BIO 111 - Principles of Life I: Biomolecules, Genetics and Evolution

(Varsha 2025)

MODULE: OVERVIEW OF BIOLOGY

Part II – ORIGIN OF LIFE

- While all living organisms have the properties of life we discussed earlier, explaining the origins of the following is most challenging

  nucleic acids (which store information)

  proteins (capture energy, replicate nucleic acids)

  membranes (which protect)

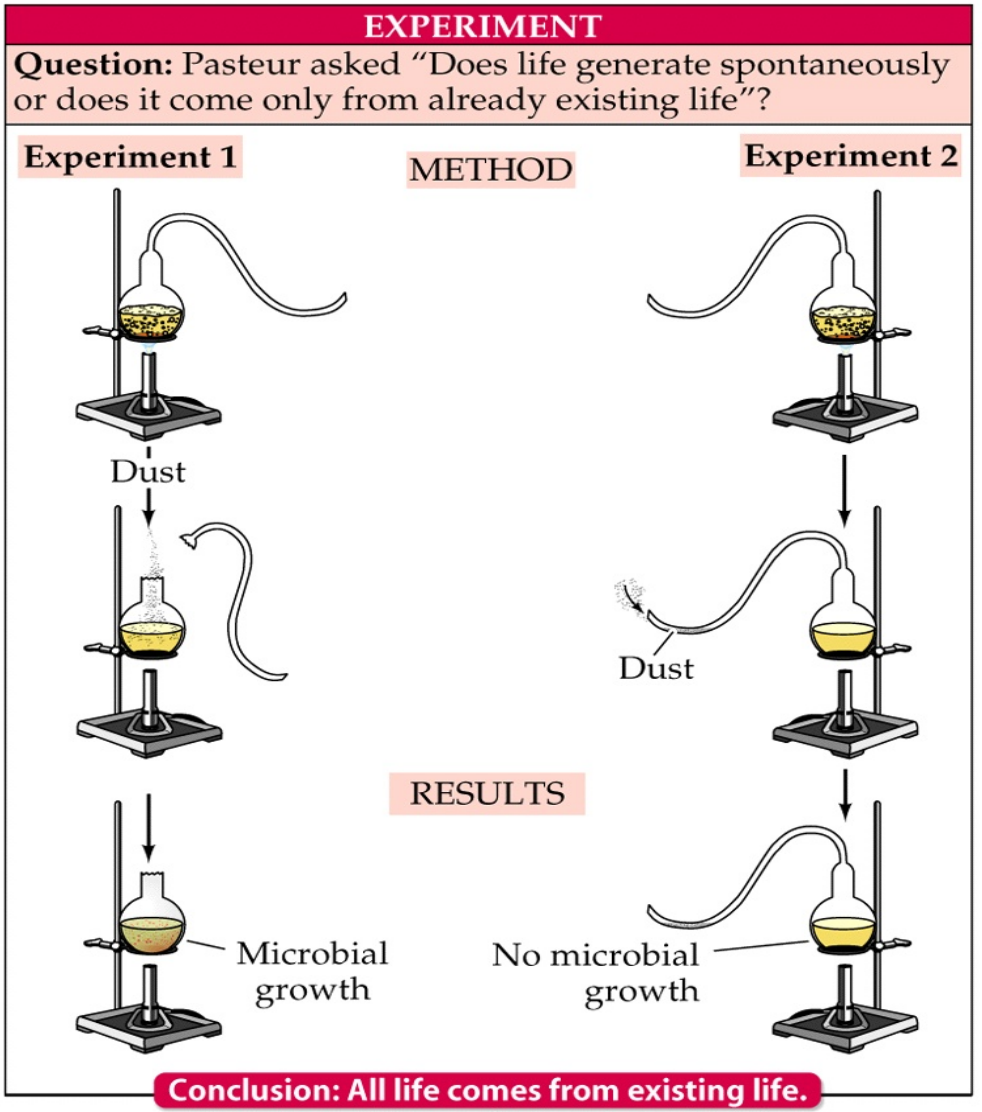
  self-replication

  Once we are able to explain the above, it is easier to explain the origins of the remaining properties of living organisms

