The Origin of Life - *Earth Life, “Weird Life”* and Astrobiology Implications

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Topics

- Can we define life and is this important to understanding the origin of life?
- Canonical characteristics of Earth life
- The origin of life
  - When
  - Where
  - How
  - What
- Weird life
Is it important that we have a definition of life and is this possible?

There are multiple definitions that can be divided into several groups

1. Darwinists (many examples)
2. Metabolists
3. Energists/Thermodynamists (e.g. Schrödinger, 1944)
4. Biosphereists (Shapiro and Feinberg, 1990)
5. Complexists
6. Others
Evolutionists definitions of life (a few)

- Life is a self-sustained chemical system capable of undergoing Darwinian evolution (Joyce, 1994)
- Life is a self-replicating, evolving system based on organic chemistry (Pace, 2002)
- System capable of evolution by natural selection (Sagan, 1970)
- Material system that undergoes Darwinian evolution (C. McKay)
- The minimal living system must be self-duplicating and mutable, and it must have the capacity for hetero-catalysis for bringing about chemical changes in the environment that support the self-duplication function (Hartman)
Definition of life: Cleland and Chyba (2002) discuss the philosophical dilemmas on the nature of definition ("Definitions specify meanings by dissecting concepts that we already possess")

Two kinds of definitions:
1. Words or terms whose existence depends solely upon human interests and concerns, such as "bachelor" or "fortnight" are readily defined.
2. "Natural kind" terms such as "life", "water" and "heat" cannot be defined by describing properties because there is more to their meanings than the features we identify (e.g. water is defined as H₂O and not by characteristics such as "cooling", "tasteless", "odorless" etc).
3. Defining life from properties of life has problems because there are "non-living" analogues. (e.g. replication - clays and other minerals replicate; ability to evolve - mineral growth involves changes "mutations" that replicate; energy and fire, etc)
• Any definition of life will necessarily be based on known properties of Earth life since that is the only life we know.
• It is possible to search for life on other planets without a definition of life.
• Cheland and Chyba believe that extraterrestrial life can be identified using characteristics of terrestrial life if we find some way to apply a “weighting function” to the characteristics.
• My comment: Carbon chemistry will always receive the greatest weight. That’s life!
Characteristics of Earth Life

1. Water is essential for active life
2. It is contained in a microenvironment (cell)
3. It is carbon based
   a. Nucleic acids consisting of 4 nucleotides
   b. Dual nucleic acid system: RNA and DNA
   c. Proteins: 20 amino acids
   d. Lipids with straight chains of methyl branched chains
   e. Metabolic energetics use phosphate anhydrides, thioesters
   f. Metabolism uses nucleophile-electrophile reactions with C=O
4. It replicates
5. It evolves (mutation and other mechanisms for acquiring genetic material, and natural selection)
Which of these canonical characteristics of Earth life has the greatest likelihood of being different in extraterrestrial carbon-based life?
Carbon-based life

• C is an abundant element in the universe. Organic compounds are ubiquitous. They make up 20% of the interstellar dust, and interstellar dust makes up 0.1% of galactic matter.

• There are many physical and chemical reactions that occur naturally that produce the key organic compounds found in Earth life and allow their condensation into macromolecules.

• Organic compounds can be synthesized abiotically with reproducibility and with catalytic activity and information potential (e.g. Sidney Fox’s proteinoid structures possessed some weak enzyme-like catalytic properties, and the amino acid composition of proteinoids is specific and reproducible despite the disordered conditions of their formation. The bonds between amino acids did not form purely at random).

• Only carbon life can be affected by Darwinian evolution?
Some Caviets about the Origin of Life
(from Orgel, NAS Limits Workshop, 2004)

- The range of conditions that permit the origin of life forms are likely to be more restrictive than the range to which organisms can adapt.
- Enzyme mechanisms may not be indicators of prebiotic mechanisms.
- The last common ancestor of life on Earth may not have functioned in the same environment as that in which life originated.
- Chemistry is the dominant science by which scenarios for the origin of life must be judged. Biochemistry may suggest scenarios but cannot validate them.
Some Hypotheses on the Origin of Life

Primordial soup - heterotrophic origin (*Oparin, 1936*)
Dissipated Structures “*Order Out of Chaos*” (*Prigogine 1980*)
Submarine Hydrothermal Vents (*Corliss et al., 1981*)
Mineral World (*Cairns-Smith, 1982*)
RNA World (*Gilbert, 1986*)
Thioester World (*De Duve, 1981*)
Pyrite World - Metabolism first (*Wächterhäuser, 1988*)
Self-organization and complexity theory (*Kauffman, 1993*)
Fe/S membrane, redox/pH front at vents (*Russell, 1994; 1997*)

Panspermia (*Arrhenius, 1908*)