ORIGINS OF CELLS

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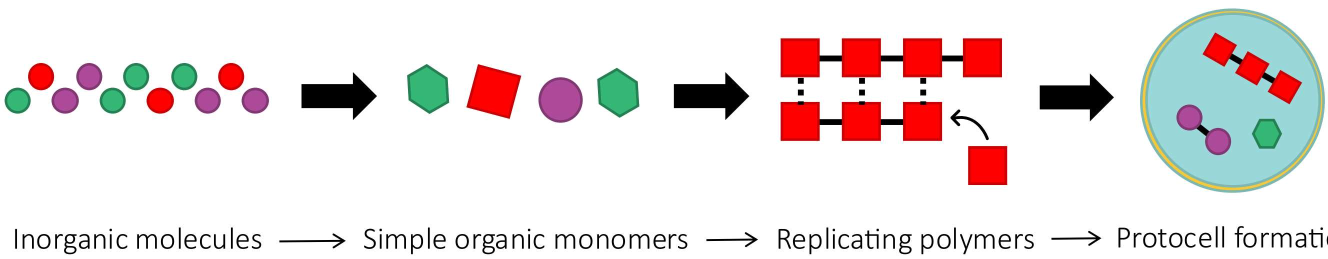
LIVING VS NON-LIVING

Living organisms are **self-sustaining**, meaning they are able to maintain the conditions needed to continue their existence. According to the cell theory, the cell is the smallest unit capable of self-sustaining life. Units that are smaller – such as **viruses** – are not considered to be living because they cannot carry out all of the functions of life independently (viruses lack metabolism and cannot reproduce autonomously of host cells).

ABIOGENESIS

Cells are highly complex structures that can currently only be produced via the division of pre-existing cells. However, the first cells must have arisen spontaneously (**abiogenesis**). It is thought this involved four steps:

1. **Catalysis** – Simple organic molecules (monomers) were synthesised from primordial inorganic material
2. **Self-Assembly** – More complex polymers were then constructed from these simple organic molecules
3. **Self-Replication** – Polymers formed the ability to be duplicated (enabling the capacity for inheritance)
4. **Compartmentalisation** – Molecules became packaged into membranes with unique internal chemistry



Abiogenesis is difficult to test as the exact conditions on pre-biotic Earth no longer exist (and are not easily replicated) and the first protocells did not fossilise so there is little evidence on which to base hypotheses.

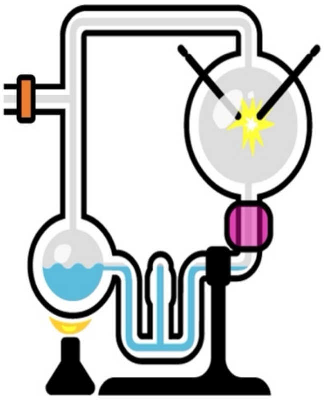
ORGANIC COMPOUNDS

The spontaneous formation of organic molecules would have required some specific pre-biotic conditions:

- A reducing atmosphere with a **lack of free oxygen** (meaning there was no ozone to block UV radiation)
- High levels of **ultraviolet radiation** (from the Sun) provided a source of energy for chemical reactions
- Volcanic eruptions introduced key materials to the atmosphere (such as **methane** and **carbon dioxide**)
- These gases produced a greenhouse effect that promoted **high temperatures** for the chemical reactions

MILLER-UREY EXPERIMENT

The Miller-Urey experiment recreated the postulated conditions of pre-biotic Earth to demonstrate the non-living synthesis of organic materials. Water was boiled to vapour to reflect the high temperatures common to Earth's original conditions. The vapour was mixed with a variety of gases to create a reducing atmosphere (with no oxygen). This mixture was then exposed to an electrical discharge (simulating the effect of lightning as an energy source for reactions). The mixture was then allowed to cool (concentrating components) and left for a period of roughly one week. The condensed mixture was then analysed and was found to contain traces of simple organic compounds (amino acids, etc.).



