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LETTER TO THE EDITOR

Chemical Evolution and the Primitive Soup: Did Oparin Get It All Right?

1. Introduction

In a recent paper, Yockey (1995) commented on a review of his book *Information Theory and Molecular Biology* (Yockey, 1992) written by Elitzur (1994). In doing so, he expressed not only his harsh criticism of the hypothesis of chemical evolution and the idea that life was preceded by a primitive soup (Oparin, 1938), but also made a number of claims regarding the composition of the Earth's earliest atmosphere, the absence of geological evidence of the primitive soup, the history of the concept of the RNA world, and of other issues related to the appearance of life, all of which I believe require some clarification. The purpose of this *Letter* is to discuss some of the statements made by Yockey (1995) and to provide the readers with alternative viewpoints.

2. Dialectical Materialism and the RNA World

Yockey (1995) addressed the issue of the ideological orientation of A. I. Oparin and the role that dialectical materialism may have had in shaping his ideas on the origin of life. This is a subject which has been discused in detail by a number of authors (Joravsky, 1962; Graham, 1972; Farley, 1974; Kamminga, 1988; Lazcano, 1992, 1995a, b). This issue is not a simple one, and its dispassionate analysis is complicated by its political aspects, including the explicitly Marxist preferences that A. I. Oparin, together with J. B. S. Haldane and J. D. Bernal, adopted as members of a generation which was involved in excruciating debates on the role of ideology in shaping scientific theories. At the very least, it is clear that dialectical materialism shaped the social environment and scientific milieu of Oparin and other Soviet scientists, many of which were sincerely persuaded that Marxism was not only an official state philosophy but also a framework on which entire research programs could be based (Graham, 1972; Farley, 1974; Tagliagambe, 1978). The outcomes of such an attitude are complex and defy simple explanations. As noted by Joravsky (1962), the uses of Marxism by a number of Soviet scientists, "range from the absurd (as in the attack by Olga B. Lepeshinskaya on cytology) to the quite important (as in A. I. Oparin's theorizing on the origin of life)."

Like others before him (Graham, 1972; Farley, 1974; Kamminga, 1988; Lazcano, 1992), Yockey (1995) has recognized the reductionist-mechanist approach in Oparin's first published work on the origin of life (Oparin, 1924). In perspective, this small volume can be considered the harbinger of his major work, a 1936 Russian book also called the *Origins of Life*, whose English translation became available two years later (Oparin, 1938). Instant conversions to dialectical material took place (and not only in the USSR) but, contrary to what Yockey (1995) states, this was not the case of Oparin. As shown not only by the comparison of these two books but also by a number of little-known papers written between 1924 and 1936, Oparin gradually adopted dialectical materialism as the epistemological framework within which he attempted to describe the origin and nature of life (Lazcano, 1992, 1995b). Oparin's long association with the Soviet establishment and with Lysenko may be unpalatable, but should not keep us from recognizing that his ideas played a major role in stimulating the scientific discussion on the emergence of life. A person's science should be judged on its validity, and not on his or her political preferences.

Yockey's (1995) description of the RNA world as a mere speculation also based on dialectical materialism is not only surprising but inaccurate. For Oparin (1938), the critical step in the transtition from the non-living to the living was not the appearance of replication, but the emergence of a primordial heterotrophic metabolism based on coupled oxidation and reduction reactions. On the other hand, the possibility that the first life forms were largely based on catalytic RNA was discussed by a number of scientists (Rich, 1962; Woese, 1967; Crick,

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1968; Orgel, 1968), who recognized the evolutionary significance of RNA's ubiquity and its potential catalytic properties. Although it is doubtful that life began with RNA itself, the discovery of ribozymes has provided support for the hypothesis that during an early evolutionary stage life may have depended on sets of replicating RNA molecules endowed with catalytic activities. By stating that the RNA world is an idea that stems from dialectical materialism, Yockey (1995) is engaging in unacceptable name-calling. It is somewhat ironic that in doing so he fails to recognize that the RNA world hypothesis comes from a scientific tradition that has more in common with the suggestions of Muller (1926), one of Oparin's lifelong critics, than with those of Oparin himself.

