Comments on Oparin's Paper on the Origin of Life

This paper by Oparin on the origin of life, which appeared in Russian in 1924, has been taken to represent the first and principal modern appreciation of the problem. Although it is one of the most often cited papers in the literature on the subject, this is the first time, as far as I can ascertain, that it has appeared in English. The English translation published in 1938 was based on Oparin's book published in 1936, which was virtually a second, and considerably revised, edition of the 1924 paper. On reading it now it is necessary to recall the state of knowledge at the time and to appreciate that it could not contain basic facts discovered after that date. Indeed, in 1924 modern biology, and particularly molecular biology, had started. Even biochemistry itself was only in its first stages. In Haldane's book, *Enzymes* (1930), an enzyme is described as "a soluble, colloidal, organic catalyst, produced by a living organism".

On the other side, the theories on the origin of the solar system were still under the influence of untenable theories, old and new, such as that of its arising from a solar filament. It should be said that Oparin himself does not use this theory, but here assumes one of its mots relevant consequences, that of the Earth first appearing in a high-temperature gas and dust form and then cooling down and solidifying.

Oparin's paper is really a monograph. It must not be considered as the fruit of long study by an expert, but rather as a young man's fresh approach to an old problem. It marked the beginning rather than the end of a new phase in the understanding of the processes involved in the origin of life; a beginning which has been followed up ever since then by Oparin himself and from which many researches of other people have stemmed. From these, one can except Haldane's approach, which, apparently, was quite independent.

The monograph is divided into five sections:

1. The theory of spontaneous generation;
2. The theory of panspermia;
3. The world of the living and the world of the dead;
4. From uncombined elements to organic compounds;
5. From the organic substance to the living thing.

The first two are concerned with the history of ideas on the origin of life. The very titles indicate their inspiration by the controversies of the nineteenth century, particularly the great debate between Pasteur and Pouchet on spontaneous generation. The apparent defeat of Pouchet made it very difficult to account for any natural origin of life, and the refutation of this view appears to have been very largely the inspiration of Oparin's work. He had to show that it was not really relevant to the problem. The spontaneous origin of life might be impossible to reproduce now, but under conditions in the dim and distant past it might well have occurred.

Another approach is discussed in the second section, the theory of panspermia. Oparin here shows that it also is essentially irrelevant. At any rate, it has nothing to do with the terrestrial origins of life because, even if it could be shown that life could come from outer space by a difficult and chancy process, it would still be necessary to explain how it arose in the first place. Panspermia only solves the problem of the origin of earthly life by multiplying it into an even more difficult one.

The third section begins to touch on Oparin's own contribution. It is one characteristic of a biochemist. It had been agreed ever since the work of Wöhler in 1928 that the elements of life were not specifically organic but were the same elements as were to be found in the Earth and the Sun. Here the differences observed were those of the extra complexity of the compounds involved in life and in the special mode of their transformation, where enzymes were involved, working at low temperatures in dilute solutions. Oparin raised the point that in this they resemble inorganic catalysts. At that time he did not go much further because very little was known about enzymes or about their mode of action, but this was to point the way to later analyses of proteins and the discovery of their genesis. It is in Section 2 that Oparin brings in the work of Graham and his recognition of the difference between crystalloids and colloids. Oparin saw it as pointing to life in the phenomena of colloids, particularly in the form of gels and coagulates. He saw in this the birth of the idea of coacervates, on which he was to do so much work in succeeding years. Here Oparin is following out the idea that in the coagulates we have the model of the first organisms. By dealing with them in a synthetic manner, Oparin attempts to bridge the main difference between the living and the dead, and, at the same time, abandons the old hypothesis of protoplasm, which he considers to be a colloidal substance of great complexity. In 1924, in the absence of a microscope of sufficient power, the degree of that complexity could not be dreamed of. It had to wait for two decades until the electron microscope was sufficiently developed. It is natural, therefore, that Oparin had to accept as the guiding idea of the genesis of organisms the ancient notion of matter and form:

> 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.

As the structure of protoplasm had

> 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... There is no essential difference between the structure of coagula and that of protoplasm.

This knowledge Oparin then uses to explain in principle the general phenomena of metabolism: "the ability of living organisms to metabolize to reproduce themselves and to respond to stimuli".

His consideration of crystals, which also have the capacity of growth and replication of form, came very close to modern ideas of self-reproduction, which has been found to be the key to molecular biology, whose ideas were at that time far below the horizon of research.

Oparin continues by pointing to physical explanations of biological responses to stimuli, likening them to the discharge of unstable systems by some action-initiating nucleus, as in explosions. He concludes by saying:

> 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 or 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.

The fourth section, which is Oparin's most original contribution to the question of the origin of life, is entitled "From Uncombined Elements to Organic Compounds". This is the forward-looking explanation of the thesis which inspires the whole work. At that time it was necessary to restate in modern terms the kind of historic process which might have led to life appearing on the Earth, in what I have called, in my own work, the myth.

