The Emergence of Life on Earth: Mystery or Scientific Problem?

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How did life emerge on the ancient earth?

- **This is one of the most difficult questions still facing science today.**

Traditional views on the origin of life

- **Human beings and other complex creatures were created by God**
- **Other organisms were repeatedly generated from matter (e.g., flies from rotten meat, crocodiles from mud)**
- **Spontaneous generation was often believed to result from God's indirect decree**

- **Belief in spontaneous generation, even of microbes, was finally abandoned at the end of the 19th century.**
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- **Natural explanations of physical phenomena were replacing religious ones from the 17th century onward.**
- **Natural explanations of the living world reached culmination with Darwin's The Origin of Species (1859)**

Darwin's Tree of Life

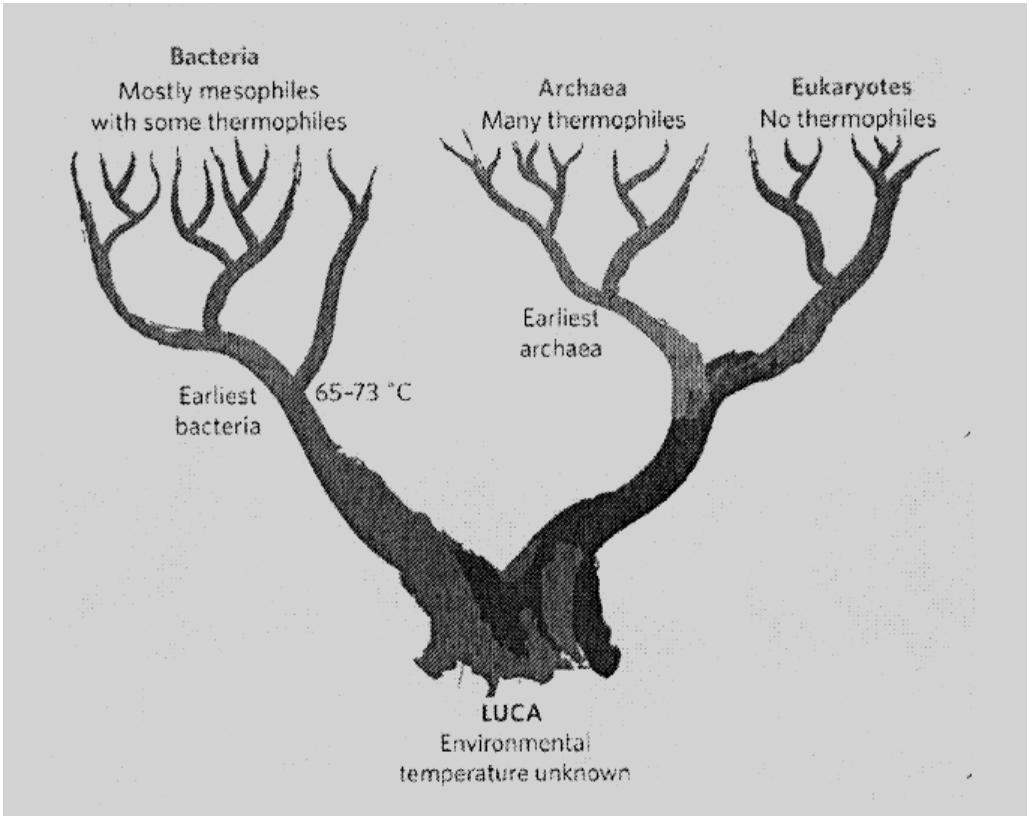
- **Darwin speculated about a "Tree of Life", stemming from a common "root" on the ancient earth, uniting all organisms ever to exist into one big family.**

