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The Oparin Hypothesis is a Falling Star

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The Oparin hypothesis from 1936 was a milestone in the origin of life research, making a model that was at least in part empirically testable, and changing the course of life studies from a long tradition of metaphysics to a scientific domain of investigation. His hypothesis is based on the idea of the prebiotic synthesis of macromolecules as a fundamental step on the road to first life. Although the Oparin hypothesis brought fresh ideas and concepts, in its description of the steps in the hypothesized transition from the inorganic to the organic world in detail, today some premises are considered unconfirmed, uncertain, or even rejected. With high respect to its metatheoretical reach and scientific impact on prebiotic chemistry, pushing the origin of first life research into an empirical context, from a contemporary viewpoint, its contribution is highly limited in the area of history of science and history of philosophy (of science).

Keywords: *biology, history of science, Oparin, origin of life, philosophy of science*

Introduction

Investigation into the origin of life has been based on purely metaphysical schemata up to the 18th century, including experiments regarding spontaneous generation. After numerous predecessors, Pasteur experimentally denied the possibility of the spontaneous generation of microbes, but he did not give an explanation as to how first life emerged on Earth. At the beginning of 20th century, Russian biochemist Alexander Ivanovich Oparin hypothesized the heterotrophic origin of life in the reduced atmosphere, pre-biological chemical evolution, and the concept of coacervate droplets as a bridge between inorganic and organic worlds. For the first time an empirically testable model was presented, followed by experiments with varying degrees of success. This article considers the impact of revealing that some of Oparin's premises are uncertain, or even rejected. But even the most serious objection is that his premises restrict the scope of research to the very narrow area of the prebiotic synthesis of the macromolecules we find in living systems. It seems that the Oparin hypothesis failed to decrease the gap between the most complicated organic substances and the most primitive living organisms, which is set as the ultimate and final goal of research into the origin of life. This article puts aside a connection with Haldane's hypothesis as well as an objection to any possible ideological influence as having no fundamental relevance to this consideration.