PROTOCELL FORMATION

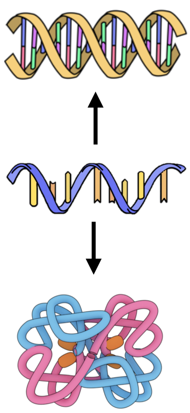
The production of simple organic molecules facilitated the spontaneous formation of membranes. In water, non-polar fatty acids will arrange to form **micelles** as the hydrophobic tails coalesce to avoid contact with a polar solution. When polar organic monomers are produced, they will attract the hydrophilic glycerol heads of the fatty acids and a spherical bilayer will form. The formation of membrane-bound containers creates a hydrophobic barrier that allows the internal chemistry of the vesicle to differ from the exterior. The ordered aggregation of non-living components (i.e. **protocells**) eventually lead to the development of the first cells.

RNA WORLD HYPOTHESIS

A core component of every cell is the **genetic material** that provides the instructions for reproducing vital chemical processes in successive cells. RNA is presumed to have been the original genetic material of a cell based on the presence of two essential properties:

- **Self-replication** – RNA acts as a template sequence from which a copy may be made
- **Catalysis** – RNA can catalyse chemical reactions (examples are ribozymes and rRNA)

RNA is the only molecule capable of both self-replication and catalytic functioning, but has since been superseded. DNA, through its superior stability (double helix structure), has taken over as the data storage form. Protein, through its variability (20 amino acids), has taken over as the catalytic form. RNA remains a **transitional form** between the two.

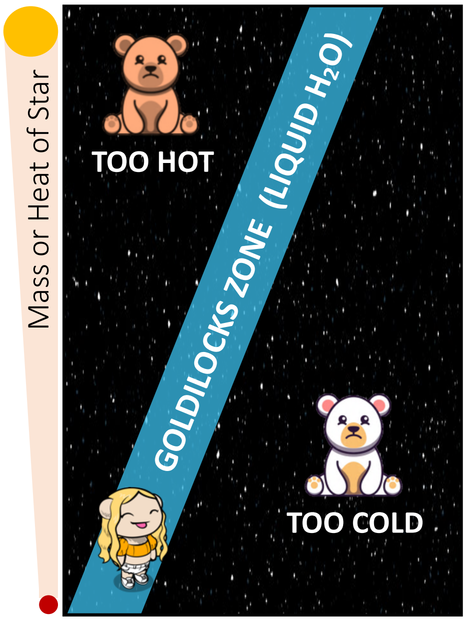


SIGNIFICANCE OF WATER

The presence of water is an essential requirement for the formation of life for a number of reasons. Water is polar, which causes non-polar lipids to spontaneously form bilayers when in solution. Water dissolves any polar or charged substance, making it a vital medium for metabolic reactions and its thermal properties will help to maintain the stable internal environment needed for homeostasis. Additionally, the construction of complex organic macromolecules requires water as an essential reagent (i.e. condensation polymerisation).

ORIGINS OF WATER

When the Earth was forming, the materials involved in its accretion would have contained a sizeable quantity of water vapour. However, high temperatures would have prevented vapour from condensing and low gravity would have resulted in most of the vapour being lost to space. Hence, the large bodies of water on Earth are thought to have instead originated from asteroids formed further from the Sun, where the cooler temperatures would have allowed the water to be frozen as ice. When the asteroids collided with Earth, the planet had achieved sufficient gravity to retain water and had cooled enough for it to condense. The presence of liquid water is an essential condition when searching for other habitable planets with extraterrestrial life. The Goldilocks zone describes the distances from a star whereby the right temperatures would exist for liquid water to exist on a planet. The relevant distances will depend on the size and temperature of the star – the habitable zone will be further away from hotter stars.



LAST UNIVERSAL COMMON ANCESTOR (LUCA)

All lifeforms on Earth share certain characteristics, suggesting that all extant organisms are derived from a common source – the last universal common ancestor (LUCA). Evidence for the existence of a last universal common ancestor include the fact that the **genetic code is universal** (all life shares a common mechanism of transcription and translation) and that certain genes are broadly distributed across all cellular organisms.

LUCA Timeline:

Because microbes do not typically leave discernible fossils, major uncertainties exist regarding the evolutionary timeline of the last universal common ancestor. Scientists can use **biochemical evidence** to try and establish a timeline – such as the presence of certain organic compounds in a rock layer or the occurrence of *stromatolites* (sedimentary deposits formed by cells). In addition, scientists can use **phylogenetic evidence** – when comparing conserved sequences in a variety of species, the time since divergence can be estimated based on the number of differences between the sequences. According to the *molecular clock* concept, if mutation rate is stable then the number of mutations indicates the time since divergence (when both nucleotide sequences would have still been identical).

