THE SPONTANEOUS GENERATION CONTROVERSY FROM DESCARTES TO OPARIN

JOHN FARLEY

THE JOHNS HOPKINS UNIVERSITY PRESS
BALTIMORE AND LONDON

NINE

FINAL ABANDONMENT

1936 TO THE PRESENT

In the opening chapter of John Keosian's *The Origin of Life*, published in 1964 and widely used by science undergraduates in North American universities, a distinction is made between mechanistic and materialistic hypotheses pertaining to the origin of life. The mechanistic, he wrote, "explains the origin of the first living thing in terms of the chance combination of the elements," while the materialistic, "takes a different approach in applying natural laws to the explanation of the origin of life." Instead of viewing the origin of life in terms of a living entity arising "all at once" by a sudden and chance combination, materialism, he argued, "views the origin of life as the result of a series of probable steps of increasing complexity, inevitably leading up to the living state."[1] From such a position it becomes completely meaningless, "to draw a line between two levels of organization and to designate all systems below as inanimate and all systems above as living."[2]

In that most modern biologists and biochemists accept that life emerged through a long and gradual process, belief in the possibility of spontaneous generation has been finally abandoned. Instead of arguing that life is analogous to a machine whose living characters suddenly appeared at the moment when all the pieces of machinery fell into place, they now argue in terms of an evolving process of gradually increasing complexity. "The pattern I propose," remarked John Bernal, the English physicist, in 1957, "is one of stages of increasing inner complexity, following one another in order of time, each one including in itself structures and processes evolved at the lower levels."[3]

Writings which stressed the evolution rather than the sudden appearance of life were not common in nineteenth-century literature. Herbert Spencer, of course, spoke in these terms as part of his all-encompassing "development hypothesis." To Spencer, "the affirmation of universal evolution is in itself the negation of an 'absolute commencement of anything.'"[4] Rather:

> The advance from the simple to the complex, through a process of successive differentiations, is seen alike in the earliest changes of the Universe to which

> we can reason our way back; and in the earlier changes which we can deductively establish; it is seen in the geological and climatic evolution of the earth, and of every single organism on its surface; it is seen in the evolution of Humanity. . . . From the remotest past which science can fathom, up to the novelties of yesterday, that in which Progress essentially consists, is the transformation of the homogeneous into the heterogeneous.[5]

Spencer's views were not widely followed in the nineteenth century, however. In part this may have resulted from the controversy then waging over the age of the earth, which seemed to imply insufficient time for the evolution of living organisms to have occurred, let alone a long prebiotic evolution as well.[6] With the discovery of radioactivity by Henri Becquerel and the Curies at the end of the century, the restrictions imposed by physicists on geological time were gradually removed, and evolutionary concepts began to be put forward again.[7] In the eleventh edition of the Encyclopaedia Britannica, published in 1910, an article by Peter Mitchell suggested that because living organisms always arise from preexisting organisms, the terms "archebiosis" or "archegenesis" "should be reserved for the theory that protoplasm in the remote past has been developed from not-living matter by a series of steps."[8]

The idea that the appearance of life may have been preceded by a long chemical evolution grew out of early spectroscopical studies of stars and the realization by astronomers that different star types represent stages in a universal stellar evolution. Norman Lockyer, the famous English astronomer, even likened star types to the geological record. "We may," he wrote, "treat these stellar strata, so to speak, as the equivalent of the geological strata."[9] However, although they spoke of inorganic evolution preceding the appearance of life, the actual appearance was usually visualized as an "all-at-once" spontaneous generation. For example, E. A. Schaefer, in his famous 1912 address to the British Association for the Advancement of Science, spoke of the "process of evolution" being "universal" and seemed to deny the feasibility of spontaneous generation when he argued:

> So far from expecting a sudden leap from an inorganic, or at least an unorganised, into an organic and organised condition, from an entirely inanimate substance to a completely animate state of being, should we not rather expect a gradual procession of changes from inorganic to organic matter, through stages of gradually increasing complexity until material which can be termed living is attained?[10]

Yet Schaefer did not attack the concept of spontaneous generation in general, merely that aspect of it that posited fully-formed complex cellular organisms, arising from inorganic matter. Indeed, he shared the then-commonly held view of biochemists that, "the chemistry and physics of the living organism are essentially the chemistry and physics of nitrogenous colloids," that the cell nucleus "possesses a chemical constitution of no very great complexity," and that, not only could the nucleus be prepared synthetically but also, with the chemical synthesis of a colloidal compound, "it will without doubt be found to exhibit the phenomena which we are in the habit of associating with the term life." Far from denying spontaneous generation, Schaefer concluded that "the possibility of the production of life—*i.e.*, of living material—is not so remote as has been generally assumed."[11]

Later, in 1938, the American pharmacologist Reinhard Beutner stressed the unlikelihood of life being created in a flash, and spoke instead of "a very gradual development of the preparatory processes."[12] However, influenced by Wendell Stanley's crystallization of the tobacco mosaic virus in 1935, Beutner claimed that "a single molecule has the essential properties of a living organism,"[13] which at "some time and somehow, must have sprung from the inanimate matter left after this fiery mass [the Earth] had cooled down."[14]