Last **U**niversal **C**ommon **A**ncestor

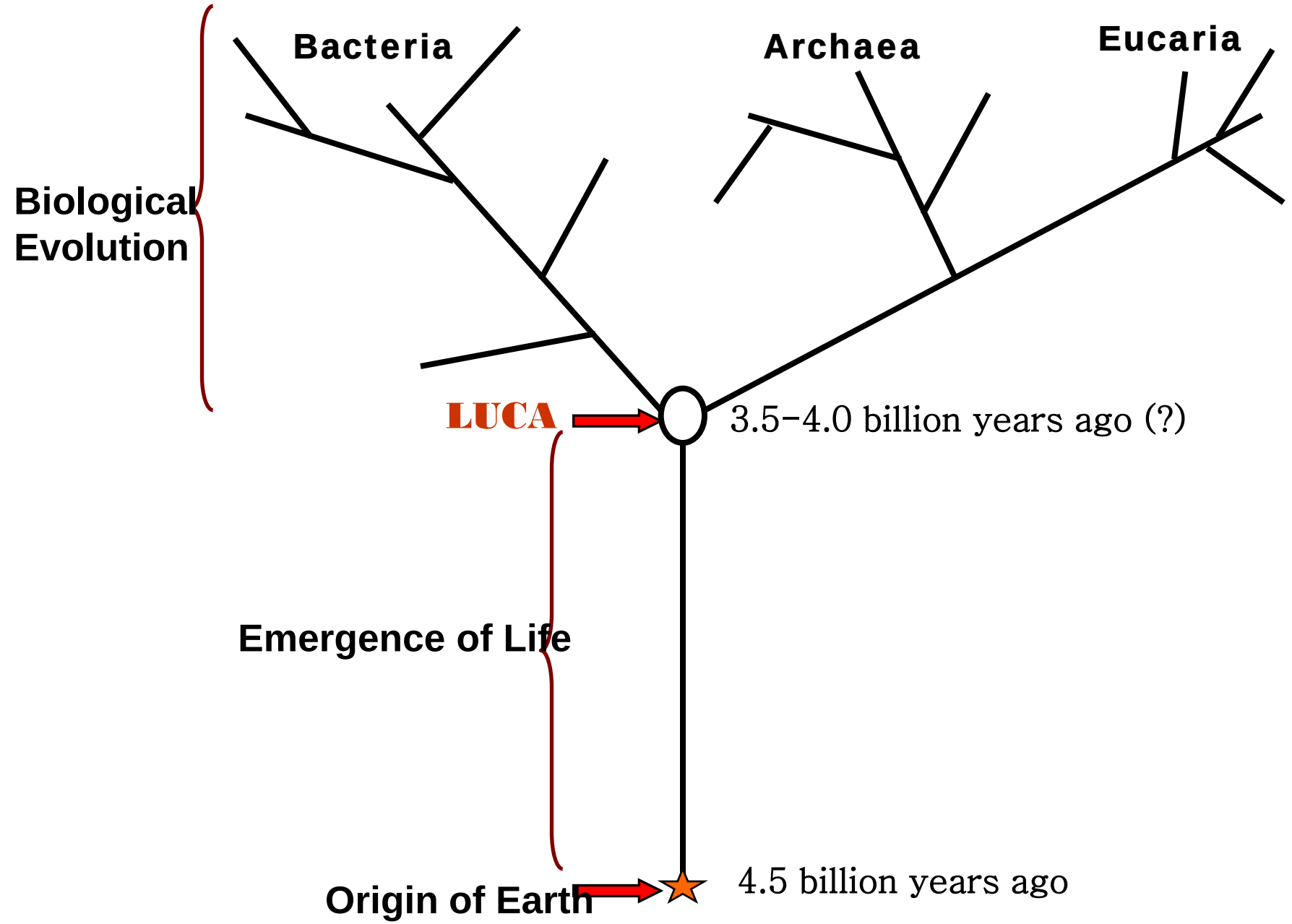
- **Current molecular tools confirm Darwin's idea, revealing that all the domains of life branched from a population of cells at the root of the "tree".**

- **This population, called LUCA, probably emerged some *four billion years ago*.**

LUCA and the three domains of life: Eukaria, Archaea, Bacteria



The emergence phase and the tree of life



“In a warm little pond”

Publicly, Darwin did not discuss the origin of the root of the tree of life – the origin of life.

- **In a private letter, however, he speculated that early life originated from chemical compounds, under the influence of energy, “in a warm little pond.”**

A breakthrough of a previous impasse

- **Alexander Oparin** in the **Soviet Union** and **J. B. S. Haldane** in **England** independently published pioneering scientific hypotheses on the origin of life in the **1920s and 1930s**.
- Their ideas were based on **the rise of Genetics and Biochemistry and on their strong evolutionary commitment**.