Spontaneous generation

- Believed for a long time that life can arise out of non-living matter spontaneously
  - maggots from rotting flesh
  - 'recipes' to grow mice, etc
- Pasteur's experiments disproved this theory

Swan neck flask expt



Panspermia hypothesis

Idea: Life could have originated elsewhere and travelled to earth. Meteors could have dislodged large pieces of debris which landed on earth

Exobiology / Astrobiology: Searching for life forms in space

However, no evidence for this hypothesis

Earth formed about 4.5 bya (billion years ago)

- Big Bang

Remained inhospitable for a few million years

- Meteors, high temperature, No free Oxygen in the atmosphere, etc

No physical record of first biological events, must be reconstructed from indirect evidence

Several tools used by biologists to put together parts like fitting parts of a puzzle together

- physical, chemical, mathematical, biological

Oldest fossils – ca. 3.5 billion years

Chemical fossils – ca. 3.8 billion years

Best estimate for origin of life: ca. 4 billion years ago

Probable sequence of events

Inorganic molecules

↓

Simple organic compounds (*building blocks of life*: nucleotides, amino acid)

↓

Complex organic compounds (*biological polymers*: nucleic acids, polypeptides)

↓

Self replicating systems

↓

Cellular Life

"What I cannot create, I do not understand"

- Richard Feynman (Theoretical Physicist)

Ideally, we should be able recreate the steps in the origin of life

Oparin-Haldane Model

Alexandr Oparin and JBS Haldane

Theoretical model for pre-biotic chemical evolution

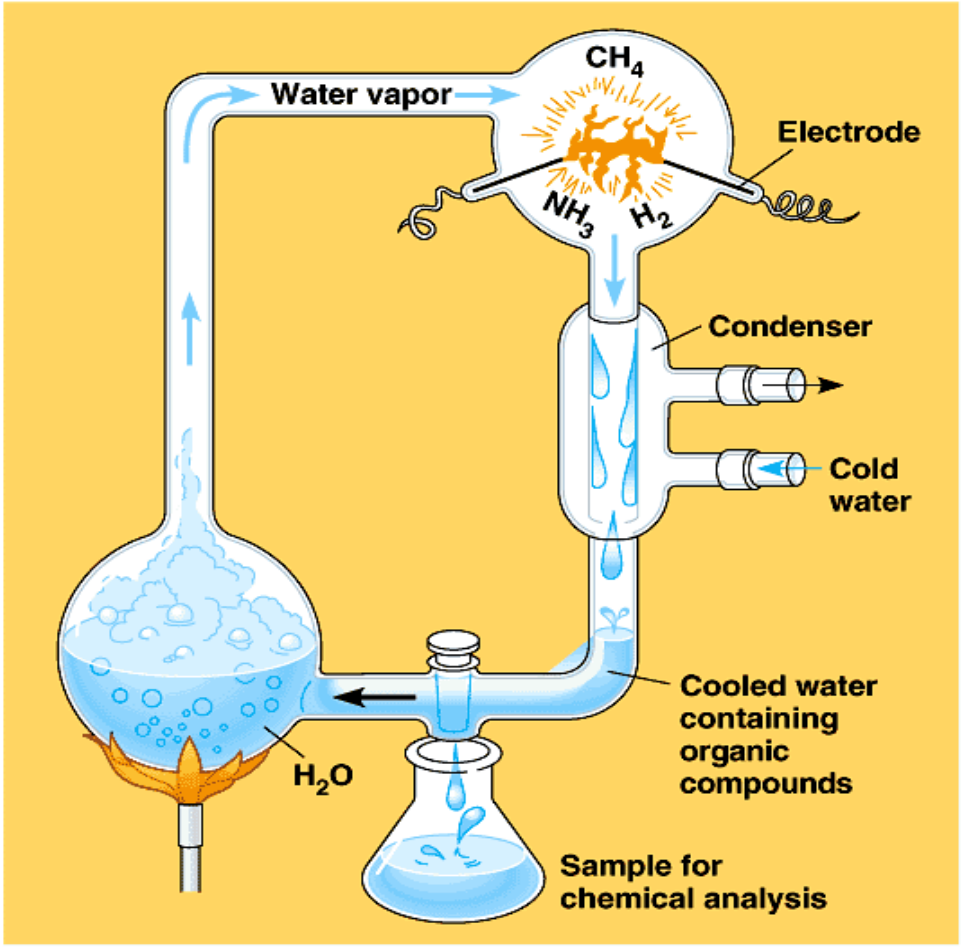
Model: Under the atmosphere of the early earth (4- 3.5 bya), inorganic molecules would spontaneously form organic molecules (simple sugars and amino acids)