Oparin had before him the task primarily of making the nature of the origin of life conceivable and defendable. He begins with cosmogony, the astronomical history of the Earth's formation, following Mendeleev, and bringing it up to date with his theory of the genesis of carbonaceous molecules through the interaction of water and metallic carbides. It is this part of the work which has suffered most from the changes in our knowledge of the stars and planets and particularly of the inner structure of the Earth. The change over from a concept of an Earth primarily at high temperatures to one assembled from cosmic dust, with the surface at least always cool, has been the biggest change. Nevertheless, the differences in these theories on the origin of life turn out to be minimal. Nobody had worked out the nature of the crust on either hypothesis and therefore no one could discriminate between their results. The main difference lies in the presence or absence of carbonaceous and carbon and nitrogen compounds.

The idea that a complex organic compound can be formed from simple molecules was arrived at by logical deductions from the very existence of such compounds structures in life. The experiments of Miller and his successors on the actual synthesis of such compounds from simple molecules, ultimately inspired by Oparin, were still more than a quarter of a century away.

The origin of the carbon compounds was traced by Oparin, following Mendeleev, to the interaction of the water in the primitive atmosphere, with the carbides formed in the iron core of the Earth. Oparin, at this stage, had not arrived at that idea of a primitive atmosphere without oxygen, for he says:

> These compounds must also have arisen when the carbides and 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.

He supported his arguments further by considering the composition of the comets and meteorites:

> 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... Thus, all the considerations and facts which we have put forward above convince us that, even it 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.

Oparin goes further to consider the formation of nitrogen compounds though he traces their origin to cyanogen, formed by the reaction of the metallic nitrides with carbon compounds. He quotes Pflüger,

> Therefore life arises from fire and its basis is derived from the time when the world was still a white-hot, incandescent globe.

From this he jumps to molecular proteins:

> As a result these transformations they gave rise to "that self-transforming protein which constitutes living matter".

He subjects this hypothesis, at the same time, to a serious criticism.

The fifth and final section, "From the Organic Substance to the Living Thing", traces the chemical evolution of complex carbon and nitrogen compounds in the primitive seas of the Earth. Here Oparin makes a very large assumption:

> We can easily create a fairly accurate picture for ourselves of this process of aggregation (polymerization) of organic substances on the Earth by studying it in 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.
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> 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 one as in the other. The difference is only in detail.

The modern biochemist has to abandon the idea that anything can be deduced from the experiments carried out now as to the impossibility of the independent origin of life.

> 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.

The last few pages of the thesis are the most tantalizing. They are really the programme of work on studying chemical-physical and physical-chemical conditions of the complex organic substances involved in colloids in the primitive ocean. Oparin depends much on the idea that the source of free energy must be present. As to the further development of life, he sees this as a matter of chemical evolution envisaged as a competition and struggle for existence between different globules. These are not molecules but coacervate droplets, where natural selection favours the better organized fragments.

> 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 substances for all, the leading part was always played by the qualitatively better organized entities.

The last few pages touch on other key problems in the maintenance of life and the renewed accumulation of energy in the primitive soup involved in taking in energy continuously from outside:

> 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.

Oparin realized that this was a problem of extreme complexity and required the most vigorous further research:

> If we compare 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.

And he sees the need to complete this mere verbal description by a new appreciation of microbiology, the discovery, so to speak, in detail of living forces:

> Our knowledge of the means of nutrition of modern lower and higher organisms leads us to the conclusion that living thing underwent many changes and tried out many possibilities before they could achieve the best form of independent nourishment or inorganic substances.

It can be seen that Oparin’s essay contains in itself the germs of a new programme in chemical and biological research. It was a programme that he largely carried out himself in the ensuing years, but it also inspired the work of many other people. There is great value to be found in setting out a clear programme or declaration of intention. The programme may, afterwards, be remodelled or even, if necessary, changed, but it must serve as a starting-point. In many of the best achievements in the history of scientific thought, the young worker must star out by revealing the necessary condition of his ignorance but this is a fertile ignorance. Oparin’s programme does not answer all the questions, in fact, he hardly answers any, but the questions he asks are very effective and pregnant ones and have given rise to an enormous amount of research in the four decades since it was written. The essential thing in the firs place is not to solve the problems, but to see them. This is true of the greatest of all scientists, Newton, and also of Lavoisier, who consciously set about to make a revolution in chemistry and, finally, Pasteur from whose work all the key ideas on the biochemical nature of the origin of life have sprung. In particular, the distinction made between aerobic and anaerobic life was Pasteur’s discovery and Oparin used it ultimately to lean towards the hypothesis of an early atmosphere without oxygen.

If we take the successive publications of Oparin on the subject of the origin of life [see main Bibliography], it can be seen that they have all been modified and in many cases even reversed; but in every case these reversals have been imposed by discoveries either in biochemistry or in cosmology. This paper is important because it is a starting-point for all the others and, thought it is clearly defective and inaccurate, it can be, and has been, corrected in the sequel. This, in my opinion, fully justifies its republication in its original form.