Origins of cells

A2.1 · HL only

When does a compartment become a cell?

HL-only A2.1: connect several capacities

A membrane bubble is not automatically alive. Making an amino acid is not making a cell.

The origin problem connects compartments, catalysis and inherited information that can evolve together.

Numerical examples are invented. This unit has no SL counterpart.

An early atmosphere is a reconstructed model

Conditions affect the chemistry that is possible

Early Earth had little free molecular oxygen and therefore little protective ozone; more ultraviolet radiation could reach the surface.

Models include greater carbon dioxide and methane concentrations than today and greenhouse warming. Conditions varied across time and place.

A single gas recipe in an apparatus is not a direct measurement of a universal ancient atmosphere.

An origin hypothesis must make testable predictions

Chemical feasibility is a limited but useful result

Ultraviolet radiation, electrical discharges, heat or chemical gradients can supply energy for reactions.

Test a defined mixture, compare controls and identify products. Organic compounds need not have been produced by organisms.

A feasible reaction under one set of conditions does not identify the whole historical route to life.

Living cells integrate several processes

Self-sustaining does not mean isolated

A cell maintains organization, exchanges matter and energy, carries information and belongs to a reproducing lineage.

Viruses rely on host cellular machinery and energy; they do not have autonomous cellular metabolism.

Fire spreads and crystals grow without being cells. One isolated property is not a sufficient life test.

Connect four capacities in one evolving system

Capacity	**Why it matters**
Catalysis	Reactions proceed fast enough under available conditions
Replication / heredity	Preserve functional information with possible variation
Self-assembly	Components organize through their interactions
Compartments	Retain interacting components and distinct internal chemistry

Current cell division leaves a historical question

Present-day production is not an origin mechanism

Cells arise from pre-existing cells today. That observation does not explain the first cellular lineage.

Abiogenesis concerns an early transition from non-living chemistry, not modern organisms appearing routinely in sterile food.

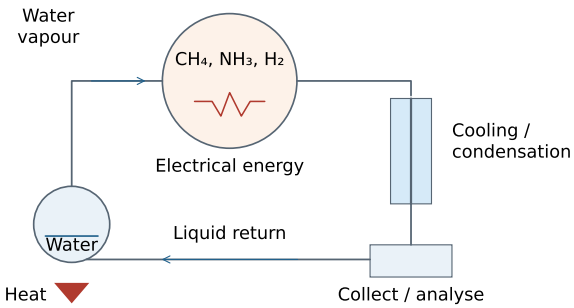
A growing bubble lacks a complete evolution model unless functional differences can be inherited through reproduction.

A cell or a virus?

	cell	virus
exchanges matter and energy (own metabolism)	✓	✗
maintains internal organization	✓	✗
carries genetic information	✓	✓
reproduces	✓	only in a host
evolves	✓	✓

So a virus is not a cell

Trace the spark-discharge model



Heating, reactants, electrical energy, condensation and collection make a defined laboratory chemical model.

What did the product evidence establish?

Building blocks under tested conditions

The classic system circulated water vapour, methane, ammonia and hydrogen past electrical discharges; cooling collected products.

Amino acids and other carbon compounds were detected. This supports abiotic synthesis of some building blocks.

It did not create living cells or establish a complete historical origin pathway.

Evaluate the method with controls and limits

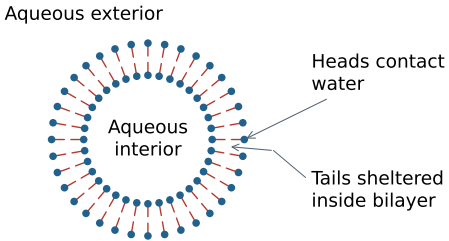
A model is useful within its conditions

A matched trial without the energy input tests its effect. Clean-material checks and blanks help assess contamination.

Chemical analysis and repeatability support the synthesis claim. Historical gas composition limits generalization to every early environment.

Failing to create cells does not invalidate a test of building-block synthesis; changing the mixture tests a different set of conditions.

A fatty-acid boundary can organize itself



A boundary can self-assemble.
Heredity and metabolism need further explanation.

> Heads contact the two aqueous regions; tails are sheltered between the head layers.

Why a boundary helps and why it is not enough

Retention must coexist with exchange

A compartment can keep reactants and catalysts together and maintain a different internal chemistry.

Too much leakage loses useful components; a completely impermeable boundary prevents necessary exchange.

Self-assembly depends on conditions, including pH, concentration and ions. A vesicle alone does not supply heredity or metabolism.

The RNA-world hypothesis joins two roles

A sequence can carry information and support catalysis

RNA can carry sequence information and serve as a template for complementary copying.

Some folded RNA molecules are ribozymes. Ribosomal RNA contributes to the peptide-bond-forming centre of modern ribosomes.