Miller-Urey experiments

Stanley Miller and Harold Urey

Simulated Oparin-Haldane's early earth & demonstrated how simple biological molecules could arise abiotically through non-biological processes

- Boiled water
- Circulated hot vapour, atmosphere of methane, ammonia and hydrogen
- Passed electric current
- Condensed the vapour and directed it into a boiling flask



Simple organic compounds (amino acids, sugars, lipids, etc)

Formation of nucleotides

- Ribose sugars that form nucleotides have been synthesized
- It has not been possible to synthesize all nucleotides abiotically through Miller-Urey style experiments
- Active field of research

Simple organic molecules to biological polymers

• e.g. polynucleotides & polypeptides have been synthesized on a mixture of two minerals

Protobionts/Protocell: aggregates of abiotically produced molecules surrounded by primitive 'membrane'

Maintain internal chemical environment separate from surroundings

Some properties associated with life, but could not self-replicate

What was the first self-replicating system?

Artificial cells and membranes have been synthesised from non-living sources.

But they require protein or DNA. What came first? Protein or DNA?

Proteins can perform complicated biological tasks but cannot REPLICATE.

DNA can store and transmit genetic information by complementary base pairing but cannot perform complex cellular tasks

Central Dogma of Molecular Biology

- Francis Crick

- DNA is **TRANSCRIBED** to RNA

- RNA is **TRANSLATED** to an amino acid chain, which makes up proteins

Information cannot be transferred from protein back to nucleic acids

The Enigma of the Origin of Life

"The largest stumbling block in bridging the gap between nonliving and living still remains. All living cells are controlled by information stored in DNA, which is transcribed in RNA (*transcription*) and then made into protein (*translation*).

This is a complicated system, and each of these three molecules requires the other two - either to put it together or to help it work. DNA, for example, carries information but cannot put that information to use, or even copy itself without the help of RNA and protein."

Kenneth R. Miller and Joseph Levine, *Biology: The Living Science* (Upper Saddle River, New Jersey: Prentice Hall), 1998, p.406-407. (Slide by Chris Macosko)

Discovery of **ribozymes** (RNA enzymes) by Altman and Cech in 1982 (shared the 1989 Nobel Prize)

Ribozymes - made of nucleic acid

- like protein enzymes, can catalyze chemical reactions

Till then RNA was considered to have the task of transferring genetic information from the DNA to proteins, which in turn carry out all the actual ‘work’ in the cell

RNA World Hypothesis

RNA preceded protein and DNA in the origin of life.

Idea: There was a time when life entirely was RNA based.

Walter Gilbert in 1986, Nobel Prize in Chemistry

Short RNA-like molecules called **Pre-RNA** (or Pro-RNA) are thought to be the earliest self-replicating molecules.