Despite their references to the evolution of life, Schaefer and Beutner seemed to have had more in common with the "sudden" mechanistic hypothesis than with Keosian's "gradual," so-called materialistic hypothesis. They, like most other biochemists of that period, proposed that "the first living thing was a macromolecule, a 'living molecule,' that was formed by the chance coming together of the elements that composed it in the proper proportions and arrangements."[15]

The Liverpool biochemist, Ben Moore, put forward views much more akin to "materialistic hypotheses" than either Schaefer or Beutner. There was, he wrote in 1921, "a universal Law of Complexity," by which matter "tends to assume more and more complex forms." Thus, he argued, beginning with the ether, more and more complex inorganic structures arose as the temperature fell, eventually leading to the synthesis of carbon and the other elements. Carbon in turn formed complex molecules and colloids, properties of which, he noted, approximate those of living structures. Later, from such a matrix, autotrophic colloids formed; life had arisen. Although necessarily vague, Moore clearly did not visualize an all-at-once appearance of life. "It was no fortuitous combination of chances and no cosmic dust, which brought life to the womb of our ancient mother earth in the far distant Palaeozoic ages, but a well-regulated orderly development, which comes to every mother earth in the Universe in the maturity of her creation."[16] In addition, the process was conceived as a continuous one, primordial forms of life being generated "all the

time and in our generation." Surprisingly he did not refute the claims of Bastian. Although more ready to accept the appearance of organic bodies than microorganisms in sterile flasks, he nevertheless felt that the latter may well appear "within a period of three to six months."[17]

What is so significant in Keosian's definition of the modern "materialistic hypotheses" concerning the origin of life, is the obvious reference to Marxist dialectical materialism in contrast to the "crude mechanistic materialism" of the nineteenth century. In particular, he writes of new laws operating at higher levels of organization which did not exist at the lower levels, and seems to take the Marxist position that denies the existence of events ascribed to what they see as lawless accidents of chance. "From the materialist view, the origin of life was no remote accident; it was the result of matter evolving to higher and higher levels through the inexorable working out at each level of its inherent potentialities to arrive at the next level."[18] In addition, Keosian's emphasis on the development of processes reflects an important aspect of dialectical materialism. That an American biochemist with no known Marxist affiliations should use such terminology under a heading of simple "materialism," reflects the enormous impact which Aleksandr Oparin has had on the issue of spontaneous generation and the origin of life. In 1936, Oparin produced perhaps the most significant book ever published on the problem. Entitled *The Origin of Life,* it was the first work to approach the issue from the standpoint of dialectical materialism.[19] In a very real sense, the acceptance of Oparin's basic position has led to the final abandonment of the spontaneous generation controversy.

Dialectical thinking with regard to nature—rather than to human society—is based on the writings of Friedrich Engels. Emphasizing the dynamic rather than the mechanical and static, Engels conceived of nature in terms of complex processes subject to a continuing historical development.[20] This development was explained by three universal laws of motion, all of which were incorporated into Oparin's writings: The Law of the Transformation of Quantity into Quality, The Law of the Unity and Conflicts of Opposites, and The Law of the Negation of the Negation.

The first law stands in opposition to biological reductionism as practiced in Engels' time. Such reductionism interpreted complex events in terms of the summation of the physical properties of its simplest parts. Thus reductionists tended to view life as a machine and the origin of life as analogous to the assembly of a machine. Dialectical materialism rejects these concepts: life is not a mere machine the origin of which can be explained by the chance combination of its component parts. Instead it postulates that, during the early history of our planet, a series of small quantitative changes took place, during which time qualitative changes also occurred. In other words, as the developmental processes slowly progressed from atoms through more and more complex molecules to simple cells, "the old laws of physics and chemistry naturally continued to operate, but now they were supplemented by new and more complicated biological laws which had not operated before,"[21] and which are not deducible from the physical laws. In the words of Engels himself, the protein "is something essentially different from the molecule, just as the latter is different from the atom."[22] Implicit in this belief lies the concept of causality. To many Marxist writers, any abandonment of rigid determinism in favor of statistical laws seemed to undermine this concept by appearing to postulate effects with no cause. Hence, for example, the well-known Marxist objections to quantum physics and Werner Heisenberg's uncertainty principle and Oparin's continued hostility to notions that life arose "by chance."

The second law, the law of conflicts, sees motion as stemming from "conflicts" of internal elements which can only exist in relation to one another. Hence Oparin's emphasis on the conflicting metabolic processes of anabolism and catabolism as the basis for genetical change, rather than the static DNA template. Finally, according to the third law, the emergence of new qualities as a consequence of quantitative changes, implies the "negation" of the previous quality which thereby may prevent the appearance of this quality again. Oparin's assumption that the very existence of life on this planet negates any further emergence of it, reflects this law.