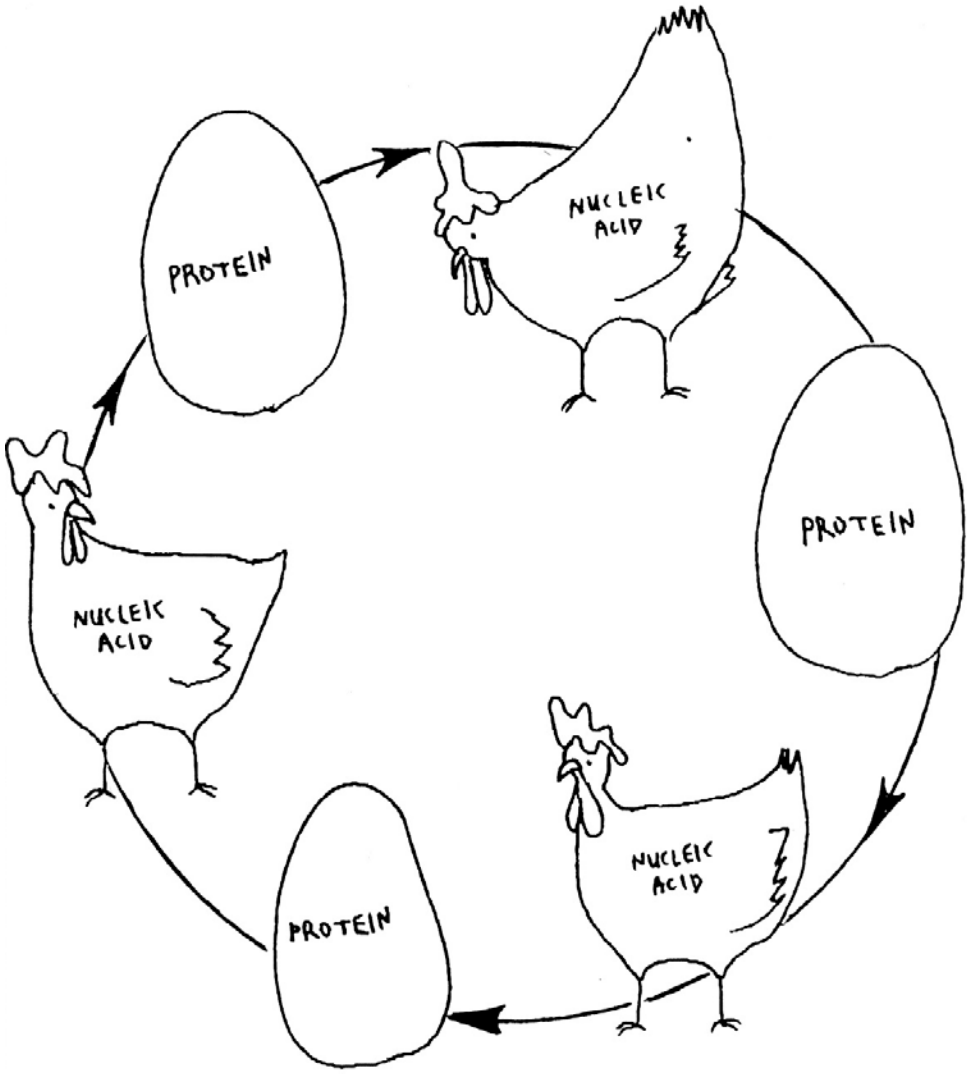
A new scientific field is born in the 1950s and 1960s

- In experiments **simulating the prebiotic earth conditions** amino acids and other organic compounds were synthesized.
- Following **the rise of molecular biology**, researchers began focusing on **specific emergence scenarios**.

Molecular biology reveals the interdependence among cellular components

- **The most remarkable among these interdependent cycles involves nucleic acids and proteins.**
- The **"Chicken-and-egg Problem"** of the **origin of life** is: **Who came first and how**, nucleic acids or proteins?

The Chicken and Egg Problem



Two research camps attack the problem from different angles

- **The gene-first group** claims that replicating molecules, the basic feature of life, had to arise first.

- **The metabolism-first group** views life basically as a multimolecular metabolic system. Primitive metabolism had to emerge first.

The emergence of life – the emergence of biological complexity

- **Darwin showed that complex biological features evolved by natural selection.**
- **Could natural selection also work on inanimate matter, in the emergence of life itself?**

A paradox?

