It will aid the reader to orient himself with regard to the evolution of species, to be reminded that in this inconceivably long span of half a billion years, registered in the Earth’s crust by some historical remains, the footmarks left by man and his close predecessors encompass barely one million years, perhaps two-tenths of one per cent.

But the origination of life, which is the subject matter of Oparin’s book, precedes by about another billion years the story of the *Origin of Species* in which Darwin picks up the thread and of this earlier period there is no existing record. While Darwin’s is a well documented story and his ideas, though highly controversial, can be bolstered with substantial factual material, Oparin’s story embracing probably another billion years lacks the support of ascertainable facts. By its very nature, a theory of how life had come into being must be highly speculative. Lacking a solid factual basis, the soundness or acceptability of such a theory can only be judged by whether or not, or to what extent, it conforms to the criterion of reasonable consistency with established knowledge in various fields of scientific inquiry. The origin of life was not an occurrence ascribable to some definite place and time; it was a gradual process operating upon the Earth over an inconceivably long span of time, a process of unfolding which consumed perhaps more millions of years than was required for the evolution of all the species of living things.

It is one of Oparin’s great contributions to the theory of the origin of life that he postulated a long chemical evolution as a necessary preamble to the emergence of life. One might think of the evolutionary process passing through three distinct chemical phases, from inorganic chemistry to organic chemistry and from organic chemistry to biological chemistry. And it is true that, if the organic chemist is familiar with wonders undreamed of by the inorganic chemist, the wonders witnessed by the biochemist in his daily tasks stagger the imagination and sharpen the envy of the organic chemist. These transitions in the history of our Earth were not isolated events but a continuous flux requiring aeons for their realisation. In interpreting the significance of the word *origin* one must free oneself of the cultural tradition and conceive it as something entirely outside the ordinary human framework of time.

The second misconception stems from associations clustering about the word *life*. To most people *life* connotes something that crawls, creeps or at least wiggles if not by means of well articulated appendages at any rate by temporary protoplasmic protrusions, or cilia, or delicate flagella. Life need not perhaps be visualized in the form of a stalking elephant but to the layman it may seem inconceivable except as some unicellular organism of microscopic dimensions. But even the most primitive unicellular organism has a complexity of structure and function that staggers the mind and is removed from the beginnings of *life* by a genealogy extending for millions upon millions of years. Possibly, as Oparin so convincingly tells us, it all began some two billion years ago as a venture in colloidal systems of microscopic size separating from the ‘hot thin soup’, to use Haldane’s happy description of the primordial ocean.

The biologist, unlike the layman, knows no lines of demarcation separating plant life from animal life, nor for that matter living from non-living material, because such differentiations are purely conceptual and do not correspond to reality. It is interesting to consider the influence which the identification of life with cellular organisms exerted on the theory of spontaneous generation. The famous and now classical experiments of Pasteur on such primitive organisms as bacteria are believed to have disposed for all time the question of the spontaneous generation of living creatures with the enunciation of the principle that every living thing must come from another living thing. The cruder and more naive experimenters, whose efforts at solving the problem of spontaneous generation were dubiously rewarded with swarms of maggots or flies, got the wrong answer because they, unlike Pasteur, lacked skill, scientific acuity, critical judgement and above all else a knack for cleanliness but all have formulated the question alike.

Basically the question was whether non-living matter can be transformed into living matter; in oilier words, whether biogenesis is possible. Pasteur’s unequivocal experiments have given no answer to this fascinating problem. They merely furnished irrefutable proof that living organisms, no matter how simple they might, cannot be generated from organic matter. Yet, sometimes in the course of evolution of our planet inorganic and organic matter must have become endowed with organisation which after hundreds of millions of years enabled it to develop into organisms. These in turn, after many more hundreds of millions of years, have spread over the surface of the planet populating the soil, water and air with an infinite variety of plant and animal forms. It may never be possible to devise experiments to possible to devise experiments to prove or disprove the possibility of biogenesis, and even Pasteur’s experiments do not disprove this, but biogenesis seems to be a reasonably consistent logical necessity.

It is more pertinent to inquire, if such a transformation of lifeless into living matter occurred once upon a time, whether this is happening at all times. ‘There is no scientific basis’, says Kavanau, ‘that life may not be originating continuously the earth. The fact that we have no evidence of such *de novo* origin is of no particular significance, for if there is such origin, we must anticipate that it would be in units far too small to be treated in the manner in which we are accustomed to dealing with organisms… It is likely, however, that the changes in the conditions at the earth’s surface, since the most favourable period for the origin of life, have been so great that present-day *de novo* origin, if it occurs, is highly infrequent.’