According to Loren Graham, by 1936 Oparin had shown a marked shift towards Marxist interpretations of the origin of life.[23] Basically, the Oparin of 1924 was a reductionist who believed life, which had arisen suddenly by chance, was completely explicable in terms of physics and chemistry. His shift away from this approach may have reflected in part the changed political climate of the Soviet Union. In the 1920s, the intellectual scene was relaxed, with no attempt being made to impose ideological conformity on the scientific community. The scientific institutions remained in the hands of prerevolutionaries, and as late as 1929 no member of the Academy of Sciences was a member of the Communist Party. Between 1927 and 1929, however, Stalin launched his massive agricultural, industrial and cultural revolution during which control of scientific institutions passed into the hands of the Communist Party. As a result, a tendency developed to politicize science, to associate prerevolutionary science with bourgeois thinking. Oparin himself, in the opening paragraph of his 1936 work, refers to arguments over the origin of life as a reflection of "the underlying struggle of social classes."[24] At this time too, there developed an emphasis on utility in opposition to the theoretical nature of science practiced by the Western trained prerevolutionary scientific elite. In 1935, for example, Oparin published a work dealing with the biochemical base of tea production. Also, in 1929, the agronomist Trofim Lysenko announced that wheat, normally planted in the winter, would ripen after a spring planting if subjected to moisture and low temperatures immediately before sowing. This process of "vernalization" obviously had profound practical implications in a country which suffered severe grain mortality during the winter months. In comparison, Western genetics, with its emphasis on fruit flies and wrinkled peas, seemed utterly sterile and useless. Not surprisingly Lysenko became a hero of socialist agriculture, and a special laboratory was built for him at the Ukrainian Institute of Selection and Genetics in Odessa. By 1935 over five million acres of the Soviet Union were being planted with vernalized winter cereals.

Concomitant with these events, many Soviet scientists began to reconstruct their science from the viewpoint of dialectical materialism. Lysenko in 1935 began using the rhetoric of dialectical materialism in his support of progressive, innovative, Darwinian, Marxist genetics, and in his attacks on clerical, antiscientific, and "methodologically bourgeois" science. Loren Graham argues that this growing tendency among Soviet intellectuals in the 1930s to use the language of dialectical materialism was not simply a political and rhetorical device to gain favor. Rather, these intellectuals, among whom was Oparin, "found historical and dialectical materialist explanations of nature to be persuasive on conceptual grounds."[25] Oparin, in his 1936 text and all subsequent writings on the problem, used the dialectical framework in a very persuasive and successful manner to attack the problem of the origin of life. It is unfortunate that most Westerners associate Marxist biology with Lysenkoism and have failed to realize some of its very positive results.

By the 1930s, with the rapid decline in colloid biochemistry and the emphasis on proteins as definitely structured "macromolecules," the innate complexity of living entities was once again being stressed.[26] All living entities, whether bacteria or viruses, must, in the words of Oparin, "be endowed with a definite and complex organization which makes it possible for them to perform a number of vital functions."[27] As such, it was inconceivable that they "could appear in a very short time, before our eyes, so to speak, from unorganized solutions of organic substances."[28] Thus, he argued, since life cannot arise spontaneously, "it must have resulted from a long evolution of matter, its origin being merely one step in the course of its historical development,"[29] and in the course of this evolution "more and more complex phenomena of a higher order became superimposed upon the simplest physical and chemical processes."[30] Eventually, there emerged systems subject to biological laws.

Oparin then set out the various stages in the evolutionary process. In doing so, he emphasized the abiogenetic formation of organic substances and the necessity of a sterile, lifeless planet on which these early stages could occur. Without such a prerequisite these early organic substances would have been destroyed by microorganisms. Of course, in the 1930s it was no longer believed that organic substances were producible only by living organisms, and thus, that the most primitive life must have arisen from inorganic matter and have been autotrophic, that is, capable of manufacturing organic substances from inorganic material.

Oparin described the first stage in the long evolutionary process as the appearance of a primary reducing atmosphere, in which carbon existed as hydrocarbons and cyanogen, and in which nitrogen occurred as ammonia, a view that was then commonly held by astronomers.[31] The second stage saw the production of more and more complex organic substances from the initial hydrocarbons, which "are pregnant with tremendous chemical possibilities."[32] As a result of condensation, polymerization and oxidation-reduction reactions in the warm waters of the primary seas, Oparin suggested that "numerous high molecular compounds, similar to those present in living cells, may appear," and that, "there is absolutely no reason to doubt that these reactions were essentially like those chemical interactions which can be reproduced at the present time in our laboratories."[33] Such reactions included the production of amino acids and other protein-type compounds.

The effect of dialectical thinking appears most clearly in Oparin's discussion of the third stage in the evolutionary process, a stage he called "the origin of primary colloidal systems." Instead of seeking to define living properties in terms of the structure of organic molecules, he argued that "the laws of organic chemistry cannot account for those phenomena of a higher order which are encountered in the study of living cells."[34]

Polymerization of pure organic molecules will not result in the appearance of living processes, and neither are the properties of mixtures of such substances merely "the sum of the properties of their components." Rather, he argued, "on mixing different substances new properties appear which were absent in the component parts of the mixture." "This alone compels us, in considering the evolution of organic substance, to rely not upon those alterations to which this or another isolated compound may be subjected, but to bear in mind alterations which take place in complex mixtures of various organic substances."[35]

Oparin discussed at length one such reaction which takes place in mixtures of organic substances, namely the self-formation of polymolecular open systems or "coacervates." The word was coined by the Dutch chemist Bungenberg de Jong in 1929 to describe the appearance of two liquid phases in hydrophilic colloids: the coacervate, rich in colloidal substances, and a noncolloidal equilibrium liquid.[36] Although many properties of such coacervates may be compared to those of protoplasm, Oparin cautioned that they should not be regarded as models of protoplasm but merely as an "essential landmark in the evolution of our appreciation of the physico-chemical properties of the protoplasm."[37] Among such properties, Oparin mentioned increase in size due to adsorption of various substances in the equilibrium liquid and the appearance of a definite structure within the coacervate droplets.

