“...sparked by just the right combination of physical events & chemical processes...”
The evolutionary tree of life can be documented with evidence. The *Origin of Life* on Earth is another story...
The Origin of Life is **Hypothesis**

- **Special Creation**
  - *Was life created by a supernatural or divine force?*
  - *not testable*

- **Extra-terrestrial Origin**
  - *Was the original source of organic (carbon) materials comets & meteorites striking early Earth?*
  - *testable*

- **Spontaneous Abiotic Origin**
  - *Did life evolve spontaneously from inorganic molecules?*
  - *testable*
Conditions on early Earth

- **Reducing atmosphere**
  - water vapor (H\(_2\)O), CO\(_2\), N\(_2\), NO\(_x\), H\(_2\), NH\(_3\), CH\(_4\), H\(_2\)S
  - lots of available H & its electron
  - no free oxygen

- **Energy source**
  - lightning, UV radiation, volcanic

What’s missing from that atmosphere?

Low O\(_2\) = organic molecules do not breakdown as quickly
Origin of Organic Molecules

Abiotic synthesis

1920
Oparin & Haldane propose reducing atmosphere hypothesis

1953
Miller & Urey test hypothesis

- formed organic compounds
  - amino acids
  - adenine

Water vapor
Mixture of gases ("primitive atmosphere")
Electrodes discharge sparks (lightning simulation)
Heated water ("ocean")
Condensed liquid with complex, organic molecules

AP Biology
produced
- amino acids
- hydrocarbons
- nitrogen bases
- other organics

Why was this experiment important??!
Key Events in Origin of Life

- **Origin of Cells (Protobionts)**
  - lipid bubbles → separate inside from outside → metabolism & reproduction

- **Origin of Genetics**
  - RNA is likely first genetic material
  - multiple functions: encodes information (self-replicating), enzyme, regulatory molecule, transport molecule (tRNA, mRNA)
    - makes inheritance possible
    - makes natural selection & evolution possible

- **Origin of Eukaryotes**
  - endosymbiosis
Timeline

- Key events in evolutionary history of life on Earth
  - 3.5–4.0 bya: life originated
  - 2.7 bya: free $\text{O}_2 = \text{photosynthetic bacteria}$
  - 2 bya: first eukaryotes
First Eukaryotes

- Development of internal membranes
  - create internal micro-environments
  - advantage: specialization = increase efficiency
    - natural selection!

- ~2 bya

Prokaryotic cell

Prokaryotic ancestor of eukaryotic cells

Eukaryotic cell

DNA

endoplasmic reticulum (ER)

nuclear envelope

plasma membrane

cell wall

nucleus

infilling of the plasma membrane
1st Endosymbiosis

- Evolution of eukaryotes
  - origin of mitochondria
  - engulfed aerobic bacteria, but did not digest them
  - mutually beneficial relationship
    - natural selection!

![Diagram of endosymbiosis](image)

Ancestral eukaryotic cell

Eukaryotic cell with mitochondrion
2nd Endosymbiosis

- Evolution of eukaryotes
  - origin of **chloroplasts**
  - engulfed **photosynthetic** bacteria, but did not digest them
  - mutually beneficial relationship
    - natural selection!

**Eukaryotic cell with mitochondrion**

**chloroplast**

**photosynthetic bacterium**

**Endosymbiosis**

**mitochondrion**
Theory of Endosymbiosis

- Evidence
  - **structural**
    - mitochondria & chloroplasts resemble bacterial structure
  - **genetic**
    - mitochondria & chloroplasts have their own circular DNA, like bacteria
  - **functional**
    - mitochondria & chloroplasts move freely within the cell
    - mitochondria & chloroplasts reproduce independently from the cell
Cambrian explosion

- **Diversification of Animals**
  - within 10–20 million years most of the major phyla of animals appear in fossil record

543 mya
CAMBRIAN EXPLOSION was characterized by the sudden and roughly simultaneous appearance of many diverse animal forms almost 600 million years ago. No other period in the history of animal life can match this remarkable burst of evolutionary creativity. Most of the Cambrian creatures shown here were reconstructed from fossils by Simon Conway Morris and Harry Whittington of the University of Cambridge.
Is there life elsewhere?

Does it look like life on Earth?

They would Ask Questions!