- **For natural selection you need life. How could life itself evolve by natural selection?**
- This could have happened **if:**

- Chemical systems that arose by ordinary physical and chemical processes,
- nevertheless met the conditions of (some sort of) reproduction, variation and competition.

The debate between the camps

- What were these chemical systems? **Which systems** could have served as **infrastructure for natural selection** on the early earth?

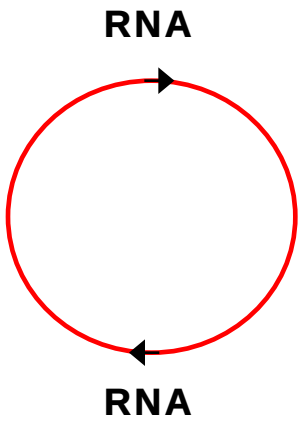
- Were these systems **“genetic” or “metabolic”**?

The gene-first answer: the RNA-world theory

- Discovery in the 1980s of the **Ribozymes,** RNA molecules in present cells that function both as genetic material and as enzymes.
- The RNA-world theory: such ribozymes emerged on the ancient earth, among them self-replicating ribozymes (both “chicken” and “egg”). This enabled the evolution of life itself.

The RNA World

nucleotides ⇨ RNA

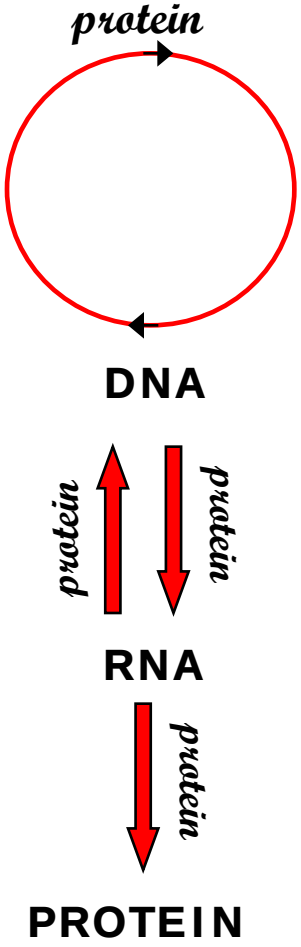


Amino acids —*RNA*⇨ Protein