These properties support a plausible dual-role system; they do not make every RNA molecule an autonomous self-copying cell.

Connect RNA copying to an evolving compartment

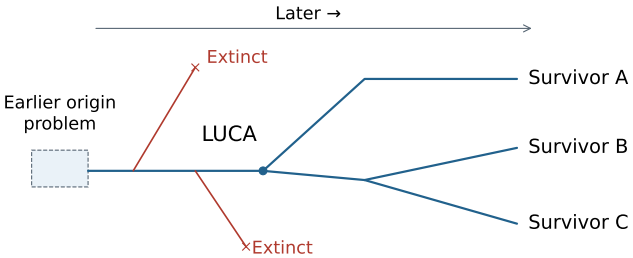
Useful effects must be inherited

An early model still needs nucleotide supply, polymer formation, copying fidelity and stability.

If inherited sequence differences affect catalysis and compartment reproduction, lineages can differ in reproductive success.

This is selection under conditions, not molecules deliberately pursuing progress or a predetermined goal.

Read the ancestor of surviving lineages



Surviving cell lineages A–C; schematic relationships.
No time scale.

LUCA is ancestral to present cellular lineages; earlier and competing lineages may have disappeared.

What supports universal common ancestry?

Combine shared information-processing features

The broadly conserved genetic code and shared fundamental genes support common ancestry.

Consistent patterns across several genes and many organisms are stronger than one superficial resemblance.

LUCA need not be the first living system, the only contemporary organism or a single identifiable fossil cell.

A similarity percentage is not a molecular clock

1. **Invented alignment.** 18 matching sites among 24 compared sites.
2. **Identity.** $I = (18/24) \times 100 = 75\%$.
3. **Limit.** The percentage supplies no calibrated change rate or account of repeated changes.

Decision

It cannot alone date LUCA or identify one modern sampled organism as another's direct ancestor.

Different evidence answers different dating questions

Evidence / method	**What it can constrain**
Fossils / chemical traces	Life present by a time, if origin and context are established
Rock dating / strata	Geological age and sequence of events
Molecular clocks	Divergence estimates using sequence models and calibrations

An ancient signal needs alternatives tested

Context and model assumptions matter

Rule out younger contamination, later fluid movement and geological alteration before interpreting a trace.

Cell-like shapes or isotope patterns need comparison with non-biological explanations and other evidence.

Clock estimates depend on rates, relationships and calibrations. The oldest fossil found is not automatically the exact origin date.

Convert a compressed geological interval

1. **Invented interval.** 3.8 to 3.2 billion years ago; not proposed origin or LUCA dates.
2. **Duration.** $\Delta t = (3.8 - 3.2) \times 1000 = 600$ million years.
3. **Interpret.** A small space on a diagram can conceal immense time and many generations.

Decision

An unscaled branch length must not be read as a measured duration.

Vents offer chemical conditions to test

Identify a source, a process and a limitation

Some hydrothermal settings provide redox or proton gradients and mineral surfaces that could support reactions.

Pores can concentrate substances. A hypothesis needs a particular chemical mechanism, not just a warm place.

Ancient precipitate structures may support early life in such settings, after geological and abiotic alternatives are evaluated.

Compare geological and genomic evidence

Agreement can strengthen a constrained hypothesis

Genomic reconstructions test whether conserved sequences and inferred metabolisms fit a vent-related early setting.

These are inferences from surviving organisms, not a direct reading of LUCA's entire environment.

Life in an ancient vent deposit does not prove a unique birthplace. Shared assumptions are not independent confirmations.

An organelle-origin model answers a later question

Existing lineages are already part of this model

Mitochondrial and chloroplast DNA, bacterial-type ribosomes and division support descent from bacterial lineages.

Endosymbiosis explains later eukaryotic organization; it already presupposes existing cells.

Not every organelle needs an engulfed-bacterium origin. One matching sequence does not explain the complete origin of life.

Try an evidence and timescale question

Calculate, then qualify the inference

An invented alignment has 21 matches among 28 sites. Find identity and explain what it does not tell you.

An invented interval runs from 3.8 to 3.2 billion years ago. Express its duration in millions of years.

Explain why amino-acid synthesis and fatty-acid self-assembly each leave further questions before a cellular system exists.

Reveal: separate a result from the wider claim

1. **Identity.** $I = (21/28) \times 100 = 75\%$; no divergence date without a calibrated model.
2. **Elapsed time.** $\Delta t = 0.6 \times 1000 = 600$ million years.
3. **Origin problem.** Building blocks and boundaries alone do not establish inherited, integrated metabolism.

Check yourself

Observation → inference → limitation

State the target: building blocks, compartments, common ancestry or later organelle evolution.

Feasibility under defined conditions is not proof of a unique historical route. A valid limit need not discard useful evidence.

LUCA is not automatically the first cell. Similarity percentages are not dates without a model and calibration.