What is particularly important in this work of Oparin was his denial of the appearance of "a single, definite, individual substance," which had characterized previous discussions of the origin of life. In its place, Oparin conceived of "a complex mixture of different high-molecular organic compounds of primary proteins, lipids, carbohydrates and hydrophil colloids," the formation of which was "unavoidable."[38] With coacervate formation, "organic matter became concentrated at different points of the aqueous medium and, at the same time, sharp division occurred between the medium and the coacervate."[39] "To initiate life," he concluded, it was necessary that these coacervates "acquire properties of a yet higher order, properties subject to biological laws."[40]

The biological laws of natural selection came into play, Oparin argued, as a result of differing chemical reactions taking place in the coacervates. Some would become unstable and disappear; others would gradually acquire minute amounts of enzyme and thereby gain a selective advantage. In time, therefore, their "inner chemical organization became strengthened in the process of natural selection, insuring a gradual evolution which finally culminated in those highly perfected enzyme systems existing at the present time."[41] This new biological factor of natural selection

> raised the colloidal systems to a more advanced state of evolution. In addition to the already existing compounds, combinations and structures, new systems of coordination of chemical processes appeared, new inner mech-

anisms came into existence which made possible such transformations of matter and of energy which hitherto were entirely unthinkable. Thus systems of a still higher order, the simplest primary organisms, have emerged.[42]

The impact of Oparin's work was profound. Although not the first writer to view the beginning of life as a gradual process, he was the first to set out a series of hypothetical steps by which life might have emerged. That it would be possible to duplicate these steps in the laboratory meant that the problem of life's beginnings became a legitimate and fruitful scientific research problem. In place of searching for a fortuitous meeting of molecules to produce an indefinable and unrecognizable living entity, biochemists could now investigate each of Oparin's stages. For this reason alone it had appeal beyond the Soviet Union, where the Marxist interpretation proposed by Oparin provided an added source of support.

The antimechanist approach of Marxist biologists such as Oparin paralleled a similar movement in Europe and North America. As Garland Allen has recently shown, during the 1920s and 1930s a trend developed in biology away from mechanistic materialism and toward a more holistic, organismic viewpoint. Stemming in part from the new quantum and relativity physics, this movement was reflected in the organismic physiology of Charles Sherrington, Walter Cannon, Lawrence Henderson, and others, in opposition to the classical gene concept; and in the embryological work of Hans Spemann, Paul Weiss, and Ludwig von Bertalanffy. These scientists displayed an intense interest in biological *interactions* and the environment in which these interactions took place. Like their Marxist counterparts, they also argued that the whole is greater than the sum of the parts. Both groups felt that knowledge of individual chemical reactions within the body was insufficient in attempting to understand the functioning of the complete organism, and that a greater emphasis on and awareness of the relationships among these chemical reactions were required. From this movement concepts such as homeostasis, intergrative action, self-regulation, and negative feedback appeared in physiology, while in embryology Paul Weiss was developing his field theory.[43] The widespread acceptance of Oparin's work can be understood when seen against this generally organismic milieu of biology, although, clearly, within the narrow confines of biochemists interested in the origin of life problem, it was the experimental opportunities flowing from the Oparin approach that had the most direct appeal.

With the end of World War II, biochemists began to investigate each of the stages proposed by Oparin. The most famous among them was Stanley Miller, who in 1953 synthesized amino acids from an "atmosphere" of methane, ammonia, water, and hydrogen. The bearing of this work on Oparin's thesis was made explicit in Miller's opening remarks in the article in which he pointed out that such an atmosphere "was suggested by Oparin."[44] In a sense, this synthesis differed little from nineteenth-century productions of organic substances. Had such a synthesis been possible at that time, only the materialists would have seen it in terms of the origin of life question. To most chemists and biologists of the nineteenth century a clear distinction existed between organic matter and living organisms. After Oparin, however, any production of organic material was viewed as a step on the long evolutionary road, particularly when the ingredients from which the amino acids arose seemed similar to the reducing atmosphere presumed to exist on the prebiotic earth.

In 1954, George Wald published an important article on the origin of life in *Scientific American,* in which he stated that Oparin's book "provides the foundation upon which all of us who are interested in this subject have built."[45] He pointed out that many organic molecules show "a spontaneous impulse toward structive formation," and gave as an example the precipitation of structured collagen fibrils from a free solution with completely random orientation. This self-assembly of collagen fibrils was the subject of a paper by F. Schmitt, published in 1956.[46]

Naturally, not all scientists were in agreement with Oparin's views, and in the 1950s two antithetical approaches to the problem came into sharp focus. There were those who, with Oparin, conceived of a long evolutionary development of life, and there were those who still spoke of a sudden, very improbable event leading to the instant formation of the first living molecule. Such a spontaneous generation of life was inevitable, "given sufficient time, and sufficient matter of suitable composition in a suitable state."[47]

The conflict between these two points of view in the 1950s must be seen against the backdrop of international politics. It was the time of the cold war, when dissenters in the Soviet Union and the United States were subjected to intolerable political and personal harassment. There was a cold war, too, in science, which impinged directly on the origin of life controversy. In 1948, the Soviet Communist Party had prohibited further teaching and research in classical Mendelian genetics as part of its ideological support of Lysenkoism. Classical Mendelian genetics had, of course, become established in the Western world following the famous *Drosophila* studies, which Thomas Hunt Morgan and colleagues at Columbia University began in 1908. It was, in addition, one of the first really significant contributions the United States had made to world science. Naturally, therefore, Americans took a legitimate but nationalistic pride in bolstering their scientific arguments in support of Mendel and Morgan. Professor Ralph Spitzer lost his job at Oregon State University in these years, for daring to suggest that Lysenko's work ought to be examined.