The Transition period

RNA —*protein*⇨ DNA

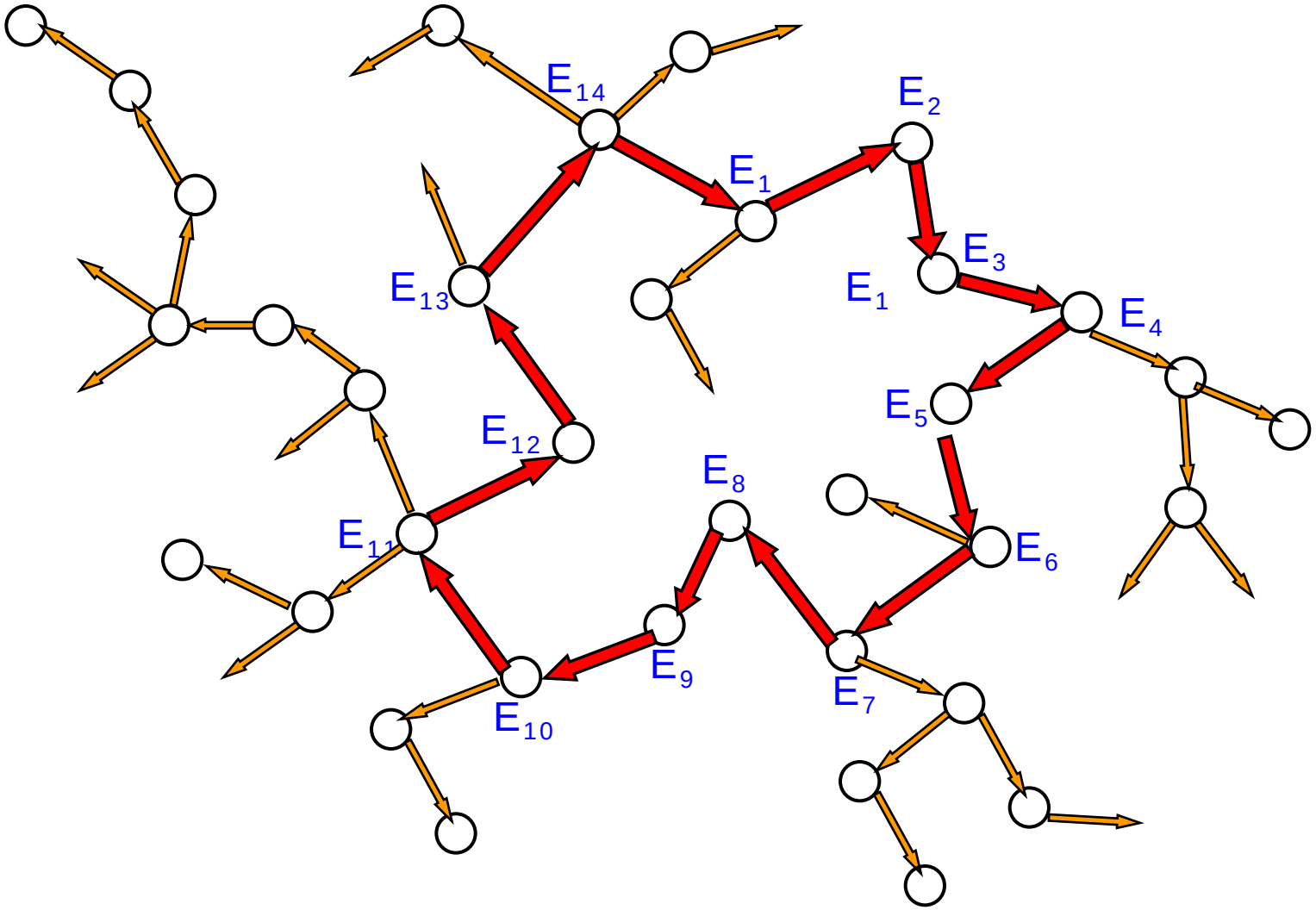
The Present World



The “metabolic” answer

- The RNA-world scenario is **highly improbable.**
- Small molecules (amino acids, peptides, small lipids) **self-organized** to form **metabolic cycles** within bubbles or **“protocells”.**
- Conditions for natural selection were met by **reproduction of the whole cycle** and **division** of protocells into “offspring”.

A Metabolic Self-Replicating Ensemble



Dilemma

- Could self-replicating ribozymes emerge in prebiotic conditions?
- Could metabolic cycles undergo evolution by natural selection?
- Chemist **Cairns-Smith** suggests that the **first evolvable systems** were made of **inorganic crystals**.
- These crystals could replicate, mutate and evolve by **natural selection**.

The logic of the arch and scaffold

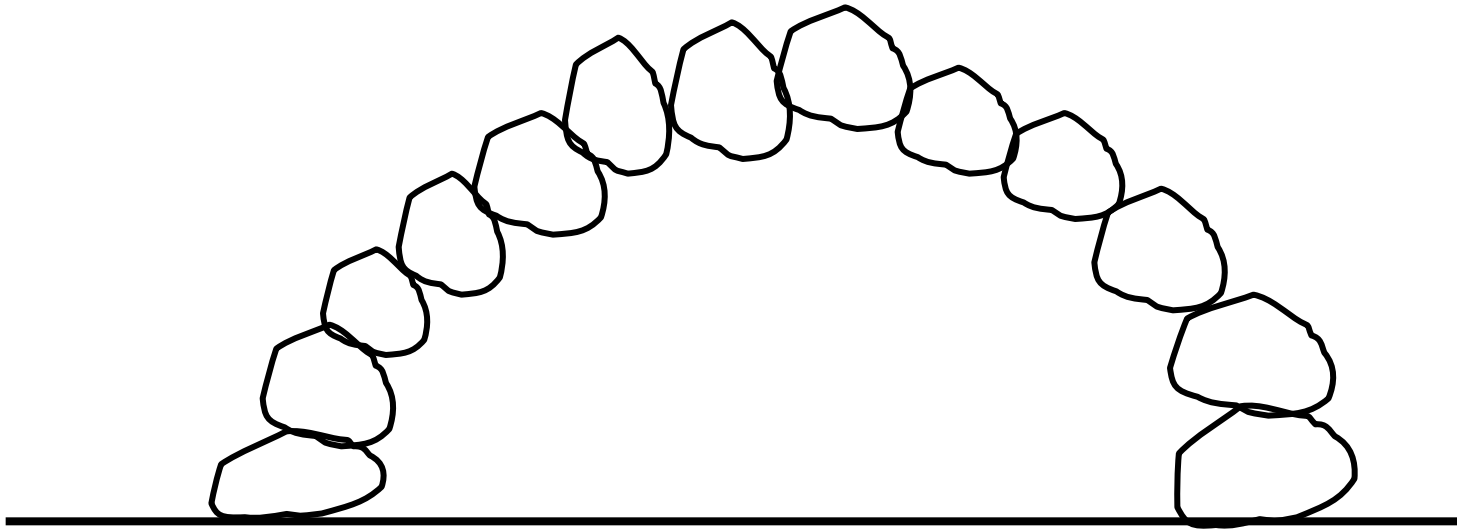
- Cairns-Smith **compares the living system to an arch of stones**: Each stone is held in place by its neighbors.