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Prelude

Scientists, as well as others, are faced with the dilemma of whether life always existed or if it originated in historical time. If we incline to the option that life arose sometime in the deep past, we need a scientific explanation of its origin. As opposed to a metatheoretical proposition, a scientific theory or hypothesis is inseparably connected to observation and/or empirical tests which could show the resemblance or divergence of a proposed theoretical explanation with nature. Ideally, an observation or empirical test could prove a theory or hypothesis true or false, but frequently an interpretation is needed. The origin of first life research stepped out early from the purely metatheoretical domain forward into the scientific territory, with the excitement of 18th-century discussions concerning the spontaneous generation of a living organism from nonliving matter. The spontaneous generation hypothesis assumed the possibility of the simple generation of living organisms from nonliving matter, previously including flies and higher animals as mice, but later reduced to infusoria. Jean-Baptiste de Lamarck, author of the first monograph, from 1809, entirely devoted to biological evolution, was strictly convinced that “spontaneous generation is the mechanism that led to the emergence of life” (Lazcano 2010, p. 6). In a turbulent back-and-forth, the pros and cons of different experiments alternated with varying degrees of credibility. In 1748 John Tuberville Needham proved that after removing mutton from fire, immersing it in water, heating it to boiling, and then closing the pot tightly – a process occurred in which in a few days resulted in a large number of different types of microorganisms in the closed pot. Afterward, the famous biologist Comte de Buffon repeatedly confirmed Needham’s experiments, making them, with his authority, publicly known and scientifically legitimate. It was assumed that the hypothesized process was a regular, widespread, and common event. On the other hand, some authors, even from the 17th century (Jan Swammerdam, Marcello Malpighi, Lazzaro Spallanzani, and Francesco Redi), firmly believed and claimed the impossibility of the spontaneous generation of living beings. In any case, up to the middle of the 19th century, spontaneous generation was considered possible and even proved until the controversy was empirically resolved in 1859 by Louis Pasteur’s experiment which demonstrated that microbes cannot spontaneously arise in properly sterilized media under contemporary conditions. His success today may seem trivial because Pasteur simply closed the laboratory containers well. The reason why Pasteur’s predecessors are not highlighted as pioneers of the denial of spontaneous generation, in particular Francesco Redi with his experimental proof of the impossibility of the spontaneous generation of insects, is because he believed in divine creation and because his experiments primarily served as a support of preexistence theory (Fry 2000, p. 27). Also, he generally believed in the idea of spontaneous generation from living tissues and plants which contained the “principle of life” (Fry 2000, p. 27) as a sort of vitalism. Redi did not receive a coronet of honor for scientific excellence, but Pasteur undoubtedly was awarded 2,500 francs in 1862 from the French Academy of Sciences for finally removing the idea of spontaneous generation from the list of serious scientific problems. His experiment, together with Darwin's *The Origin of Species*, marked the end of an era of only philosophical and religious interest in the subject matter (Kamminga 1988, p. 1). Pasteur given his award in 1862, but he resolved the 'controversy' even earlier with his famous swan-neck flask experiment, in the same year that Darwin published his *The Origin of Species*. Another coincidence is that in 1862, the French translations of *The Origin of Species* appeared on the scientific stage. Darwin himself firmly believed in the lack of evidence regarding the possibility of spontaneous generation, but also firmly stayed away from any categorical claim on the origin of life. His opinion varies from the last sentence in *The Origin of Species*: "There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one…" (Darwin 1979, pp. 459–460), to a rejection of any speculation on the origin of life, from 1863: "It is mere rubbish, thinking at present of the origin of life; one might as well think of the origin of matter" (Mayr 1982, p. 582), as well as the famous letter from 1871 that Darwin wrote to his friend Hooker regarding a "warm little pond" as a possible source of the chemically formed protein compounds needed to build first organism. However, "Darwin took for granted a natural origin of life" and believed it would be possibly to prove that living beings originated "from inorganic … matter in accordance with the law of continuity" (Peretó et al. 2009, p. 404). In addition to his giant scientific achievement, Pasteur doubted that the idea of a creator could contribute anything to the scientific explanation of the life phenomenon and its origin (Farley 1986, p. 39). On the other hand, Pasteur was a supporter of antimaterialism, "a true believer in God ... claiming that matter cannot organize itself to form life" (Fry 2000, pp. 49–50).[1] His extended effort in looking for a "cosmic asymmetric force" as the origin of the source of life was barren. Although Pasteur successfully and empirically denied the possibility of spontaneous generation, the ultimate scientific explanation of life was not grasped by his experiment. This empty space was filled with a number of hypotheses, from Eduard Pflüger, Svante Arrhenius, Leonard Troland, Alfonso Herrera, José Rodríguez Carracido, and Rodney B. Harvey, to Hermann J. Muller. While they offered scientifically based explanations, they were "largely devoid of direct supporting evidence" and because of that they remain just "incomplete speculative schemes" (Miller and Lazcano 2002, p. 82). Around the twenties of the 20th century there appeared a new player in the area, Russian biochemist Alexander Ivanovich Oparin. Oparin's hypothesis on the origin of life, based on biochemistry, was a theoretical inspiration for modern theories and a signpost for the key experiments that marked the independent field of origin of life science in its beginnings (Kamminga 1988, p. 1). Oparin's hypothesis is usually merged with Haldane's into the Oparin-Haldane hypothesis, based on their common view that the origin of life on Earth necessary required the plentiful synthesis of organic compounds in primordial Earth's conditions. Differences between the two hypotheses could be reduced to the primacy of the metabolic system and colloidal coacervates as an intermediate stage between inorganic and organic worlds in

[1]Pasteur made an effort conducting unsuccessful experiments trying to prove the existence of "a cosmic asymmetric force ... responsible for the formation of active organic compounds and hence life" (Fry 2000, p. 50). Also, Pasteur discovered the phenomenon of molecular asymmetry (chirality).

Oparin's view, and the primacy of reproduction and viruses as an intermediate stage between inorganic and organic worlds in Haldane's opinion.

A Rising Star

Alexander Ivanovich Oparin's booklet from 1924,[2] titled *Proiskhozhdenie zhizni* (*The Origin of Life*), is often mentioned as a game-changer in the area of research into the origin of life. In fact, this short book was only a pamphlet – a book from 1936 *Vozniknovenie zhizni na zemle* (*The Emergence of Life on the Earth*), introduced significant novelties and became a cornerstone of future theoretical considerations and empirical tests. The differences between the two texts are multiple and important:

> The paper from 1924: (1) did not take into account an anoxic primitive atmosphere, without oxygen-O_2, (2) the drop of organic molecules was supposed to be the last step on the way to cell life, (3) the origin of life was seen as a result of an improbable chance mechanical event, declaring no real difference between inorganic and organic nature, (4) the transformation from inorganic to organic life by first gel came out of a colloidal solution, quite in accord with the contemporary biocolloidal theory, and (5) biochemical processes were interpreted as crucial for the explanation of the living system;
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> The book from 1936 assumed: (1) that the atmosphere was reduced, with no free CO_2 and no O_2, (2) the concept of the coacervate (based on Bungenberg de Jong's work) was introduced as an intermediate stage between the inorganic world and the living world, (3) the origin of life was seen as a highly probable result of the general laws of nature by universal evolution in which living systems have unique features, (4) the transformation from the inorganic to the organic had happened through complex interactions, and life appears as a complex interaction of chemical processes, and (5) Oparin pointed out the protein-first molecule scenario in the origin of life chronology, where the metabolic aspect of cell functions happened first (first cells, enzymes, and then heredity material – he could not know at that time about the DNA model).

