GENERAL SCIENCE NOTES

A NEW ATTEMPT TO UNDERSTAND THE ORIGIN OF LIFE: THE THEORY OF SURFACE-METABOLISM

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WHAT THIS ARTICLE IS ABOUT

The question of how living matter came into existence has not yet been answered by the theory of evolution. For the past thirty years or so, the stock evolutionary explanation consisted of schemes which first produced (on paper) ponds rich in organic matter (known as the primordial soup or organic broth), and second, which transformed the contents of the organic soup (again on paper) into proteins and nucleic acids.

Recently an alternative theory of the origin of life was published, which presents the concept of "surface metabolism" as the process which gave rise to living matter.

This theory suggests that the forerunners of living matter were formed underwater, on metallic surfaces. Negatively charged, simple organic molecules bound to positively charged (pyrite) surfaces, forming ever-growing, two-dimensional organic films. Eventually portions of the organic layer detached from the surface and formed three-dimensional cell-like structures. In time these units would evolve into primordial cells which would have been the precursors of living matter as we now know it.

This proposal represents a sharp refutation of the organic-broth theory. Nevertheless, it is a pencil-and-paper exercise which has not been buttressed by experimental proof. It offers no new insight into the problem of the origin of biological information in nucleic acids and proteins or into the origin of the non-equilibrium, steady state of chemical reactions presently operating in living matter.

Since the days of Haldane and Oparin in the 1920s, life scientists have earnestly grappled with the problem of the origins of life on Earth in an evolutionary context. The "pencil-and-paper" talk turned to serious experimental work in the 1950s, after Stanley Miller and Harold Urey showed that certain excited gaseous mixtures can give rise to amino acids. Fortified with some laboratory successes, the now familiar "chemical-broth" theory of chemical evolution emerged to dominate the thinking of evolutionary theorists for decades to come. Over the past thirty years countless textbook chapters, review articles and monographs have elaborated the events that were supposed to transform inorganic matter into living cells. An entire generation of students grew up learning that life originated from a warm aqueous environment — "the primordial soup". This broth-like medium served as a reservoir loaded with organic substances, out of which emerged building materials for biologically important macromolecules. These in turn assembled themselves into living cells.

After decades of living with this proposed evolutionary scenario, scientists began to voice serious objections to the organic-broth theory. Criticisms included thermodynamic difficulties, the implausibility of the existence of a strictly anoxic primordial atmosphere and problems of demonstrating the primordial synthesis of some key building-block substances such as ribose and nucleotides, not to mention biologically relevant forms of nucleic acids and proteins.

Alternative hypotheses began to appear. One proposal resurrected the almost century-old notion of panspermia (i.e., life from an extraterrestrial source). Another postulated that the first "organisms" may have been made of crystals of clay; this was suggested to bridge the phenomenal gap between the simple inorganic compounds found in inanimate matter and the sophisticated organic substances which compose living cells and organisms.

However, the notion of panspermia simply pushed the entire problem of life's origin to some unknown extraterrestrial location, and the proposal of initial "clay organisms" did not solve the problem of where and how organic molecules originated. Nevertheless, these new postulates, although unsuccessful in replacing the organic-broth theory as the dominant evolutionary explanation for the origin of life, did create a crisis of confidence in the ability of evolutionary theorists to explain the origins of life. The main reason for retaining the organic-broth theory, in the words of Scherer[1] was: "...if this rejection is substantiated, there will remain no scientifically valid model of the self-organization of the first living cells on Earth."

To remedy this situation, a brand-new theory of the origin of life was proposed recently. This chemical evolutionary idea — the "Theory of Surface Metabolism" — was published in the December 1988 issue of *Microbiological Reviews,*[2] and it occupies 32 oversized pages. Its author is Günther Wächtershäuser of Munich, West Germany.

The article was written as a proposal for a "viable alternative to the broth theory." It suggests that the first chemical evolutionary events occurred on underwater, metallic surfaces. The first "organisms," according to this theory, were continuously spreading two-dimensional films of negatively charged organic molecules (one molecule thick) attached to positively charged pyrite.

The substrates for the growth of the organic film would have been small, one- or two-carbon containing molecules, such as carbon dioxide, formaldehyde, formic acid, and acetaldehyde, as well as ammonia, hydride ions and electrons. The ultimate origin of all carbon-containing components, however, would have been carbon dioxide.

The delivery of these substances to the growing "organism" would have been accomplished by positively charged "general purpose shuttles," which form a "bucket-brigade" type chain, somewhat in the fashion of existing respiratory chain components. In fact, some of these shuttles are the postulated precursors of many coenzymes. The types of reactions and substances that would endure and be incorporated into more complex systems later are postulated to have been autocatalytic, i.e., promoting the formation of further copies of themselves.

