The Necessity of Precursor Cooperatives for the Origin of Life

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Models for the origin of life are confounded by the interdependent and non-reducible relationships between nucleic acids, proteins, and other organic and non-organic molecules that comprise living systems. The prevailing theory, postulated by numerous researchers, suggests self-replicating nucleic acids, specifically RNAs or a derivative thereof, were the precursors of life. Such theories are attractive because RNA can store information and, under some circumstances, can also catalyze simple chemical reactions.

Recently, RNA-only models have come under criticism since RNA by its nature is inherently unstable, and logical stepwise mechanisms to explain how the central dogma evolved from an RNA world have been elusive. In light of this, protein- or metabolism-first models have also been proposed. These models suffer from the reciprocal problem: proteins (as well as non-protein metabolic pathways) are stable and capable of complex enzymatic reactions, but unlike nucleic acids, they cannot store information and are exceedingly complex. As such, the odds of sustained spontaneous formation defy plausibility.

Here, we describe an ancient microbe, *Primum viverea*, herein postulated to be the First Common Ancestor (FCA) evidenced by extremely primitive genomic features and a substantially reduced ribosome. FCA was discovered in aerial samples collected from the lower- to mid-stratosphere. The organism is a scavenger, living in a volatile environment with limited carbon resources and subject to intense ultraviolet light. To cope with these rugged conditions, it has robust DNA and RNA repair mechanisms to reverse UV damage and stores chemical energy through a set of UV absorbing molecules that show similarity to cyanobacterial pigments. The cell membrane is composed of a simple phospholipid monolayer as found in some archaea. Phylogenetic analysis of 22.8 billion independently isolated micro-organisms positions FCA at the root of both the bacteria and archaea kingdoms, and molecular clock analysis dates it to ~4.3 billion years ago; suggesting life originated in the atmosphere, which at that time would likely have been 1,000 times denser than it is today. The primitive genomic complement of this organism consisting of large numbers of small, non-coding RNAs, and a simplified genetic code implies both small RNAs and simple proteins were available at the inception of life.

Based on these features of FCA, a cooperative model for the origin of life is proposed herein. According to the model, life began as a consequence of synergistic relationships that spontaneously developed between nucleic acids, amino acids, lipids, and energy storage molecules. Not unlike other models, the cooperative model starts with an environment in which large numbers of nucleic acid oligomers had spontaneously developed through synergistic chemical relationships with other organic molecules that both polymerized nucleotides and stabilized them; the so-called primordial soup. These cooperative relationships led to the enrichment and persistence of all contributing members of the group.

Amino acids were probably essential to these early synergistic interactions by providing stability to some nucleic acids via physical interactions, or in other instances serving as catalysts for nucleic acid driven reactions. These molecular cooperatives favored increased complexity as natural selection at this stage strongly favored the retention not of individual biomolecules, but entire groups. Some members of the group likely had simple peptide biosynthesis activities. This was necessary for the selection of functional peptides which can only form under a relatively high rate of trial and error (as opposed to their simpler nucleic acid counterparts). Nucleic acids capable of producing peptides that aided in RNA stability and/or replication would have been strongly favored.

This process led to specific nucleic acids “encoding” specific peptides; the basis for modern protein biosynthesis and the central dogma of biology. As more and more nucleic acids in the cooperative adopted the ability to synthesize proteins, many of the primitive enzymatic roles carried out by RNAs were replaced by proteins, as is the case in modern cells.

Based on the genome structure of FCA and its large number of apparently self-synthesizing non-coding RNAs not encoded within the genome, it appears the storage of RNA as DNA copies likely occurred later, after DNA-RNA-protein cooperatives had already formed. While the cooperative model provides a basis for the development of the modern genetic code, several additional concurrent factors must also be considered.

First, sets of DNA-RNA-peptide cooperatives must have formed within lipid membranes—which also must have been provided spontaneously by the environment. Such simple membranes have been identified in diverse environments, and it is accepted that their presence in the primordial soup is plausible. It is anticipated that these lipids were necessary and actively participated in these early codependent chemical relationships, particularly the establishment of electrochemical gradients by energy capturing porphyrin-like molecules.

Because the spontaneous generation of life required multiple unlikely synergisms among specific groups of randomly occurring, renewable organic molecules that formed under special conditions present only during early planetary formation, it is predicted that the occurrence of life is an incalculably rare event in the universe, if not unique.