In the early 20th century, the prevailing theory of the origin of life definitely was anchored in a firm belief "that the first forms of life had been autotrophic microbes" (Lazcano 2010, p. 10), which was seen as a 'natural' proposed source of organic material needed for later heterotrophic living beings. Because of the high complexity of the autotrophic metabolic system, Oparin assumed a much simpler heterotrophic[3] anaerobe bacteria as the first form of life. These bacteria simply used already existing organic compounds. The next step is obvious: it is necessary to find a way that organic material could be formed outside of living beings. Oparin was not a proponent of the well-known theory of the exogenous

[2] In fact, this short book was published in November, 1923.
[3] The heterotrophic origin first hypothesis already existed in a less developmed form in Lipman and Harvey (Lazcano 2010, p. 10).

synthesis of organic materials, where these materials are formed in outer space and brought to Earth by meteorites (lithopanspermia) or cosmic dust under the pressure of radiation (radiopanspermia), which contained organic materials because “it is in direct contradiction to the objective facts of contemporary science” (Oparin 1957, p. 57). Contemporary science does not resolve this problem and it still does not have a convincing answer to “the origin of the biomolecules from which the first living systems on the primeval earth developed” (Rauchfuss 2008, p. 87).

Oparin’s hypothesis relied on Mendeleev’s (the famous inventor of the periodic classification of chemical elements) argument that hydrocarbons could be formed on Earth and outside of a living being through the action of water on carbides[4] as it “is completely justified by both earlier and later studies” (Oparin 1957, p. 128). The idea of the primary synthesis of organic compounds from carbides has its origin in calcium-carbide technology, in the naive belief that “nature uses human technology” for that purpose (Raos 2017, pp. 58–59). In his booklet from 1924, Oparin already assumed the origin of carbohydrates and proteins (Oparin 1994, p. 63) followed by “rapidly formed droplets of gel-like material ancestral to the first cell” (Lazcano 2010, p. 10). The organic material was formed outside of a living being in the primordial organic soup, as a stage in a continuous path from the inorganic to the organic world. The next step along this path is “the transformation of organic compounds into an organic body” (Oparin 1994, p. 65). The answer to when this happened is not without doubts, as well as its form: autotrophic or heterotrophic. Almost from the beginning of the Earth’s initial formation in the Hadean, “the weight of evidence does suggest that Earth has supported microbial life” (Zahnle et al. 2010, p. 49). According to contemporary prevailing consensus, the emergence of life on Earth was extremely fast, stromatolites found in Apex chert deposits (the Warawoona group in Australia) suggests 2.3-3.5 billion years old traces of life, and the Greenland Isua Greenstone Belt rock formation contains samples that indicate the origin of life as 4 or even 4.2 billion years old (Griesemer 2008, p. 271). The fossils discoveries contain imprints resembling the bodies of modern cyanobacteria or blue-green algae – and the conclusion was drawn that the fossils are the remains of highly developed cells with possible photosynthesis capacity (Schopf 1993, Fry 2000). This evidence could be interpreted as a denial of a heterotrophic first life form. It is necessary to mention objections to the authenticity of these findings: carbon isotope ratios used as evidence of the presence of organic material is not reliable because it could be “due to non-biological causes” (Fry 2000, p. 125), the purported microfossil-like structure could be interpreted as “secondary artifacts formed from amorphous graphite ... there is no support for primary biological morphology” (Brasier et al. 2002, p. 76), claims that “the Apex filaments exhibit no biological morphology ... available evidence indicates that the microstructures exfoliation of potassium mica flakes ...” (Wacey et al. 2016, p. 296), and “we cannot yet be absolutely certain whether the enigmatic Apex chert structures are artifacts or evidence of the first life” (Deamer 2011, p. 49). However, new geological evidence are highly compatible

[4]Mendeleev's (Mendeleyev in Russian) argument is well known as the abiogenetic hypothesis of the origin of crude oil and natural gas.

with the hypotheses of the chemoautotrophic origin of life (Wächtershäuser 2006, p. 1789) and the early Earth environment suggest that the first ecosystem was anaerobic (Canfield et al. 2006, p. 1819).