3. The Primordial Protoplasmic Globule

As Yockey (1995) notes, the idea that life was an emergent feature of nature was widespread during the past century. Authors like Pflugger, Hensen, Allen, Löw and others attempted to explain the origin of life by introducing principles of historical explanation, albeit in a much less articulated form and without the multidisciplinary methodological standards that Oparin helped to establish (Kamminga, 1991). It is therefore not surprising that terms like "primordial protoplasm" are found in 19th century sources; from the 1840s to the turn of the 20th century, several ideas on the nature of protoplasm coexisted, but had different and sometimes even opposing meanings (Ling, 1984; Welch, 1995). Study of life's defining properties was understood by many as the physico-chemical characterization of protoplasm, and thus became part of colloid chemistry (Olby, 1970). It is also well-known that in some cases attempts to understand the appearance of life led to a wide variety of laboratory models of protoplasm, some of which rank, from a modern perspective, well-within the absurd.

Why Oparin (1938) did not refer to Loeb's (1924) writings on colloids and their relation to proteins (Yockey, 1995) is difficult to guess (but may have to do with the availability of Western scientific literature in the USSR during the 1930s). Nevertheless, any careful reader can understand his choice of Jong's (1932) coacervates as models of precellular systems. As Oparin (1938, p. 159) himself noted, "the formation of complex coazervates (sic) in the Earth's hydrosphere was unavoidable because their formation requires very simple conditions, merely the mixture of two or more high-molecular organic substances being necessary".

4. The Prebiotic Atmosphere: Neutral or Reducing?

There is no geological evidence of the physical setting of the origin of life, i. e., there are no surviving intact sediments from the time of life appearance, which is generally thought to have taken place sometime between 4.0 to 3.5×10^9 years ago. Direct information is lacking not only on the composition of the terrestrial atmosphere during the period of the origin of life, but also on the temperature, ocean pH values, and other general and local environmental conditions which may have been important to the emergence of living systems.

Like others, Yockey (1995) has expressed his skepticism regarding the reducing character of the primitive atmosphere. However, the relative amounts of atmospheric CH_4, CO, and CO_2 prior to the emergence of life are unknown. Although it is generally agreed that free oxygen was absent, there is no geological evidence as to whether the Earth's earliest atmosphere was reducing or neutral. What Yockey (1995) is advocating is a $CO_2 + N_2$ atmosphere, which is the theoretical outcome of model calculations involving (a) the rapid photochemical destruction of CH_4 in a cloudless primitive atmosphere, and in the absence of large amounts of metallic iron-rich accreted meteorites; and (b) the incorporation of high pressures of carbon dioxide to raise the temperature of the primitive Earth by a greenhouse effect in order to avoid the complete freezing of the oceans (Kasting, 1993).

It is probably fair to say that today such nonreducing models are favoured by atmospheric chemists, while prebiotic chemists lean towards more reducing conditions ($CH_4 + N_2$ or $CO_2 + H_2 + N_2$), under which the abiotic syntheses of amino acids, purines, pyrimidines, and other compounds are very efficient (Stribling & Miller, 1987). The possibility that the primitive atmosphere was not reducing does not creates insurmountable problems, since the soup could still form. Atmospheric carbon dioxide could have been photoreduced by ferrous iron in solution, and pyrite formation, ($FeS + HS \rightarrow FeS_2 + H^+ + e^-$, $\Delta G^\circ = -9.23$ kcal/mol; $E^\circ = -620$ mV) on submerged rocks or other environments, may have provided an important source of electrons for the reduction of organic compounds (Keller *et al.*, 1994). These reactions, together with proposals of extraterrestrial organics input (Chyba *et al.*, 1990) and of a thioester world (De Duve, 1995), are compatible with the idea of a primitive soup and can be incorporated into the descriptions of the prebiotic environment without straining the overall structure of the theory of chemical evolution beyond recovery.