- It seems that such intricate structure **could not form naturally and gradually.**

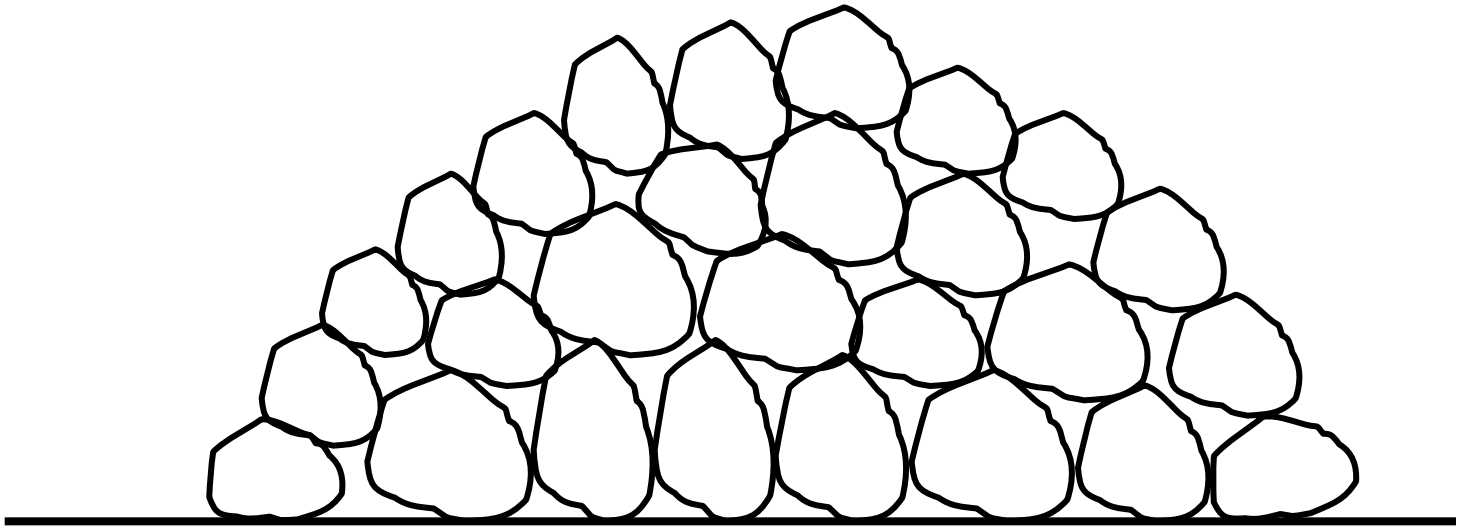
- The natural solution is to build a mineral scaffold on which an organic arch is built.

“How can you build any kind of arch gradually?

G. Cairns-Smith (1985)



The Scaffolding



Creationism and Evolution

- The new creationists, the **Intelligent Design** supporters, claim that **life is too complex** to have emerged and evolved naturally.

- The first cell had to be created and designed by an "**Intelligent Designer**".

Is the conflict empirical? Can one prove that life emerged naturally?

- **It is a philosophical conflict** between religious and naturalistic **worldviews**.
- The naturalistic worldview **developed historically** on the basis of the empirical achievements of science.
- This worldview is a stimulus for future research in the origin and evolution of life.