Regardless of the age of the first life controversy, all soup theories rest on the first life dependence on a food source from their environment, together with "a common assumption that emerging life was heterotrophic" (Fry 2000, p. 163). Oparin claimed that a necessary step on the way from the inorganic to the organic world includes the abundant synthesis of organic compounds on primitive Earth (and its atmosphere). The most important step on this path was the transition from the inorganic to the organic compounds of carbon (Oparin 1957, p. 109). Oparin proposed a specific hypothesis regarding the composition and constituents of the early atmosphere that made a possible synthesis of the organic compounds needed for the (chemical) assembly of the first life. His proposal assumed a two-phase model: "after the production of organic compounds of fairly high molecular weight, a phase separation occurred, resulting in formation of microscopic organic droplets" (Oró 2002, p. 16). Oparin called these droplets coacervates and describe them as a stage in "the evolution of organic substances" and "a powerful means of concentrating compounds of high molecular weight, in particular protein-like substances, dissolved in the hydrosphere" (Oparin 1957, p. 303). Coacervates "are small liquid droplets of two immiscible liquid phases, often caused by the encounter of macromolecules with opposite charges or sometimes from the association of hydrophobic proteins" (Astoricchio et al. 2020, p. 706). Coacervates could emerge by different organic and inorganic hydrophilic and hydrophobic colloids, with the possibility of enzymic protein incorporation (Oparin 1957, pp. 303, 310). The core of the Oparin hypothesis is a kind of pre-biological chemical evolution: from prebiotic organic synthesis to coacervate formation, then to coacervate heterotrophic 'metabolism' and further by selection pressure to autotrophic metabolism, including photosynthesis, etc. (Kamminga 1988, p. 8). In his first text from 1924, the emergence of life was not more than an exceedingly difficult mechanical problem, but in the second book it became a difficult chemical problem. It is worth mentioning that Oparin and many other Soviet life scientists were under the strong influence of Ernst Haeckel, "who was convinced that in Monera the gel-like protoplasm was the organ of both inheritance and nutrition" (Lazcano and Peretó 2017, p. 82).

> Haeckel wrote in 1866 "insofar as we are able to regard the plasma chiefly as the nutritive component of the cell and, on the other hand as the reproductive component […], we are justified in regarding the nucleus as the principal organ of inheritance and the [proto]plasma as the principal organ of adaptation. In the case of the cytode [i.e., Monera], where nucleus and plasma are not differentiated, we will have to regard the entire plasma as the common organ having both functions" (Lazcano and Peretó 2017, p. 82).

Haeckel and Huxley believed that simple life forms easily originated from inorganic materials. Based on Haeckel's hypothesis, Huxley examined the muddy soil of the North Sea in 1868, finding a gelatinous substance, believing it to be the remnants of the primitive Monera protoplasm. Huxley named one such creation *Bathybius haeckelii* in honor of Haeckel.

To resolve this impediment, as a convinced Darwinist, Oparin extrapolates the mechanism of Darwin's evolutionary processes from biology to the same hypothesized mechanism that operates on the chemical level, conceived earlier substantively with Pflüger (1875) and nominally with Moore (1913) as 'chemical evolution' or as a mechanism of natural selection on the chemical level. For him, "a biochemist who studies the processes underlying various vital phenomena can draw a picture of the successive stages in the evolution of matter which led up to the emergence of living beings" (Oparin 1957, p. 102). Twenty years later, at the First International Symposium on "The Origin of Life on the Earth" held in Moscow in 1957, Oparin declared that "An evolutionary approach to the study of our problem will, therefore, open up a wider vista of possibilities for its solution" (Oparin 1959a, p. 2). The evolutionary mechanism is responsible for the 'growth' of chemical material in the protometabolism of coacervates, being capable of the absorption and assimilation of organic material from the environment, and being capable of their transformation into its own growth and development. This is the "possible link between coacervate bodies and primitive living organisms" (Kamminga 1988, p. 8). Today the model of the coacervate is still considered valid, although the structure of Oparin's originally proposed coacervate model is no longer considered prebiotic (Kolb 2015). On the other hand, some experiments reconsider the validity of the Oparin coacervate model with more optimistic expectations. "Recent work on RNA compartmentalization and catalysis in liquid droplets provides additional support for Oparin's concept of primitive photocells in a primordial 'RNA world'" (Brangwyne and Hyman 2012, p. 525). Another experimental conclusion is similar: "Contemporary research on the early cell formation based on development of an artificial photocell system find compartmentalization in a prebiotic setting as an important aspect of such early cell formation" (Jia et al. 2014, p. 1). These authors believe that "… understanding how ATPSs (aqueous two-phase systems, AN) and coacervates interact and combine with fatty acid and phospholipid vesicles may lead to a greater understanding of the possibilities for the development of early cells in an RNA world" (Jia et al. 2014, p. 8). These experiments engender great optimism in the revitalization of the validity of the Oparin's hypothesis but additional support is needed for acceptance.