5. The Search for the Leftovers of the Primitive Soup

The lack of precise definitions of synonimous terms like "primitive soup", "primordial broth", or "Darwin's warm small pond" has led in a few cases to major misunderstandings, including the simplistic image of a worldwide tarry ocean rich in self-replicating molecules accompanied by all sorts of biochemical building blocks ready to be incorporated into prokaryotic-like protobionts. The term "Darwin's warm small pond", which has long been used for convenience (and is thus equivalent, for instance, to Newton's apple, Maxwell's demon, or Schroedinger's cat), refers not necesarily to the entire ocean, but to parts of the hydrosphere where the abiotic synthesis, accumulation, and interaction of organic compounds may have taken place (oceanic sediments, fresh water lakes, shores, eutectic environments, small ponds undergoing wet-and-dry cycles, etc.).

It is true that there is no geological evidence of such a soup but, contrary to what Yockey (1995) writes, a major truism in historical disciplines (including evolutionary biology) is that the absence of evidence is *not* evidence of absence. Digging up the past may be a hit-or-miss proposition. That the prebiotic broth never existed can not be concluded from the absence of large amounts of organic compounds in terrestrial rocks of 3.8.to 4.0 × 10^9 years old, because no such samples are available. There could be no survival of the soup because the biochemical monomers would decompose in 3.5 × 10^9 years even at 25°C, to say nothing at 150°C or even higher temperatures. However, the presence of different biochemical monomers (proteinic and non-proteinic amino acids, carboxylic acids, purines, pyrimidines, etc.) in the 4.6 × 10^9 year-old Murchison carbonaceous meteorite, which comes from an asteroid, makes it plausible, although it does not prove, that such syntheses could also have taken place on the Earth (Lazcano & Miller, 1994).

The low $\delta^{13}C_{org}$ values which have been determined for the 3.8 × 10^9 year-old Isua formation have been interpreted to imply that oxygen-releasing photosynthesis was already in operation on a global scale (Schidlowski, 1988). However, these highly metamorphosed sediments have been heated to 500°C and may be the wrong place to look for remains of the primitive soup. Since the processes leading to the emergence of life and the evolution of cyanobacteria may have required no more than 10 million years (Lazcano & Miller, 1994), microbial life may have already existed by Isua times. Whether this was the case or not is still an unsettled issue, but the Isua rocks were deposited almost one billion years after the Earth was formed. Evidence of the soup would necessarily have been obliterated by then, since prebiological evolution and the origin of life could have occurred at any time after the planet accreted and cooled down. Theoretical estimates suggest that the entire Earth remained molten for only a few hundred million years after its formation 4.6 × 10^9 years ago (Wetherill, 1990). Thus, the hydrosphere may have existed for 4 billion years, but the entire world ocean is estimated to go through the ridge crests every 10^6 (Lowell *et al*., 1995) to 10^7 years (Edmonds *et al*., 1982). Therefore, by Isua times a significant portion of the hydrosphere would have circulated through hydrothermal vents several hundred times facing temperatures of 350°C or more, which would have destroyed most of the organic compounds formed abiotically. While the suggestion that the Isua ^{12}C isotopic enhancement is due to the existence of Archean microbial communities may be correct or not, the conclusion that it proves that the prebiotic soup never existed simply is not true.

6. The Primitive Soup: Consommé, Gazpacho, or Vichyssoise?

According to Yockey (1995), theoretical estimates suggesting an extremely dilute soup also argue against the hypothesis of chemical evolution. The concentration of the primitive soup would depend on the ultimate sources of organic compounds. If reducing conditions are assumed, the oceanic concentration of glycine could have values of the order of 10^{-4} M, but if the organic compounds were only of extraterrestrial origin, then the glycine concentration in the prebiotic broth would be as low as 10^{-8} M (Stribling & Miller, 1987).