Three factors converged at this time to bring the issue of the origin of life into the political arena. First, Oparin and many of his supporters were obviously Marxists using the rhetoric of dialectical materialism[48]; second, Oparin himself was closely associated with Lysenko; and third, the major opposition to Oparin came from the American geneticists and those working on bacteriophages who, after the work of James Watson and Francis Crick, conceived of the origin of life in terms of a sudden spontaneous generation of the first DNA molecule.

In 1956, a revised and much enlarged edition of Oparin's 1936 work appeared. Entitled *Origin of Life on the Earth* and translated into English a year later, it presented dialectical arguments more forcibly and clearly than before. In the introductory chapter, for example, after criticizing any attempt "to explain the origin of life by separating it from the general development of matter," Oparin wrote:

> A completely different prospect opens out before us if we try to approach a solution to the problem dialectically rather than metaphysically, on the basis of a study of the successive changes in matter which preceded the appearance of life and led to its emergence. Matter never remains at rest, it is constantly moving and developing. . . . Life thus appears as a particular very complicated form of the motion of matter, arising as a new property at a definite stage in the general development of matter.[49]

Oparin was deeply involved in the Lysenko controversy. Zhores Medvedev reports that, in 1948, while heading the biological section of the Academy of Science, Oparin refused to allow the appointment of plant physiologist D. A. Sabinin, an opponent of Lysenko, to a post in the soils section of the Academy.[50] In 1950, Oparin joined with Lysenko in supporting the award of the Stalin Prize to Olga Lepeshinskaia for her work on the spontaneous generation of cells from a noncellular nutrient medium. Graham describes this episode as "one of the low points" at Oparin's career, for, both before and after this, he was opposed to any such sudden appearance of fully-formed cells. He later came under increasing criticism from Lepeshinskaia and her supporters.[51] Finally, in 1955, when Lysenkoism had lost much of its support among Soviet scientists, a petition, signed by more than three hundred of them, requesting Lysenko's removal from the presidency of the Lenin All-Union Academy of Agricultural Sciences and Oparin from the secretaryship of the Academy of Science, biological section, was granted.

That life originated with the appearance of the gene was first stated by the American geneticist H. J. Muller in 1926.[52] Attracted by his communist sympathies, he visited the Soviet Union in 1933, only later to become an opponent of both Stalinism and Lysenkoism. In direct contrast to Oparin, he continued to believe that life could be so well defined that the exact point at which it began could be determined. In other words, he accepted that life began by a spontaneous generation. In 1947, criticizing the "so-called organism-as-a-whole" view of life, whose origin was "an incomprehensible enigma," he argued that, "all other material in the organism is made subsidiary to the genetic material, and the origin of life is identified with the origin of this material by chance chemical combination."[53] Muller restated these views in 1955, two years after Watson and Crick had published their model of DNA structure.[54] To Muller and those who agreed with him, the gene is the unique "living" molecule, which is characterized by the ability to reproduce itself and mutate and to produce specific metabolic enzymes.

Such a view evoked strong reactions from Soviet scientists during the first International Symposium on the Origin of Life, which took place in Moscow in August 1957. Although Oparin claimed correctly that "the principle of the evolutionary origin of life" provided a basis for the program of the symposium, he erred in stating further that "this principle was shared by all the participants in the conference."[55] It was not shared by a number of American visitors such as Norman Horowitz, Wendell Stanley, and Heinz Fraenkel-Conrat, although Sidney Fox, Erwin Chargaff, and Stanley Miller clearly shared it.

Wendell Stanley, in a paper entitled "On the Nature of Viruses, Genes and Life," argued that viruses and genes were basically nucleic acids and thus, "the distinction between living and non-living things . . . seemed to be tottering." He further maintained that with nucleic acids, "we are dealing with life itself."[56] Horowitz took a similar view. Arguing against Norman Pirie's well-known claim that life is indefinable, he claimed life was manifested in mutability, self-duplication, and heterocatalysis and that it "arose as individual molecules in a polymolecular environment."[57] The same position was taken also in a paper by Fraenkel-Conrat and B. Singer.[58]

Erwin Chargaff, in his usual forceful way, disagreed with his countrymen. "Is life itself only an intricate chain of templates and catalysts and products?" he asked. "Is the cell really nothing but a system of ingenious stamping presses, stencilling its way from life to death?" "No", he answered, "for I believe that our science has become too mechanomorphic."[59]

The Marxists present naturally took issue with the "mechanomorphic" point of view. Bernal, for example, after arguing that nucleic acids' arising by a fortuitous combination of elements would have taken longer than the life of the universe, claimed that, "the problem has been wrongly posed," and continued: "There is no question, to anyone who has examined the evidence, of the need to explain the origin of life as consisting of one decisive step, because it plainly did not originate as such."[60] Rather than using the easily misconstrued term "spontaneous generation" to describe the appearance of life, Bernal introduced the term "biopoesis" to the meeting, to include all the slowly evolving, life-making processes.[61]