Oparin offered a possible scenario of chemical evolution, processes, and steps that may be responsible for the synthesis of more complex organic substances in the primordial soup – as the organic chemical pool which was the hypothesized source for the way toward the first life form. But even more important, this was at least partially testable in the case of minutely detailed descriptions of the prebiotic synthesis of organic compounds needed for the formation of living systems. This means that Oparin's set of assumptions relating to the conditions on primordial Earth could be reproduced in controlled laboratory conditions and tested to see if achieved results are in concordance with assumptions. Although Oparin made a testable hypothesis, he never executed experiments by himself to prove or reject it – except for coacervates. In examining the biochemical processes of the simplest structures in his laboratory, Oparin made noticed important differences between artificially obtained coacervates and drops which were, probably, naturally grown through evolutionary processes (Oparin 1959b, p. 428). Apart from these experiments, it seems that Oparin privileged theoretical concepts over experimental work for several reasons:

> First, it may have been a matter of style... Second, Oparin's expertise was not in chemistry, so even having an experienced chemist do experiments under his direction would have been unlikely to prove successful. A third reason is that the methods of analytical chemistry developed rapidly in the period 1935–1953, well after Oparin's initial work (Miller et al. 1997, p. 351).

The best-known experiment that tested the Oparin (Oparin-Haldane) hypothesis was the Miller-Urey experiment at the University of Chicago in 1953, which successfully synthesized biomolecules from selected inorganic components under assumed prebiotic conditions. In his 1953 paper with the experiment's results, "A Production of Amino Acids Under Possible Primitive Earth Conditions," Miller (1953, p. 529) made only three references, and one was to Oparin's book from 1936. Miller simulated a reduced atmosphere with a mixture of methane, ammonia, hydrogen, and water (vapor). This chemical mixture was exposed to electrical discharges of 60,000 volts and a heat of 350 to 920 K, imitating a lightning storm in early Earth's atmospheric conditions. The results were promising: formaldehyde and cyanide were formed, and after that, the synthesis of amino acids occurred spontaneously (Benner at al. 2010, p. 74). These chemical reactions were already known as the Strecker synthesis from Albert Strecker's 1850 experiment. The most abundant relevant substances produced by the Miller-Urey experiment were formic acid (4%), glycine (2.1%), lactic acid (1.6%), and alanine (1.7%). As we know, amino acids are the fundamental building blocks of proteins, which are the building blocks of living beings – so it seems the circle is closed. But, the experiment failed to synthesize the most important macromolecules purine and pyrimidine, which remains one of the major problems "for an understanding of the origin of life" (Miller and Urey 1959, p. 150). The experiments of Joan Oró from 1961, and of many others later, were conducted with more success in regard to the synthesis of the purine base adenine (a key component of nucleic acids), from a solution of urea, and the purine base guanine (Bada and Lazcano 2009, p. 56). Both bases, purine adenine and guanine, result from the condensation of HCN with urea as a byproduct.

Still, it is possible to say that "all of the most impressive prebiotic syntheses produce garbage by the standards of synthetic organic chemistry ... with a percent or two of the desired nucleotide base" (Orgel 2002, p. 140). Together with these objections, the Miller-Urey experiment is questioned in many other of its points, and complaints were targeting on its wrong assumption about the composition of the atmosphere: it seems that the amount of methane (and ammonia) on early Earth was much smaller, and carbon was probably present largely as carbon dioxide and nitrogen. It seems that the "nonbiological synthesis of biomolecules under these conditions has been sought" (Benner et al. 2010, p. 74). A repeated experiment in 1983 with the correct combination of gases produced "nitrites which destroyed amino acids as quickly as they form," but later experiments with added iron and carbonate minerals produced plenty of amino acids (Fox 2007, p. 2). The chemical composition of the primordial atmosphere is a crucial point in the debate on the formation of life, but all models on the primordial atmosphere on Earth are only hypothetical (Rauchfuss 2008, p. 31). So, up to now "There is no geological evidence for the existence of Oparin's prebiotic soup" (Miller et al. 1997, p. 352). Of course, absence of evidence is not evidence of absence: the wide array of organic compounds of biochemical significance found in the old carbonaceous chondritic meteorites which are coeval with the time of formation of the Earth could strengthen the hypothesis that similar compounds may have existed in the terrestrial environment. This hypothesis is logically possible but not proved.