At such low concentrations the probability of chemical interactions between the different organic compounds becomes quite small, and the emergence of self-replicating systems capable of undergoing Darwinian evolution, whatever their nature was, appears to be extremely unlikely. However, these concentrations are average values estimated for a worldwide ocean with a volume $V_{ocean} = 1.5 \times 10^{21}$ liters. Even the lowest limit of 10^{-8} M glycine calculated by Stribling & Miller (1987) from Chyba's *et al* (1990) estimates of accreted extraterrestrial organic compounds represents a large potential energy supply. Assuming fermenting 2μ bacterial cells with 70% water content and 1 mol ATP per mole of glycine, a 10^{-8} M oceanic concentration of glycine corresponds to 10^{25} cells! The obvious conclusion is that processes relevant to the origin of life may have taken place in environments different from the oceanic average, such as eutectic sea water or drying lagoons, in which different physicochemical mechanisms such as adherence of biochemical monomers to mineral surfaces could have raised their local concentrations (Ferris *et al*., 1996). This possibility by no means contradicts the soup hypothesis: as noted by von Kiedrowski (1996), experiments attempting to demostrate the potential role of active mineral surfaces such as clays in prebiotic polymerization reactions still require the soup to provide the starting material.

7. Chirality and the Monophyletic Origin of Life

Physical and chemical properties of the two optical enantiomers of compounds are the same in an optically inactive environment. There are no known abiotic mechanisms which would have favoured the assymetric synthesis and/or accumulation of only one of the biochemical enantiomers in the primitive Earth or on the parent body of carbonaceous meteorites. This has led many (but not all) researchers in the origin of life to conclude that the preference of organisms for the combination of *both* L-amino acids *and* D-sugars is due to chance, i.e., that the origin and evolution of living systems on Earth or elsewhere based on D-amino acids and L-sugars would be equally likely. The L-amino acids *and* D-sugars combination found in all known organisms can be thus properly considered as additional evidence of the monophyletic origin of terrestrial life (Elitzur, 1994). It is true, as Yockey notes, that D-amino acids are found in living systems. However, they are absent from enzymes participating in mainstream metabolic pathways, and their biosynthesis begins with L-enantiomers. It likely that the presence of D-amino acids in some antibiotics and other biological products is a secondary adaptation and not an evolutionary vestige from primordial times. It is somewhat amusing that Yockey's (1995, p. 354) insistence that the L-amino acids *and* D-sugars combination found in all extant organisms can not be due to chance puts him on the same side as Oparin, whose systematic rejection of an onthological role for purely random events was largely based on a somewhat orthodox interpretation of dialectical materialism.

8. Conclusions

Oparin's most important achievement may have been the methodological breakthough that transformed the study of the origin of life from a purely speculative problem into a workable research program. As Farley (1974) notes, Oparin's (1938) volume "is probably the most significant book ever published on the origin of life". Most of workers in the field are aware that many of Oparin's original ideas have been superseded, leading to changes that have improved the postulates and assumptions underlying his initial hypothesis. Over the years it has become clear that the open character of the theory of chemical evolution has allowed the incorporation of new discoveries and the development of more accurate descriptions of possible primitive scenarios without destroying its overall structure and premises (Kamminga, 1986).

It is somewhat disturbing to find in Yockey's (1995, p. 351) discussion of the hypothesis of chemical evolution an unjustified attempt to disqualify the pioneering character of Miller's (1953) laboratory simulation of the primitive Earth. Even if one disagrees with the assumptions underlying this classical experiment, it deserves recognition not only because of its intrinsic merits, but also because it opened new avenues of empirical research on prebiotic chemistry. Because of the many uncertanties in current descriptions of the origin of life, scientific dissent from mainstream ideas should not only be welcomed but also encouraged. The most fertile and useful criticism is the one that provides coherent, testable alternative viewpoints. It is a pity that the latter are missing in Yockey's (1995) paper.

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