The Soviet Marxists, who were present in large numbers, also attacked those who claimed DNA to be a "living molecule." Aleksandr Braunshtein, for example, who in 1959 became laboratory chief at the U.S.S.R. Academy of Sciences Institute of Radiation and Physico-Chemical Biology, stressed again that "the transition to life only occurs when these compounds and many other substances are unified into complicated systems."[62] Some of the participants were known supporters of Lysenko, who, by 1957, had regained his hold on Soviet genetics with backing from Nikita Khrushchev. One such supporter was Nikolai Nuzhdin, a geneticist in the Institute of Genetics at the U.S.S.R. Academy of Sciences, who had already published papers attacking what he termed "reactionary Mendelism-Morganism." He saw in Stanley's paper "the evergrowing tendency to ignore the qualitative specificity of living material which distinguishes it from non-living material." Such a tendency had entered biology, he claimed, from the work of physicists, who "consider the possibility of a more complete explanation of biological phenomena solely in terms of their understanding of the laws of physics and chemistry." Mentioning next the genetic concepts of the horticulturist Ivan Michurin, who opposed theories involving specific carriers of heredity, he concluded:

> I am glad to point out that, both in Academician Oparin's monograph and in many of the papers, many suggestions have been made concerning the question on which I am touching. It will undoubtedly play a great part, not only in the study of the origin of life, but also in genetics. From what has been said it clearly follows that, however important the part played by nucleic acid in biological processes, its molecule was not the original basis of life. It is not a "living molecule" but one of the parts of a living structure which can only fulfil its biological function against the general background of metabolic processes taking place within the cell. The synthesis of the protein molecule depends on nucleic acid just as much as the synthesis of the latter depends on the protein molecule. This is quite understandable. Living material is a complex of compounds which determine the regular course of the processes which constitute life. One cannot isolate an individual component without interfering with the living material, still less can one understand life on the basis of such an isolated component, however thoroughly its functions may have been studied. The same applies to the phenomenon of heredity as well and, in general, to any property of living material.[63]

In June 1964, when Nuzhdin's name was put forward for membership in the Academy of Sciences, his supporters described his achievements in the following terms:

> Nuzhdin had paid much attention to the problems of the struggle with anti-Michurinist distortions of biology, constantly criticizing various idealistic trends in the study of heredity and variation. His general philosophical works, in connection with the further development of the materialistic teaching of Michurin . . . are widely known.[64]

Nuzhdin's views deserve mention if only to illustrate that, behind the seemingly innocuous questions being posed, there lay deep ideological and political differences which loomed large in the cold war of the 1950s.

One must not overemphasize the political aspect of the meeting, however. The Soviet scientists did not form a homogeneous group of Lysenko supporters. Most of them supported the Oparin position without specific mention of Lysenko.[65] Olga Lepeshinskaia, by this time at odds with Oparin over his claim that the original forms of life could not exist in the present time, took part in the discussions during the conference. The doctrine that cells only arise from preexisting cells was disclaimed by her on the basis of her own laboratory findings, in which "non-cellular forms of life" had been transformed into bacterial cells.[66]

Oparin defined the distinction between his views and those of the geneticists very succinctly. "Is life only inherent in the individual molecule of protein, nucleic acid or nucleoprotein, and is the rest of the protoplasm merely a lifeless medium?" he asked. "Or is life inherent in a multimolecular system in which proteins and nucleic acids have an extremely important role, though it is that of a part, not that of a whole?" In Oparin's view the functionally efficient and highly structured molecules that one finds in living systems could never arise all at once by a spontaneous generation, but only through a long evolutionary process. In a rather delightful analogy, he likened his opponents' view to that of Empedocles, "who held that first there developed arms, legs, and eyes and ears and that later, owing to their combination, the organism developed."[67]

Oparin and Muller continued to exchange barbs well into the 1960s, and even today the issue remains unsolved. In 1961, Oparin once again attacked the idea that nucleic acid was somehow the first living molecule which arose by a fortuitous chemical combination:

The more concrete the biochemical studies of the self-reproduction of living beings, the more obvious it becomes that the process is not just bound up with this or that particular substance or a single molecule of it, but is determined by the whole system or organization of the living body which . . . is flowing in nature and is in no way to be compared with a stamping machine with an unchanging matrix.[68]

In 1966, two years after the downfall of Nikita Khrushchev and the subsequent decline of Lysenko, Muller once more attacked Oparin's view and drew attention to his support of Lysenko:

It is a curious anachronism, however, that even today some of the most eminent biochemists and biologists, doing very valuable work in their respective fields, still adhere to this view [that protoplasm is primary] and its corollary concerning life's origin. Unfortunately, it became much publicized and elaborated, beginning in the 1930's, by the Lysenkoist Oparin in his book, *The Origin of Life* (1938 *et seq.*), as part of the attempt to down-rate the significance of genetics.[69]

The historical association of the origin of life question with the Lysenko-Mendel debate has led many modern biochemists to see the major question as: "Which had primacy in the origin of life, nucleic acids or proteins?"[70] This was not the basic issue, however. The fundamental question was whether life arose in one decisive step, as Muller postulated, or through a long and gradual process, as Oparin maintained.