- A much supported hypothesis in the field: The RNA world was a crucial step in the origin of life

- **A population of RNA molecules can undergo evolution by natural selection**

- **RNA molecules can function both as genetic material and as enzymes**

What kinds of primitive systems could support natural selection?

- Gene-first camp: Replicating molecules – RNA or RNA-like

Examples of prebiotic factors that could have built the infrastructure for natural selection

- Physical and chemical selection of stable structures
- Chemical selection of amino acids leading to peptides with specific sequences
- Prebiotic catalysts: specific minerals, metal ions, short peptides
- Autocatalysis: e.g., some peptides could catalyze their own synthesis, leading to more efficient peptide catalysts
- Assembly of lipid vesicles
- Assembly of chemical reactions on the surface of minerals

- **Reproduction**
- **Variation in offspring**
- **Inheritance of the variations**
- **Relative advantage conferred by some variations**
- **Competition for resources**

- Prebiotic chemists attempted to reconstruct the emergence of the first genes and the first metabolic systems.

Continuity and Novelty in the Emergence of Life

- **The origin-of-life process was an integral part of a continuum stretching from processes on the primordial Earth to biological evolution.**

- **During the origin of life unique biological properties (e.g. replication and metabolism) gradually developed.**

- **Continuity and novelty characterize every phase of the evolutionary process.**

The origin-of-life question was formulated in scientific terms following the rise of molecular biology in the 1950s and '60s

Relevant discoveries: √ **The structure of DNA;** √ **DNA as the genetic material: DNA replication and mutability, transcription Of DNA into RNA, translation of RNA into proteins;** √ **Interaction between DNA, RNA and protein enzymes**

Crucial discovery: **All organisms share the same basic biochemical structures and mechanisms**

Cairns-Smith's formulation of the conditions of evolution of "things" through natural selection

- *If* you have things that are reproducing their kind;
- *if* there are sometimes random variation, nevertheless, in the offspring;
- *if* such variations can be inherited;
- *if* some such variations can sometimes confer an advantage on their owners;
- *if* there is competition between the reproducing entities – *if* there is an overproduction so that not all will be able to survive to produce offspring themselves -
- Then these entities will get better at reproducing their kind." (*Seven Clues to the Origin of Life*. 1985:2)

Last Universal Common Ancestor: LUCA

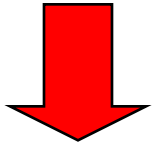
- ✓ Already contained the major cellular components
- ✓ Evolution of the Tree of Life from LUCA accounts for the universality of life
- ✓ Fossils of cells and remnants of biogenic carbon found in the oldest rocks on Earth indicate that LUCA emerged 3.5 to 4 billion years ago (?)

- **Science does not aim at first at reconstructing the exact, actual prebiotic processes.**

- **Rather, its goal is to reconstruct a possible scenario by which life could have emerged.**

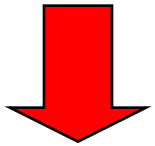
- **Growing knowledge of primordial conditions increasingly narrows the gap between the possible and actual processes.**

The starting point of the origin-of-life process:



Accumulation of organic molecules on the primordial Earth which probably have arrived from outer space on comets, meteorites, and dust grains, or could have also been synthesized in different sites on Earth

The end-point of the origin-of-life process:



The emergence of LUCA

Michael Behe's definition of an "irreducibly complex system"

- "Biochemistry has discovered within each cell intricate systems whose function depends on the interaction of their multiple components. If a single component is missing, the system ceases to function."

- Behe's Conclusion: Such systems, either at the origin-of-life phase, or during biological evolution, could not have evolved gradually from precursor systems

  Reason: Any earlier system that is missing a part is, by definition, non-functional and thus could not have been favored by natural selection

Theoretical and empirical refutations of the notion of irreducible complexity

- There is more than one way to make such systems (e.g., flagellum)

- Two major pathways are proposed for the evolution of complex, interdependent systems:

  (a) Gradual, parallel development of structure and function in various organisms (e.g., the evolution of human eye from less-complex eyes)

  (b) Cooption of structures used for a certain function into other structures evolving a different function
  (e.g., evolution of motility systems in bacteria by cooption of secretory systems)

How did life emerge according to ID?