The conditions on the Earth during the past couple of billion years have undergone such radical alterations that biogenesis may no longer be possible. However, as Oparin points out, even if biogenesis were operating at the present time, the innumerable predatory organisms which populate the Earth would quickly destroy the products of biogenesis. It will in no measure detract from Oparin’s credit for this brilliant idea to point out that no less illustrious a biologist than Charles Darwin himself expressed a similar thought in a letter he wrote in 1871:

> It is often said that all the conditions for the first production of a living organism are now present, which could ever have been present. But if (and oh what a big if) we could conceive in some warm little pond, with all sorts of amonia and phosphoric salts, light, heat, electricity, etc., present, that a protein compound was chemically formed ready to undergo still more complex changes, at the present day, such matter would be instantly devoured or absorbed, which would not have been the case before living creatures were formed.

The origination of life was a transition from organic to biological chemistry, from lifeless to living matter, from the inanimate to the animate realm of nature. But what is life? Is it something which resulted which resulted from the organisation of organic matter? Irritability, motility, growth, reproduction may be good aids to differentiate a live from a dead organism but it is questionable whether these represent the fundamental properties of primordial life. There is good reason to think that a certain period of the Earth’s history must have been marked by complete sterility, i.e. absence of organisms; therefore, the fundamental property or properties of living systems must must have appeared in highly complex protein macromolecules antedating the appearance of cellular organisms. Proteins containing nucleic acid are the only constituent of organisms which are known to possess the capacity to grow and reproduce directly by self-duplication or by replication. But as organic compounds they can neither grow nor reproduce. Neither viruses nor genes, both of which represent nucleoprotein systems, can duplicate or replicate themselves unless they are incorporated within a suitable cell or nucleus.

Considered simply from the point of view of capacity to reproduce, are these nucleoproteins living or non-living systems? Being unable to furnish the free energy needed for syntheses associated with their reproduction, they lack the fundamental property characteristic for living systems of converting, transporting and storing energy. An ability to metabolise, involving some system of catalysts is another fundamental property which cannot be conceived of except in conjunction with a mechanism for converting free energy, and we are deeply indebted to H. F. Blum *(Time's Arrow and Evolution,* 1951) for his masterly analysis of this extremely important aspect of this subject.

One should add, as a fundamental property of living systems, a characteristic of their metabolism to form only one of the two optically active antipodes (i.e. either the D or the L form of an active compound but never both, as is the case in organic synthesis). It is not clear how this remarkable characteristic of living systems had arisen or whether it contributed to the transformation of non-living to living matter.

Almost a hundred years ago Engel propounded the thesis that life is a manifestation of the existence of proteins but he did not know that in reality life is a manifestation of catalysis by means of enzymes which are proteins. Chemical reactions in plant and animal organisms proceed at very high velocities. Without catalysis there could be no life. In fact, the bulk of protoplasm is filled with enzymatically specific active proteins. Yet enzymes are not living matter. Nearly every enzyme requires some inorganic component which may itself be catalytically active but in combination with protein this activity is enormously increased. Possibly the enzymes have evolved from these inorganic catalysts and thereby the tempo of biochemical reactions has been stepped up a thousand or even a million-fold.

The unfolding of the tremendous diversity of living organisms within the last half a billion years, as compared to the relatively very slow evolution of the preceding billion years may have resulted from the association of the primitive metal catalysts with proteins. But we know that the protein catalysts (enzymes) had already been operating at the very dawn of the appearance of plant and animal life. Although enzyme systems have been highly diversified in the course of evolution, their basic pattern has persisted through the geologic ages. It might almost be asserted that the earliest organisms had acquired the basic principles of biochemical catalysis and no new principles had been invented to replace them.

Thus, the very lowly Bryozoa are known to have maintained morphological uniformity for hundreds of millions of years. If we assume that the Bryozoa have also maintained physiological uniformity throughout their inconceivably long-life history, it must be concluded that the enzymes of heavy metal electron transfer have been operating in cellular respiration ever since living organisms have inhabited the Earth. Evolution has flowered from the Bryozoa (and probably long before them) to the vertebrates but the heavy metal electron transfer enzyme system has persisted through all these hundreds of millions of years as the basic design of cellular respiration.

Similarly, if we consider the lowly bread mould (Neurospora), also of very ancient and venerable geologic age, we witness the persistence over millions of years of enzyme systems which, with some modifications, are still found operating in higher organisms, including man. The co-enzyme factors (the so-called vitamin B complex) seem to be universally distributed and, what is more significant, the chains of biochemical reactions by which each factor is synthesised appear to be the same in most divergent organisms. The biochemical unity suggests that the coenzymes became part of a basic metabolic plan laid down even before evolution, acting through natural selection, had created a highly diversified flora and fauna.