Despite Oparin's association with the denigrated Lysenko and his hostility to much of modern genetics, Oparin's views on the origin of life have persisted. This can be attributed to the successful experimental testing of his four-stage process:

1. Appearance of hydrocarbons and cyanides and their immediate derivatives in cosmic space and during the formation of the earth and the subsequent development of its crust, atmosphere, and hydrosphere.
2. Conversion on the earth's surface of the initial carbon-containing compounds into more and more complex organic substances—monomers and polymers—appearance of the so-called "primordial soup."
3. The self-formation, in this soup, of polymolecular open systems capable of mutually interacting with the environment and capable of growth and multiplication on the basis of this interaction—appearance of probionts.
4. The further evolution of "probionts," the development of more perfect metabolism, more perfect molecular and super molecular structures accomplished through the basis of prebiological selection—the appearance of the primordial organisms.[71]

Indeed, the American biochemist, Sidney Fox, regarded "the problem in principle as more solved than unsolved."[72]

Today, the majority of biologists and biochemists seem committed to the evolutionary viewpoint of Oparin. Such commitment does not imply, of course, that there has been an encroachment of dialectical materialism into European and North American science. Rather, the evolutionary viewpoint has enabled the question of life's beginnings to be treated, for the first time, as a legitimate scientific research problem. On more theoretical grounds, the evolutionary approach has also received support from the publication of Harold Blum's *Time's Arrow and Evolution.* Curiously, however, although it had appeared in 1951, Blum's work was hardly mentioned during the 1957 International Symposium.

Blum, like Oparin, saw the origin of life as a transition between the nonliving and living, in which the spontaneous production of complex molecules, such as polypeptides, was thermodynamically "beyond all probability." He argued, also, that, were a group of scientists of different disciplines allowed to travel back in time to witness the beginning of life, there would be no universal agreement as to the exact point at which life began. On thermodynamic grounds, the origin of any one of the major properties of life, he argued, "is difficult enough to conceive, let alone the simultaneous origin of all." He concluded his chapter on the origin of life by suggesting that "we abandon the idea of a definite moment of origin and assume that a series of events represents the beginning of life rather than one definite point of this series."[73] With the publication of this work, Oparin's dialectical interpretation of the beginning of life became justified on the basis of predictions stemming from the second law of thermodynamics.

With the broad acceptance of Oparin's scheme, the issue of spontaneous generation should be resolved finally. Life did not arise by a spontaneous generation. That is to say, that a functional living entity, whether that be a mouse, maggot, bacterium, virus, or "living molecule," did not make an all-at-once appearance from material with no lifelike qualities. Life emerged slowly as part of a long developmental process, all stages of which were highly probable at the time they occurred. As such, it becomes meaningless to draw a line through these stages and to call stages below the line nonliving and those above living. It, therefore, also becomes meaningless to speak of a spontaneous generation of life, either today or in the past. Oparin's scheme allows for the evolutionary process to be a continuous one, but the very existence of life itself renders it impossible for the early stages to be repeated—all probionts would be destroyed by the bionts. Furthermore, argued Oparin:

If we can form a clear picture in our minds of the whole grandiose nature of this evolution, we must now regard as ludicrously naive the hopeless attempts which have been made to reproduce the spontaneous genesis of life in decaying decoctions and infusions of organic substances. The path followed by nature from the original systems of protobionts to the most primitive bacteria and algae was not in the least shorter or simpler than the path from the amoeba to man.[74]

There are those, however, who still believe in the sudden appearance of a *first,* functionally organized, living molecule, and who thus believe that life arose in the past by a spontaneous generation. Such an assumption is not only untestable but involves some dubious arguments. Its proponents stress that, although the chance combination of molecules which would produce a living entity was extremely improbable, it was not impossible. Thus, given the vast eons of time available before life appeared on the planet, the correct combination of molecules arising "by chance" becomes inevitable. In the words of George Wald: "One only has to wait: time itself performs the miracles."[75] The problem is, however, that as long as the presence or absence of life is known only for our planet, as long as the number of "trial" combinations of molecules is unknown, and as long as the time period remains unspecified, no meaningful statement as to the probability of life's arising can be made. That "time itself performs the miracles" is a truism and tells us nothing. An assessment of the probability that a complex entity such as DNA arose all at once demands that the time interval be specified. The possibility that *any* event can occur will approach one—that is, absolute certainty—as the length of time increases and, at infinite time, the possibility actually becomes one. Indeed, at infinite time, it becomes mathematically certain that a Shakespearean play will be composed by the fortuitous meeting of the letters of the alphabet. Similarly, if the time interval is lengthened so as to become "indefinite," then the possibility of any event's occurring will approach one asymptotically. It is possible by using such arguments—what Peter Mora has termed "the infinite escape clause"—to prove anything. Indeed, one can claim this probability-argument to be, with complete justification, the twentieth-century equivalent of Divine Creation:

These escape clauses postulate an almost infinite amount of time and an almost infinite amount of materials, so that even the most unlikely event could have happened. This is to invoke probability and statistical considerations when such considerations are meaningless. When for practical purposes the condition of infinite time and matter has to be invoked, the concept of probability is annulled. By such logic we can prove anything.[76]

The conflict between Oparin and Muller, between emergence and spontaneous generation, now rests on the relative assessment of two conflicting hypotheses. What is the more likely: that a complex living entity, having all the essential properties of life, arose suddenly, or that there has been a series of steps of increasing complexity, each step having a level of probability such that the occurrence of each would have been likely during the available time span? Although Oparin himself seems to have held a curiously anachronistic view of "chance," opposing spontaneous generation from much the same standpoint as eighteenth-century opponents, most modern biochemists and biologists have concluded that emergence is more probable than spontaneous generation. That a complex "living molecule" could have arisen all at once seems to be so improbable, having a probability so close to zero, that it appears virtually impossible. Time itself will perform that miracle, but adherence to such an hypothesis seems unnecessary when faced with a more-likely second hypothesis: that life emerged slowly. That possible stages in this gradual process have been reduplicated in the laboratory now provides additional armament for the Oparin hypothesis.