Because of the long-term uncertainty in establishing the facts on this topic, the "Miller-Urey experiments of 1953 are of only historic interest today" (Rauchfuss 2008, p. 88). But even if experiments are conducted under the unconfirmed premises of the composition of the primordial atmosphere and other conditions of early Earth, and despite the debate regarding the relevance of produced chemical compounds, its results prove the logical possibility of the in vitro synthesis of the macromolecules important in building a life outside of living beings. This means the Miller-Urey experiment gains success in proving the logical possibility of natural processes in producing the chemical building blocks of life. In the same way, the Miller-Urey experiment proves the fundamental theoretical premises of the Oparin hypothesis of the possibility of the prebiotic synthesis of organic molecules. Any expected optimism spurred by the Miller-Urey experiment has waned over the years because the forthcoming understanding of how life began was not realized. The peak of this experiment is exhausted by evidence of the in vitro prebiotic synthesis of the important macromolecules – but the final goal set by Oparin has not been achieved "The most important, as well as the least studied, stage of the evolutionary process under consideration would seem to be the transition from the most complicated organic substances to the most primitive living organisms. This is the most serious gap in our knowledge" (Oparin 1957, p. 101). The verdict on the importance and impact of the Miller-Urey experiment on the scientific value of the Oparin hypothesis could not be decisive: the relevance of any scientific experiment is only one side of the coin. On the other side of the coin, it is necessary to compare the fundamental theoretical premises of Oparin's theory, and then test the demand coming from the philosophy of science considering its testability and predictability (through empirical observation and experiment).

Verdict

Basic apparatus in the evaluation of the Oparin hypothesis could be assembled through three mechanisms: to determine whether the premises of the Oparin hypothesis are in accordance with the facts, if these facts confirmed or opposed by the experiment, and whether these two previous mechanisms obey the demand of the philosophy of science toolkit.

The premises of the Oparin hypothesis were comprehensively reconsidered on the sixtieth anniversary of the first Russian printing of the *Vozniknovenie zhizni na zemle* (*Origin of Life on Earth*), in a short article by three authorities in the area of the scientific research of the origin of life, Miller, Schopf, and Lazcano. The first of them, Stanley Miller, conducted the famous Miller-Urey experiment. From their article it is possible to extract contemporary scientific facts that do not support the premises of the Oparin hypothesis: there is no geological evidence for the existence of Oparin's postulated prebiotic soup, there is no proof that abiotic synthesis took place on primitive Earth, the proposed glucose fermentation as the first source of metabolic free energy is no longer considered valid, the long periods of time needed for the emergence of life has been superseded, and the coacervate model as a first organism model is no longer held to be plausible (Miller et al. 1997, p. 352). Alongside this, his hypothesis completely dismissed the possibility of replication as well as the role of DNA in the explanation of the origin of first life (as it was not known in that time, but even later Oparin did not include a genetic component of life as important for the explanation of first life origin). Although he was originally inclined to pre-Mendelian genetics he later learned about the role of nucleic acids in heredity. It seems that Oparin for so many years did not admit the importance of genetic nucleic acids in heredity and their role in the origin of life not because of pure scientific reasons:

> Oparin's refusal to assume that nucleic acids had played a unique role in the origin of life resulted not only from his unwillingness to assume that life can be reduced to a single compound such as the "living DNA molecule" … but also within the framework of Cold War politics, his complex relationship with Lysenko, and his long association with the Soviet establishment (Lazcano 2010, p. 10).

Under the strong influence of Soviet agronomist Trofim Lysenko, who was supported by the Communist Party, and who believed that acquired traits are inherited (Lamarckism, AN) and denied the existence of genes (Borinskaya et al. 2019, p. 1), Oparin strictly followed these ideas.

He "eventually acknowledged the role of nucleic acids in the origin of life" and assumed that "protein synthesis was the evolutionary outcome of the interaction of primordial polypeptides and polynucleotides within the boundaries of precellular systems" (Lazcano 2010, p. 10).

All these facts regarding basic premises are derived from the scientific effort in the comprehension of the origin of life as well as from Miler-Urey and all the other subsequent experiments of the same kind. These experiments prove the logical possibility of the Oparin general scenario and could be used as strong evidence that the macromolecules that are important for life systems can emerge in abiotic milieu under controlled laboratory conditions. This was a huge step toward understanding the possible pathways on the road to the transition from the inorganic to the organic world. But, up to now there has been no experiment which could undoubtedly confirm or reject the premises set by the Oparin hypothesis. Also, the most important gap between the most complex inorganic compounds and the simplest living systems was not narrowed by the Oparin hypothesis in a way that could be recognized as a scientific explanation. The peak of testing the Oparin hypothesis is a trap by proof of the logical possibility of the in vitro prebiotic synthesis of the important macromolecules. The difference between the logically possible and the logically necessary is clear, and this difference cannot be ignored nor neglected. Because of this, from the logical point of view, Oparin hypothesis, even at the time of its origin, could be only contingently true.