Stromatolite

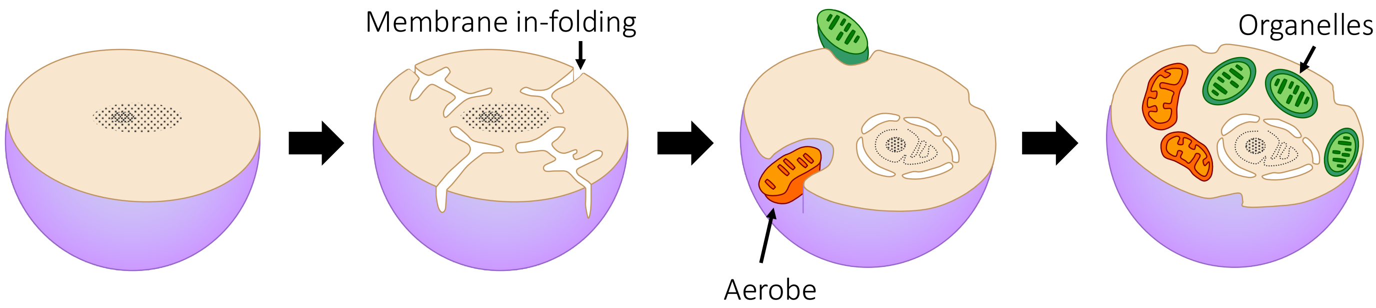
LUCA Location:

Evidence suggests that the last universal common ancestor likely existed in the vicinity of hydrothermal vents. The precipitation of minerals from the vents can result in the preservation of biological structures. **Fossilized evidence** of bacteria have been discovered in ancient seafloor hydrothermal vent precipitates that are dated as being ~3.7 billion years old. **Genomic analysis** also supports the theory that the LUCA developed in proximity to hydrothermal vents. Genes proposed to belong to LUCA suggest that it was a *thermophilic chemoautotroph* – conditions that would be needed for an organism found in proximity to hydrothermal vents (it is predicted that LUCA used the hydrogen from the vents as an energy source).

Hydrothermal Vents

ENDOSYMBIOSIS

The first cells were prokaryotic and lacking compartmentalisation. Eukaryotes are believed to have evolved via *endosymbiosis* – whereby one cell was engulfed by another and became assimilated into its structure. **Mitochondria** are presumed to have evolved when a prokaryotic ancestor engulfed an aerobic bacterium, which over time lost its independent utility and developed into the modern organelle. Similarly, **chloroplast** (plant cells) likely developed as a consequence of the internalisation of a photosynthetic cyanobacterium.



EVIDENCE FOR ENDOSYMBIOSIS

Mitochondria and chloroplast are believed to have evolved via a process of endosymbiosis:

- **Membranes** – Both have a double membrane structure (supporting initial endocytosis)
- **Antibiotics** – Both are susceptible to antibiotics (compounds that targets prokaryotes)
- **DNA** – Both have their own DNA which is circular and naked (like in prokaryotic cells)
- **Division** – Both reproduce via a fission-like process (similar to bacterial binary fission)
- **Ribosomes** – Both have their own ribosomes (which are 70S in size – like prokaryotes)

MULTICELLULARITY

Multicellularity has evolved repeatedly in living organisms – all plant and animal species are multicellular, along with most fungi and several species of eukaryotic algae. Multicellularity offers several distinct survival advantages. Being multicellular allows an organism to **exceed size limits** normally imposed by SA:Vol ratio limitations. Multicellular organisms can have **longer lifespans** (as the organism can survive the death of an individual cell) and multicellularity fosters complexity by allowing for the specialisation of cell types within an organism (via differentiation). One challenge facing multicellular organisms is the occurrence of **cancer**.

CELL DIFFERENTIATION

Multicellular organisms are capable of completing functions that unicellular organisms cannot undertake – due to the actions of individual cells combining to create synergistic effects (**emergent properties**). The cells become specialised as a consequence of different patterns of gene expression. These differing patterns are coordinated by extracellular signals (**transcription factors**) that are triggered by environmental changes.