According to this theory, as isoprenoid-like (a type of hydrocarbon) lipids became incorporated into the surface-films, hydrophobic domains formed, which eventually sequestered portions of the organic film and became detached from the pyritic surface. The detachment would occur when positively charged, loose metallic "grains" would come near the lipids and attract the anionic fatty acids.

Energy for the surface reactions is postulated to come from redox type reactions, such as the formation of pyrite from hydrogen sulfide and ferrous ions. Once cells form, it is proposed that the phosphate-containing molecules become good sources of energy in fermentative-type reactions, until the emergence of an electron transport-chain. Biosynthetic reactions would be maintained by the influx of non-ionic nutrients, such as hydrogen sulfide, nitrogen, carbon dioxide and carbon monoxide which freely pass into the cells. Due to their auto-catalytic metabolism, these cellular structures would grow and divide in the absence of a genetic apparatus.

The surface-metabolic theory suggests that the genetic machinery, transcription and translation capabilities of cells came later. Nucleic acids are supposed to have formed from polyanion surface-bonded poly-hemiacetal structures which originated from glyceraldehyde phosphate and dihydroxyacetone phosphate. These polymers, dubbed as "phospho-tribose", are thought to be not only the precursors of nucleic acids, but breeding ground for the synthesis of purine bases and purine-related coenzymes. Amino-acid pathways and the genetic code were also supposed to be later developments.

Although the author frankly states that "surface organism has so far not been found in nature and it may be extinct," the article closes with the suggestion that there may be places on earth where it may be discovered. Accordingly,

> *... it must be a place with liquid water having a nearly neutral pH and high salinity, a place with a high temperature and a high pressure; a place where hydrogen sulfide, carbon dioxide, and nitrogen are pressured into reaction in the presence of ferrous and other catalytic metal ions; a place where hot volcanic exhalations clash with a circulating hydrothermal water flow, a place deep down where a pyrite-forming autocatalyst once gave, and is still giving, birth to life.*[3]

Serious effort was made by the author to integrate known chemical and biochemical facts into his scheme, and work backwards from the known to the unknown. In the process some interesting generalizations emerged, such as the notion that the anionic components of cells must have originated from the original surface-binding organic film. Many aspects of the theory are stated in terms of experimentally testable mechanisms, and the reader is left to wonder why some of the fundamental assumptions, such as the formation of an organic film under the stated conditions, were not tested.

Several problems are inherent in this proposed scenario for the origin of life. Of all the chemical interconversions possible between water, carbon dioxide, etc., the ability to bind to positively charged surfaces is posited to be the sole factor in selection. Once this is stated, the discussion proceeds with the implied assumption that there will be uninterrupted supplies of useful substances available for growth. Clearly, the mechanisms of metabolic intermediate formation is not the main burden of the theory.

It is pointed out that conversion of bound biomonomers to surface-bound polymers is thermodynamically more favorable than the equivalent process in aqueous solution. However, under those conditions the opportunity for biomonomers to interact would also be severely curtailed.

If it could be demonstrated in the laboratory that complex organic layers can form from simple inorganic matter under some reasonably realistic, "primordial" conditions, evolutionary theorists would be in a stronger position to propose chemical evolutionary schemes. Nevertheless, even if all of the proposed processes of “surface metabolism” could be demonstrated in the laboratory, the results would be light years away from producing living matter as we know it.

Living and non-living matter are separated by such a vast qualitative difference that a “spontaneous” or even a “directed” transition from the non-living to the living is essentially unthinkable. Wächtershäuser tries to help his cause by redefining a (hypothetical) growing film of random organic molecules as a “surface organism”. But these are merely semantics. A spreading film of crude oil on the surface of the ocean, leaking from a tanker, would hardly deserve this term, even if it is growing and dividing into smaller patches.

The ultimate aim of the surface-metabolism theory is the same as previous chemical evolutionary postulates: to account for the emergence of living cells from a sterile environment. The hypothesized end product in this case is a membrane-bound collection of organic molecules, which eventually transform themselves into recognizable precursors of modern-day cells. But quite apart from the formidable difficulties in the biochemistry for the formation of nucleic acids and proteins, no suggestion is offered as to the source of biological information which resides in present-day informational macromolecules. Neither is there a recognition by the theory that living matter is characterized by a dynamic steady state of chemical reactions, the sum of which is far from equilibrium. Consequently, no solution is offered as to how such a state can come into existence in a spontaneous system.

Thus, while the theory of surface-metabolism represents a prodigious effort to explain the origin of living matter, it falls far short of its goal. It will probably hasten the eventual demise of the organic-broth theory and usher in a period of time when the honest alternative to the creation account of the Scriptures will be bewilderment.

ENDNOTES

1. Scherer S. 1985. Could life have arisen in the primitive atmosphere? Journal of Molecular Evolution 22:91-94.
2. Wächtershäuser G. 1988. Before enzymes and templates: theory of surface metabolism. Microbiological Reviews 52:452-484.
3. Ibid., p 480.