Michael Behe: “Nearly four billion years ago, the designer made the first cell, already containing all the irreducibly complex biochemical systems.”

Walter Bradley and Charles Thaxton: The information for the first nucleic acids on Earth came from some intelligence. Life originated from a “Who rather than from a What.”

The argument from Design

William Palley: A watch is designed (crafted) by a watchmaker.

(1802)

By analogy, organisms are designed by God.

ID movement: Artifacts are designed by human intelligence.

By analogy, biological irreducibly complex systems are purposefully designed by a supernatural Intelligent Designer.

Is the “analogy method” a valid scientific method?

- Artifacts, human designers, and organisms are all open to empirical observation
- A supernatural designer is not
- The analogy cannot be put to an empirical test

What is “Theistic science”?

Theistic science views supernatural, purposeful agents as legitimate causes in explaining natural phenomena

Could natural selection have taken part in the emergence of life?

Natural selection can result in the evolution of complex and adaptive structures in a population of molecules or in any group of entities that conforms to the following set of conditions:

- **Reproduction**
- **Variation in offspring**
- **Inheritance of the variations**
- **Relative advantage conferred by some variations**
- **Competition for resources**

The metaphor of the scaffolding and arch seems to imply a purpose

Natural Selection is a natural process capable of generating complex adaptive systems that appear to be designed

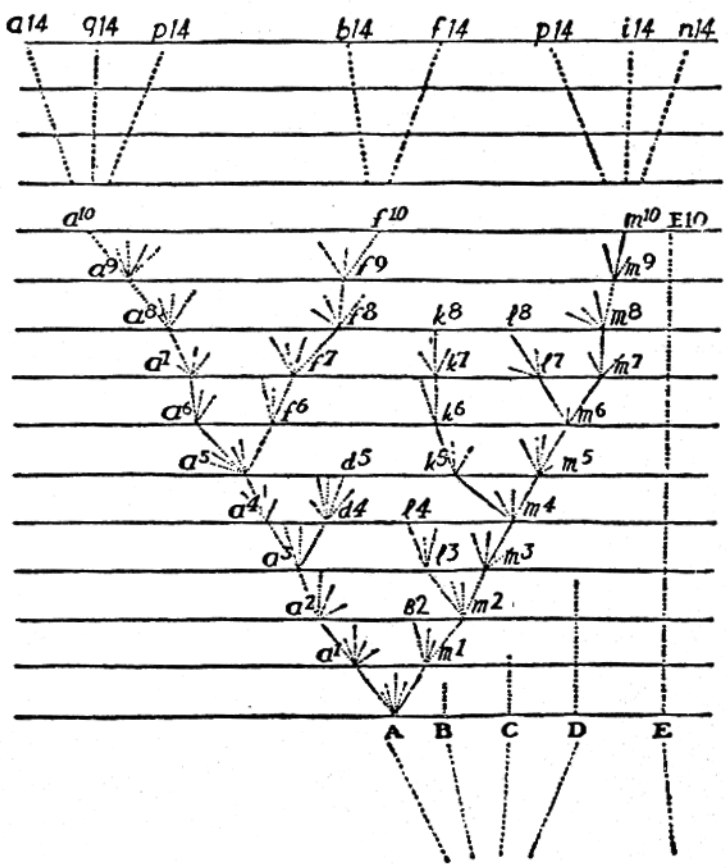
Both scaffolding and arch could have been built by natural processes with no need for purposeful, supernatural intervention

Origin-Of-Life and the nature of science

There is substantiated knowledge on several aspects of the emergence-of life process.

Yet, so far, no single scenario has led to the reproduction of a living system in the laboratory.

Does this mean that the scientific status of origin-of-life research is in doubt?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- **Science is based on empirical work but also on theoretical and philosophical presuppositions**

- **The scientific worldview, including the evolutionary conception, is strongly substantiated by the achievements of science**

- **Scientists persist in their efforts to solve the origin-of-life question, based on their commitment to the evolutionary conception**

- **This commitment is not dogmatic. It is based on abundant empirical data and it serves as a productive guide for further research**

The ID argument begs the question:

- An Intelligent Designer is a valid cause only within "theistic science"
- "Theistic Science" is valid only if the existence of an Intelligent Designer is independently substantiated
- This cannot be done. Hence, an Intelligent Designer is assumed to begin with rather than proved