Regarding the demand coming from philosophy of science, it is necessary to repeat that scientific theories are subject to change: this means that sometimes a theory does not represent the best current knowledge about a specific phenomenon anymore and has to be abandoned, sometimes a theory loses parts of its scope and relevance, or its elements need improvements according to new scientific insight and can be repaired. The example of the first is superseded Stahl's phlogiston theory, the second is classical causal classic physics, powerless in regard to the explanation of quantum phenomena limited to submicroscopic phenomena and probabilistic predictions, and the numerous models of atoms could be seen as an example of the third kind of the destiny scientific theory. A rejected or revised theory is not true because an appropriate entity or fact to which it has to correspond does not exist or does not exist in a way theory predicted or explains. A rejected theory is at fault because its propositions do not correspond to facts and/or is not very well supported by other scientific theories or when there is no expected resemblance between the theoretical and empirical realm. In the two other cases, theories continue their existence. Where would the Oparin hypothesis be located within these possibilities? Does it have to be abandoned, is it not relevant anymore, or could it be repaired and improved? The importance and impact of Oparin's hypothesis is tremendous as a conceptual breakthrough because it transformed "the origin of life study into a broad-based workable research program" (Miller et al. 1997, p. 352). Oparin's hypothesis, to be sure, is creditable for setting the "methodological standards for all future work in the field ... and continue to stand as an exemplar" (Kamminga 1998, p. 9), and even for establishing a firm (meta)theoretical and methodological framework for further scientific research. But, if we evaluate the Oparin hypothesis as a specific scientific theory, then we have to admit that some of its premises are not known or definite (prebiotic soup, glucose fermentation, the long period of times needed for the emergence of life), and some of them are even rejected (the coacervate). But the most serious objection to the Oparin hypothesis is that its scope is restricted to the very narrow area of the possible prebiotic synthesis of the macromolecules we find in living systems. Even if it could be successful in explaining prebiotic synthesis, the Oparin hypothesis did not decrease the most important gap between the most complicated organic substances and the most primitive living organisms. The explanation of this transition is the ultimate and final goal of origin of life research.

Conclusion

The Oparin hypothesis changed the course of the origin of first life research from purely metaphysical speculation to empirical investigation. His hypothesis created a new (meta)theoretical framework, was a conceptual insight, and developed detailed steps in the hypothesized process on the path to the origin of first life. By this Oparin made his hypothesis to be at least partially empirically testable, which was carried out several times. On the other hand, the Oparin hypothesis was founded on unconfirmed or indefinite premises which are not plausible according to the contemporary knowledge of our best scientific theory. His hypothesis has a high metatheoretical value, but as a specific scientific hypothesis, its contribution is highly limited to the area of the history of science and the history of philosophy (of science).

References

Astoricchio E, Alfano C, Rajendran L, Temussi PA, Pastore A (2020) The wide world of coacervates: from the sea to neurodegeneration. *Trends in Biochemical Sciences* 45(8): 706–717.

Bada JL, Lazcano A (2009) The origin of life. In M Ruse, J Travis (eds.), *Evolution: The First Four Billion Years,* 49–80. Cambridge, Massachusetts and London, England: The Belknap Press of Harvard University Press.

Benner SA, Kim H, Kim M, Ricardo A (2010) Planetary organic chemistry and the origins of biomolecules. In D Deamer, JW Szostak (eds.), *The Origins of Life,* 67–88. Cold Spring: Cold Spring Harbor Laboratory Press.

Borinskaya SA, Ermolaev AI, Kolchinsky EI (2019) Lysenkoism against genetics: the meeting of the Lenin all-union academy of agricultural sciences of August 1948, its background, causes, and aftermath. *Genetics* 212(1): 1–12.

Brangwyne CP, Hyman AA (2012) In retrospect. The origin of life. *Nature* (491): 524–525.

Brasier MD, Green O, Jephcoat A, Kleppe AK, Van Kranendonk MJ, Lindsay JF, et al. (2002) Questioning the evidence for earth's oldest fossils. *Nature* 416(Mar): 76–81.

Canfield DE, Rosing MT, Bjerrum C (2006) Early anaerobic metabolisms. *Philosophical Transactions of the Royal Society B* 361(1474): 1819–1836.

Darwin C (1979) *The origins of species by means of natural selection*. New York: Random House.

Deamer D (2011) *First life: discovering the connections between stars, cells, and how life began*. Berkeley: University of California Press.

Farley J (1986) Philosophical and historical aspects of the origin of life. In *Treballs de la Societat Catalana de Biologia*, 37–47.

Fox D (2007, March 28) *Primordial soup's on: scientists repeat evolution's most famous experiment*. Scientific American.

Fry I (2000) *The emergence of life on earth: a historical and scientific overview*. New Brunswick: Rutgers University Press.

Griesemer J (2008) Origins of life studies. In M Ruse (ed.), *The Oxford Handbook of Philosophy of Biology,* 263–290. New York: Oxford University Press.

Jia ZT, Hentrich CI, Szostak JW (2014) Rapid RNA exchange in aqueous two-phase system and coacervate droplets. *Origins of Life and Evolution of Biospheres* 44(1): 1–12.