The first cells are thought to have been formed by the enclosure of self-replicating RNA and associated molecules in a phospholipid **membrane.**

- **DNA** more stable than RNA
- DNA based replication systems eventually evolved, and DNA took over as genetic material
- Proteins took over as the major catalysts and structural components

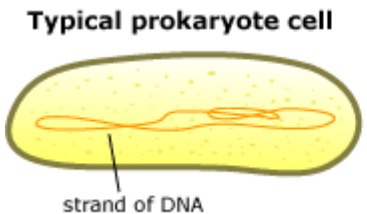
- The first **prokaryotic cells** were thus assembled
- Diversified in metabolism and phenotypes

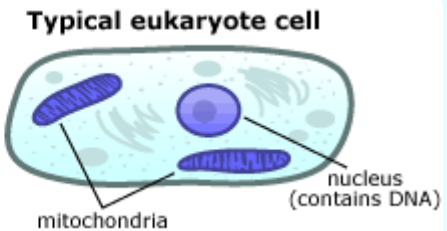
- Photosynthetic bacteria – ca. 2 bya
- Released Oxygen into the atmosphere
- This allowed aerobic respiration and further diversification

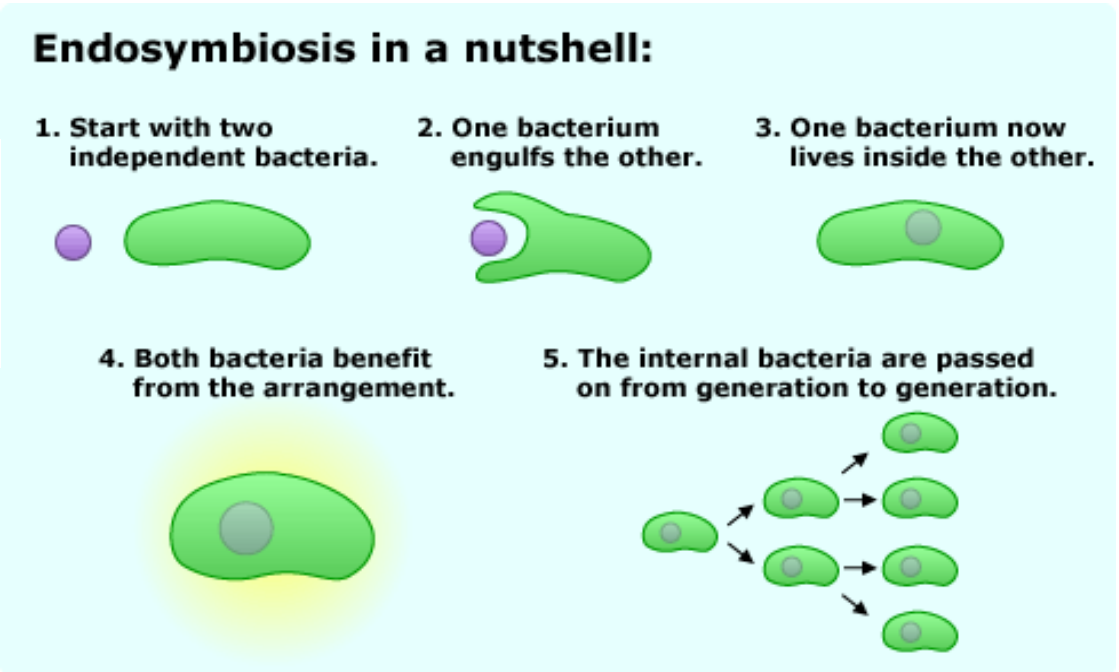
How did eukaryotes evolve?

- One of the main differences between prokaryotes and eukaryotes is that eukaryotes have membrane enclosed organelles.
- The endosymbiotic theory tries to explain the origin of organelles such as mitochondria and plastids

Evolution of eukaryotes (ca. 2.1 bya) - Endosymbiont theory







evolution.berkeley.edu/evolibrary/article/0_0_0/endosymbiosis_03

Evolution of multicellularty (> 1.5 bya)

- related to size advantage

- Unicellular organisms cannot be large (*surface area: volume ratio*)

- Multicellularity allowed organisms to become large

- Multicellularity thus allowed organisms to have a size advantage and also retain the advantage of small cell size

- Multicellularity eventually allowed living organisms to diversity greatly in form