The only known means for storing, transforming and mobilizing energy for the metabolism in living organisms is the system of high energy phosphate bond, namely Adenylic Acid ? Adenosinediphosphate ? Adenosinetriphosphate. This system, which is chemically related to the nucleic acids, played a paramount role in the transfer of free energy from the very beginning of life and undoubtedly played a very critical role in the transition from the non-living to the living state. The system has thus been preserved through the long geologic ages apparently unchanged. Though this, too, is one of the most essential endowments of life and, since non-living became living matter, it persisted in the organised cellular structure, yet this all-important system for transfer of free energy, outside its biological setting, is just organic matter.

If life is a manifestation of the existence of proteins, or more correctly a manifestation of catalysis by means of protein enzymes, the origin of life must have coincided with the origin of proteins if not actually preceded by them. Did protein precede the enzymes or did the enzyme the proteins? If growth and reproduction depend upon nucleoproteins, the nucleoproteins should have antedated the emergence of protein and of living organisms. But the synthesis of proteins could not have occurred without the aid of energy transformers or appropriate enzymes. This line of reasoning of what came first in the processional of life can be continued *ad infinitum* without any tangible gain in understanding because this line of reasoning starts from a wrong premise.

One becomes captive of a chain of arguments attempting to solve the paradox of how substances, absolutely indispensable to the existence of living systems, came into being *before* the living systems existed, which alone seem to possess the ability to produce these essential components. The problem is really quite insoluble since it is formulated upon a tacit assumption that the emergence of living from non-living could only have followed a hierarchical order, thus A ? B ? C ? D ? E ? L but life could have originated not as the end link of a chain of consecutive events but by simultaneous coordination of several factors.

As long as the cell is considered as the unit of life, the origin of life must remain a paradox. But like the erstwhile atom in chemistry, the cell has lost its prestige as the ultimate unit in biology. Both the atomic and the cellular theories have become obsolete. The cell, like the ‘indivisible’ atom, is now recognised as a highly organised and integrated system built up from extremely small and distinct particles.

Whether the ultimate particles of life have been found and identified is very doubtful, some of the units themselves being highly organized entities, but the concept of a cell as the unit of life has been thrown out of the window together with the atom. It has long been recognised that a cell consists of two main parts, the nucleus and the cytoplasm. The nucleus further differentiated into a nucleolus and chromosomes, the latter consisting of tiny particles, the genes, which are arranged in fibrils and are propagated by self-division.

These particles are composed predominantly of nucleoproteins extremely rich in deoxyribonucleic acid (DNA). This DNA is unique nuclear constituent but is most likely the genetic material. The nucleus is extremely poor in enzymes and its only demonstrable biochemical potentiality is the synthesis of nucleic acids. Removed from the cell, however, the isolated nucleus rapidly loses its viability and fails to function when it is replaced into an enucleated cell. Without the necessary mechanisms to furnish its energy requirements, it is completely dependent upon the cytoplasm, but it is not parasitic. In all probability it supplies the cytoplasm with ribonucleic acid (RNA), and their interrelationship should be described as symbiotic. Speaking figuratively, a nucleus isolated from the cytoplasm has no future, nor much of present either.

Protoplasm is a highly complex colloidal system of such lability that it tends to break down spontaneously. During life it is in a steady dynamic state, and energy furnished by the metabolic mechanism is constantly required to maintain its structure intact. But since metabolism is a regular sequence of chemical reactions which must occur at the right time and at the right place, the protoplasm must be a highly integrated system of enzymes whose activity is strictly controlled (by alternate activation and inactivation). Any disturbance in the enzyme pattern will tend to destroy the orderly structure of the protoplasm; any alteration of the protoplasmic structure will disturb the harmonious functioning of the enzymes. The cytoplasm consists of several types of particles possessing varying degrees of complexity of organisation, such as mitohondria, microsomes, Golgi bodies, chloroplasts, etc. The mitochondria are large liponucleoprotein organelles occupying perhaps a third of the cytoplasm. They consist of a complex of enzymes so completely interdigitated as to constitute practically a single entity structurally and a regular power house functionally. They catalyse a great variety of reactions consisting of aerobic oxidations (fatty acids, amino acids, tricarhoxylic cycle) as well as oxidative phosphorylations and some syntheses.

However, separated from its nucleus, the cytoplasm has no enduring future. It still displays for a while various functions (irritability, contractility, respiration, etc.) and maintains itself with the energy delivered from its particulates but deprived of the companionship of its nucleus beyond a certain time limit its ability to grow, reproduce, differentiate as well as synthesise specific proteins fails to materialise. The life of the cell can thus be regarded as the resultant of the continuous interaction between nucleus and cytoplasm. But the interaction is conditioned upon the fitness between them so that the interaction is in the nature of symbiosis.

