The Origin of Life

I. Introduction: What is life?

II. The Primitive Earth

III. Evidence of Life’s Beginning on Earth
   A. Fossil Record: a point in time
   B. Requirements for Chemical and Cellular Evolution:
      1. Abiotic synthesis
      2. Polymerization
      3. Protobiont formation
      4. Mutable genetic blueprint

What features define living systems?

- 1. Exhibit multiple levels of organization with emergent properties.
- 2. Share a similar chemical composition: CHNOPS
- 3. Made up of cells.
- 4. Capable of transforming energy.
- 5. Maintains homeostasis.
- 6. Capable of responding to stimuli.
- 7. Exhibit coordinated/directed growth and development.
- 10. Can effect changes on its environment.

The Origin of Life

- Early Earth was a very different place than it is now.
  - Chemically reactive atmosphere
  - Very little Oxygen
  - Very High UV and other energy sources

Reconstructing the history of life:

- The fossil record
- Experimental models and simulations
- Deductions based on existing organisms
15 Billion Years of History compressed into 30 seconds:

- The Big Bang (15 bya)
- Condensation of Solar System (5 bya)
- The Third Planet (4.6 bya)
  - Earth and Primitive Atmosphere
  - Crust Solidifies (4 bya)
  - Oceans and land masses (solid, liquid and gas states)

The scale of geological time and fossil evidence:

- 750 mya = Animals
- 1.5 bya = Multicellular
- 2 bya = Eukaryotes
- 3.5 bya = Oldest prokaryotes

Fossil Evidence for the Origin of Life
3.5 billion years ago:
and the global catastrophe they caused…

Early (left) and modern (right) prokaryotes

Filamentous cyanobacteria fossils
Stromatolites

Stromatolites in Northern Canada

Pasteur
- Spontaneous Generation vs. Biogenesis
- Where does life come from?

Requirements for Chemical and Cellular Evolution:
A. Abiotic synthesis and accumulation of monomers (e.g., simple sugars and amino acids) ...easy
B. Condensation of monomers into polymers (molecules macromolecules) ...clays, etc.
C. Formation of protobionts: chemically isolated systems ...size of bacteria and can self-replicate
D. Origin of genetic material: directive, continuity and changeable (mutable) ...hard?

Experimental Evidence for Abiotic Synthesis:
- A. Oparin and Haldane’s Hypothesis (1920’s):
  - Elemental requirements: CHNOPS
  - Reducing atmosphere (no O2), very different from today
  - Energy sources
- B. Miller and Urey: Testing with Primitive Earth apparatus
  - H2O, H2, CH4, NH3
  - CO2, CO, N2
The Miller-Urey experiment: brewing the "prebiotic" soup

After a few weeks:
- All 20 Amino Acids
- Urea
- Fatty acids
- Sugars
- Nitrogenous bases
- Nucleotides
- even ATP!

But Earth is not so special after all…
- Most of these same organic compounds have been found in space and in meteors and comets!
- Murchison Meteorite- September 28th 1969
- Interstellar dust clouds
- Deep space chemistry (NASA)-1992

The odd case of chirality…
All left handed A.A.

Stage 2. Synthesis of Polymers
- Polymers can be formed by dripping monomers onto hot sand, clay or rock.
- Water evaporates and monomers spontaneously bond together into polymers
- Many Polypeptides (proteins) made this way
- Alternative ideas- Deep-sea vents

Evidence for the production of organic polymers:
Helped by catalysts!
- Polymerization= dehydration synthesis
  - $-\text{H} +\text{OH-} \rightarrow -\text{H}_2\text{O}$
- Building blocks become concentrated on hot sand, clay - forming proteinoids
- The importance of clay, zinc, and bubbles to concentration and catalysis
- Other mineralizing events: iron pyrite (FeS$_2$) formation (joining of iron and sulfur releases electrons that lead to bonding)
Stage 3. Chemical Isolation: Protobionts
- Microspheres from proteinoids
- Liposomes from phospholipids

What is a cell or organelle? What do they do?

Stage 4. Self Replicating Molecules

Evolution of Genetic Material

The Central Dogma: DNA → RNA → Protein
Chicken and the Egg…?

DNA from Proteins…Proteins from DNA…hum
Stepwise evolution of a complex process
RNA-based genome and catalysis… "RNA world"
RNA-directed protein synthesis
DNA-RNA-protein…DNA and protein much more efficient…Nat. Selection would select and starts the ball rolling

Origin of Eukaryotic Cells- Symbiogenesis and the Endosymbiotic Theory
Where does the food come from?

### Table 14.1 Nutritional Classification of Organisms

<table>
<thead>
<tr>
<th>Nutritional Type</th>
<th>Energy Source</th>
<th>Carbon Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photosynthetic (autotrophs)</td>
<td>Sunlight</td>
<td>CO₂</td>
</tr>
<tr>
<td>Chemolithotroph (heterotrophs)</td>
<td>Inorganic chemicals</td>
<td></td>
</tr>
<tr>
<td>Photosynthetic</td>
<td>Sunlight</td>
<td>Organic compounds</td>
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**Taxonomy and Systematics:**
a broader classification system that also shows evolutionary relationships

- A hierarchical system:
  - **Kingdom**
  - **Phylum**
  - **Class**
  - **Order**
  - **Family**
  - **Genus**
  - **Species**

- 2 Kingdom system: K. Plantae = autotrophs and K. Animalia = heterotrophs
- 5 Kingdom system: Monera, Fungi, Protista, Animalia, Plantae
- 3 Domain System:

**Five Kingdoms**

- Bacteria
- Archaea
- Eukarya

**3 Domains with “Kingdoms”**

- Bacteria
- Archaea
- Eukarya

- Plastids
- Animals
- Fungi
- Chromalveolates
- Green algae
What are species?

- **Biological Species Concept**
  - Group of reproducing individuals
- **Morphological S. C.**
  - Groups of “same” looking things
- **Phylogenetic S. C.**
  - Group of individuals distinct in their ancestry and descent
- **Nebulous S. C.**

Speciation

- What is a “Species”?
  - *Biological Species Concept* defines species as “groups of interbreeding natural populations that are reproductively isolated from other such groups”

Reproductive Barriers

- **Pre-zygotic barriers**
  - Temporal isolation: Mating or flowering occurs at different seasons or times of day
  - Habitat isolation: Populations live in different habitats and do not meet
  - Behavioral isolation: Little or no sexual attraction between males and females
- **Post-zygotic barriers**
  - Hybrid inviability: Hybrid offspring fail to develop or fail to reach sexual maturity
  - Hybrid sterility: Hybrids fail to produce functional gametes

Speciation

Allopatric Speciation
How much change is needed for a new species to evolve?

Polyploidy and division errors

How quickly does evolution happen?

Patterns of Evolution

• The cone of increasing diversity vs. the model of decimation and diversification

Decimation and Diversification

Patterns of Evolution

Two methods for establishing animal phylogeny ... using molecular based and grade-based systems