Kamminga H (1988) Historical perspective: the problem of the origin of life in the context of developments in biology. *Origins of Life and Evolution of the Biosphere* 18(1–2): 1–11.
Kolb VM (2015) Oparin's coacervates as an important milestone in chemical evolution. In *Proceeding SPIE 9606, Instruments, Methods, and Missions for Astrobiology XVII*, 960604.
Lazcano A (2010) Historical Development of Origins Research. In D Deamer, JW Szostak (eds.), *The Origins of Life*, 5–20. Cold Spring, Cold Spring: Harbor Laboratory Press.
Lazcano A, Peretó J (2017) On the origin of mitosing cells: a historical appraisal of Lynn Margulis endosymbiotic theory. *Journal of Theoretical Biology* 434(7): 80–87.
Miller S (1953) A production of amino acids under possible primitive earth conditions. *Science* 117(3046): 528–529.
Mayr E (1982) *The growth of biological thought. Diversity, evolution, and inheritance*. Cambridge: The Belknap Press of Harvard University Press.
Miller S, Lazcano A (2002) Formation of the building blocks of life. In JW Schopf (ed.), *Life's Origin*, 78–112. Berkeley: California University Press.
Miller S, Urey H (1959) Organic compound synthesis on the primitive earth. *Science* 130(3370): 245–251.
Miller S, Schopf J, Lazcano A (1997) Oparin's 'Origin of Life: Sixty Years Later'. *Journal of Molecular Evolution* 44(4): 351–353.
Moore B (1913) *The origin and nature of life*. New York: Henry Holt and Company.
Oparin A (1957) *The origin of life on the earth*. Third Revised and Enlarged Edition. Translated from the Russian by Ann Synge. New York: Academic Press Inc. Publishers.
Oparin A (1959a) Introductory address. In AI Oparin, AG Pasynskii, AE Braunshtein, TE Pavlovskaya (eds.), *Proceedings of the First International Symposium on The Origin of Life on the Earth*, 1–3. New York: Pergamon Press.
Oparin A (1959b) Biochemical processes in the simplest structures. In AI Oparin, AG Pasynskii, AE Braunshtein, TE Pavlovskaya (eds.), *Proceedings of the First International Symposium on The Origin of Life on the Earth*, 428–436. New York: Pergamon Press.
Oparin A (1994) The origin of life. In D Deamer, GR Fleischaker (eds.), *Origins of Life. The Central Concepts*, 31–81. Boston: Jones and Bartlett Publishers. Reprinted from JD Bernal, *Origin of Life*. London: Weidenfeld & Nicholson, 199–234. (Translation of AI Oparin, *Proiskhozdhenie zhizny*, 1924, Moscow).
Orgel L (2002) The origin of biological information. In JW Schopf (ed.), *Life's Origin: The Beginnings of Biological Evolution*, 140–158. Berkeley: University of California Press.
Oró J (1961) Mechanism of synthesis of adenine from hydrogen cyanide under possible primitive earth conditions. *Nature* 191(Sep): 1193–1194.
Oró J (2002) Historical Understanding of Life's Beginnings. In JW Schopf (ed.), *Life's Origin. The Beginnings of Biological Evolution*, 7–46. Berkeley: University of California Press.
Peretó J, Bada J, Lazcano A (2009) Charles Darwin and the origin of life. *Origins of Life and Evolution of Biospheres* 39(5): 395–406.
Pflüger E (1875) Beiträge zur Lehre von der Respiration I. (Contributions to the doctrine of respiration I). *Archiv für die gesamte Physiologie des Menschen und der Tiere* 10: 251–367.
Raos N (2017) Carbide chemistry and Oparin's theory on the origin of life. *Bulletin for the History of Chemistry* 42(1): 57–62.

Rauchfuss H (2008) *Chemical evolution and the origin of life*. Verlag: Springer.

Schopf J (1993) Microfossils of the Early Archean Apex Chert: new evidence of the antiquity of life. *Science* 260(5108): 640–646.

Wacey D, Saunders M, Kong C, Brasier A, Brasier M (2016) 3.46Ga Apex Chert 'Microfossils' reinterpreted as mineral artefacts produced during phyllosilicate exfoliation. *Gondwana Research* 36(Aug): 296–313.

Wächtershäuser G (2006) From volcanic origins of chemoautotrophic life to Bacteria, Archaea and Eukarya. *Philosophical Transactions of the Royal Society B* 361(1474): 1787–1808.

Zahnle K, Schaefer L, Fegley B (2010) Earth's Earliest Atmospheres. In D Deamer, JW Szostak (eds.), *The Origins of Life*, 49–66. Cold Spring: Cold Spring Harbor Laboratory Press.