It is significant that the nucleus with its inclusions (genes), which alone has no durable present, and the cytoplasm (with its various in inclusions), which alone has no enduring future, can by proper juxtaposition synthesise proteins for growth and reproduction with the d of nucleic acids and with aid of high energy phosphate derivatives of adenylic acid as transformers and transmitters of energy. Thus, the cell becomes a very efficient organism. Furthermore, the protein synthesis is directed toward highly specific proteins which imprint a high degree of specificity upon the manifestations of life in different organisms. And, it may be added parenthetically, provided it is not destroyed by some accident or extraneous influence, that the cell acquires a future and that future is is infinity.

A few random examples of biological symbiosis may serve to emphasise the profound significance of this phenomenon as the pattern which might have been operative not only at the cellular or particulate level but even at the macromolecular level in the transformation of non-living to living matter. Haemoglobin, the red blood pigment, has been usually regarded as a strictly animal product. In recent years it was discovered that haemoglobin is formed in the root nodules of legumes harbouring nitrogen fixing bacteria. The far-reaching significance of this biological observation lies in the fact that neither the root nodules nor the microorganisms, by themselves are capable of effecting this synthesis. Only in the infected nodule is haemoglobin being synthesised. Two entirely different living systems enter a symbiotic partnership and out of this interrelationship something new emerges, the synthesis of a complex substance, which neither system alone could fulfil. It is true that in this instance the creative situation terminates in a biochemical blind alley (and the course of evolution is full of blind alleys) but instead of bringing forth a ‘freak’ of nature this event could conceivably have opened a new biological era.

Another pertinent story can be told about chlorophyll, a green pigment closely related chemically to haemoglobin. This pigment is found in plants in special organelles, the chloroplasts. Chlorophyll absorbs light waves in the purple and red range of the spectrum and thus traps radiant energy. This gives the plant cell containing chloroplasts a source of free energy to perform anabolic processes which cells lacking this mechanism are unable to accomplish. It is interesting to note that chlorophyll itself is unable to accomplish the photosynthetic reaction except as a component of a chloroplast.

Chloroplasts are small green bodies enclosed in the cytoplasm of higher plants and of green algae. The reaction sequence of photosynthesis begins and ends within the chloroplast. The reaction sequence of photosynthesis begins and ends within the chloroplast. Isolated from the surrounding cytoplasm the chloroplast can evolve oxygen from water when exposed to light but it cannot use carbon dioxide as oxidant in this reaction. Nor can the isolated (intact) chloroplast carry out photosynthesis, which indicates that this depends upon cooperation with the cytoplasm. In other words, photosynthesis which is one of the most important means for accumulating free energy available in nature has emerged from a symbiotic arrangement. Neither participant in the partnership is capable of accomplishing this synthesis.

Existing separately and independently chlorophyll, chloroplast and cytoplasm may have remained at the level of organic matter. The concatenation of all three (by chance or accident) within the plant cell opened up new vistas of evolutionary potentialities by tapping the inexhaustible source of the sun’s energy and making it available for biological progress.

A concluding word should be added about viruses. Both the virus and the gene represent the simplest substances known to be autoreproducible. Both are largely or entirely nucleoprotein macromolecules. Plant viruses contain only ribonucleic acid (RNA) and animal viruses contain both RNA and DNA, whereas genes contain deoxyribonucleic acid (DNA). Nevertheless, viruses and genes have some things in common. Thus, neither can reproduce itself except within a suitable type of cell. However, if the genes (nucleus) and cytoplasm fit each other (i.e., belong to the same or closely related species) their symbiotic relationship culminates in normal development; if the virus and host cell fit each other, the virus usually multiplies and in doing so destroys the host (parasitic relationship). The discarded virus, unless it can invade another cell, reverts to the status of non-living matter. But, as Andrewes points out in his 1951 Leeuwenhoek Lecture, a stable virus-host cell equilibrium may become established and 'reach a state of closer and closer union, culminating in the blissful surrender of perfect symbiosis.' Could viruses have become transformed into genes?

Thermodynamically directed chemical evolution could conceivably proceed indefinitely without changing from a non-living to a living state. Only when organic matter had achieved a high degree of organisation and had acquired diverse propensities through the concatenation of such substances (with chance as the only arbiter) did primordial life emerge as a new dimension in nature: matter perpetuating its own organisation. Natural selection, operating upon chance variations, set the evolutionary direction along numerous pathways which living things have followed irresistibly.

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