Unfortunately, many supporters of the evolutionary viewpoint still speak of "the spontaneous generation of life" and "the first organism," thereby confusing the whole issue. One of the most perplexing papers in this regard was George Wald's. While admitting that Oparin had provided the foundation for modern approaches to the problem and that "the origin of a living organism is undoubtedly a stepwise phenomenon, each step with its own probability,"[77] he nevertheless insisted that, "as natural scientists learn more about nature they are returning to a hypothesis their predecessors gave up almost a century ago: spontaneous generation." Although, clearly, we are dealing here with a matter of semantics, it only confuses the situation to state that the only alternative to a supernatural creation is belief in spontaneous generation and that today, "we now have to face a somewhat different problem: how organisms may have arisen spontaneously under different conditions in some former period, granted that they do so no longer."[78] Whether he admits to it or not, Wald is here using the language of the late nineteenth century, with all its ambiguities. There is indeed another alternative to that of creation or spontaneous generation, the alternative best expressed by the word "biopoesis"—the whole evolutionary process leading from inorganic beginnings to the emergence of life.

Unfortunately, the dialectical viewpoint, which fully supports such an approach, is itself subject to misunderstanding regarding spontaneous generation. The Soviet scientist A. S. Konikova criticized the use of the term "biopoesis" at the 1957 conference on the grounds that it failed to indicate a "qualitative break in nature." "The scheme provides a correct and consistent materialist picture of the form of development of nature but does not disclose the main point of these stages of development: it does not reflect the transition from chemistry to biology."[79] Indeed, recent work on self-assembly of macromolecules has illustrated that "major evolutionary changes may have yielded sudden leaps forward such as could not have been forecast from knowledge of the predecessors."[80] It makes little sense, and is confusing historically, to equate such leaps with the concept of spontaneous generation. To do so would imply that before such an event no lifelike processes were in operation and that after the leap all such processes had appeared.

Oparin himself could be misinterpreted in this way when he writes that life "is not separated from the rest of the world by an unbridgeable gap, but arises in the process of the development of matter, *at a definite stage* [emphasis added] of this development as a new, formerly absent quality."[81] However, in using such terminology he is referring to the stage at which new biological laws come into play and not to a sudden passage from a nonliving to a living state. Unfortunately, however, Oparin has continued to use the term "origin of life," rather than the less confusing "emergence of life," in all his writings, in an attempt to denote that there is a point in the evolutionary process at which qualitatively new biological laws come into operation. His continued use of this terminology has had the unfortunate effect of clouding over the fundamental difference between those who believe in the spontaneous generation of a first living molecular state and those who accept the evolutionary approach. Recently, Oparin has become more circumspect in the term's use. In 1968, he dropped the word *Origin* from the title of one of his books and used instead *Genesis and Evolutionary Development,*[82] and, in a more recent article, he seems to favor *appearance* and *emergence* over *origin.*[83]

Some recent papers have suggested that a recurring biopoesis may be a very distinct possibility; Keosian himself coined the term *neobiogenesis* for such events.[84] Unfortunately, Adolph Smith and Dean Kenyon have referred to such a possibility as "the contemporary spontaneous generation of life."[85] Once again we are dealing with an unfortunate usage, for they clearly accept the evolutionary viewpoint: they describe life's appearance as a "spontaneous generation spread over millions of years." Spontaneous generation, of course, means a sudden transition from a completely nonliving state to a fully-living state, which by definition cannot be spread over a long period of time.

However, Smith and Kenyon also make the quite fascinating claim that "both mycoplasma and viruses may be originating *de novo* within cells and tissue fluids of host organisms," and that "such newly formed units of life may play important roles in some disease processes." They hypothesize that "within the body fluids of host organisms, rapid back-and-forth movement is occurring between the states of organization of living matter," a suggestion that has some uncomfortably close relationships to previous claims in support of heterogenesis. They also suggest that the common notion of "infectious diseases," based as it is on the belief that the infectious agent comes from similar parents, needs reexamination. "In summary," they argue, "we are proposing that a new dimension be considered in biology, the back-and-forth movement between what is commonly considered life and death." These remarks cannot be said to represent a reappearance of the belief in spontaneous generation. Despite their use of the words *life* and *death,* it clearly makes little sense to label one of their states of organization "dead," and another "alive." It seems to provide one more example of unnecessary confusion brought about by adherence to outdated terminology.

Most, but not all, modern biologists and biochemists have abandoned any belief in spontaneous generation. This has come about through general acceptance of the evolutionary viewpoint as expressed by Aleksandr Oparin. Contrary to popular belief, therefore, the present state of the controversy has not resulted from disproof by infallible experimental evidence. The issue is one which has been abandoned many times before, only to reappear at a later date under a different guise. Whether the final chapter in the history of the spontaneous generation controversy has now been written it is impossible to say.