REVISION GUIDE

Where did the *first cell* come from?

Origins of cells

Every cell alive today came from another cell, but the first one cannot have. Find out what makes something alive, what early Earth was like, what the Miller-Urey experiment showed, how membranes and RNA may have come first, and what the evidence says about LUCA, the ancestor of all life. Higher level only.

6 chapters

The interactive guide, with every animation:

biologybybradford.com/guides/ib-biology-a2-1-origins-of-cells

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	Check yourself	16
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By the end you can

- [ ] Describe the conditions on early Earth and how they may have let carbon compounds form without life A2.1.1
- [ ] Distinguish living from non-living, and explain why viruses are usually counted as non-living A2.1.2
- [ ] Explain why the spontaneous origin of cells is hard to explain, and what had to arise first A2.1.3
- [ ] Evaluate the Miller-Urey experiment as evidence for the origin of carbon compounds A2.1.4
- [ ] Explain how fatty acids can form vesicles, and why a compartment was needed A2.1.5
- [ ] Explain why RNA is thought to have been the first genetic material A2.1.6
- [ ] Outline the evidence for a last universal common ancestor A2.1.7
- [ ] Outline how the dates of the first cells and of LUCA are estimated A2.1.8
- [ ] Outline the evidence that LUCA lived near hydrothermal vents A2.1.9

Tick each one when you can do it without the book.

A2.1.2 HL A2.1.3 HL CELLS AS THE SMALLEST UNITS OF SELF-SUSTAINING LIFE CHALLENGE OF EXPLAINING THE SPONTANEOUS ORIGIN OF CELLS

01 What counts as *alive*?

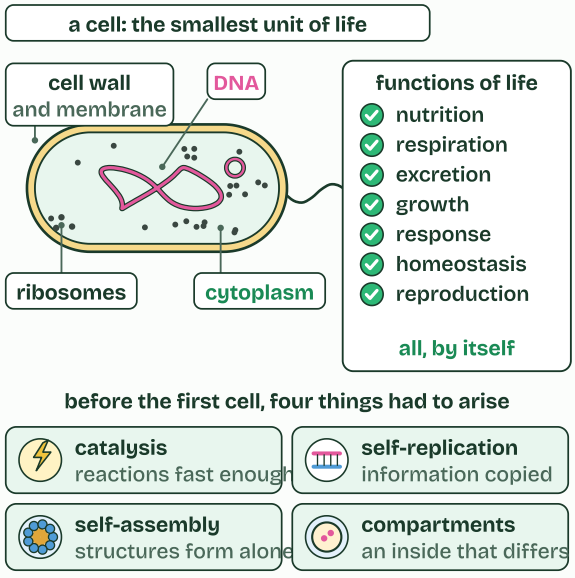
Living things carry out all the functions of life: they take in nutrients, respire to release energy, excrete waste, grow, respond to their surroundings, keep their insides steady and reproduce. A cell is the smallest thing that does all of these by itself, so the cell is the smallest unit of self-sustaining life. A molecule of DNA, an enzyme or a mitochondrion taken out of a cell does none of them alone.

Viruses sit on the line. They have genes made of nucleic acid and they evolve, but outside a host cell they do nothing: no metabolism, no respiration, no growth, no response. They have no cytoplasm and no ribosomes, so they cannot make their own proteins, and they are copied only by the machinery of a cell they infect. For these reasons most biologists count viruses as non-living.

That makes the first cell a puzzle. Today every cell comes from the division of an existing cell, and a cell is far too complex to assemble by chance in one step. Before the first cell, four things had to arise: **catalysis**, so that reactions could happen fast enough; **self-replication** of molecules, so that information could be copied; **self-assembly** of structures such as membranes; and **compartmentalization**, so that the chemistry inside could differ from that outside.

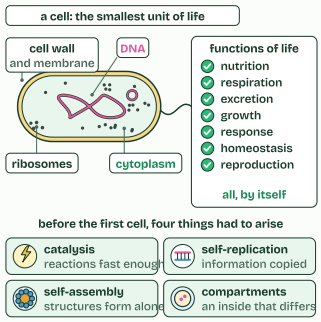
KEY POINTS

- The cell is the smallest unit that carries out all the functions of life.
- Viruses are usually counted as non-living: no metabolism, copied only inside a host.
- The first cells needed catalysis, self-replication, self-assembly and compartments.



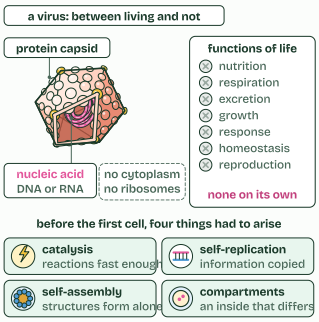
SWITCH IT
2 SETTINGS

1



A cell

2



A virus

WATCH OUT

Having genes and evolving is not enough to be alive. A virus has both, yet does nothing by itself outside a cell.

PREDICT

Which feature of a virus is the strongest reason for calling it non-living?

(A) It is far smaller than any cell, so it is too small to hold the parts that life needs

(B) It has no metabolism of its own and can only be copied by the machinery of a host cell

(C) Its genes can be made of RNA instead of DNA, which no living organism ever uses as genes

Decide before you look. Answer on page 17.

02 A world *without oxygen*

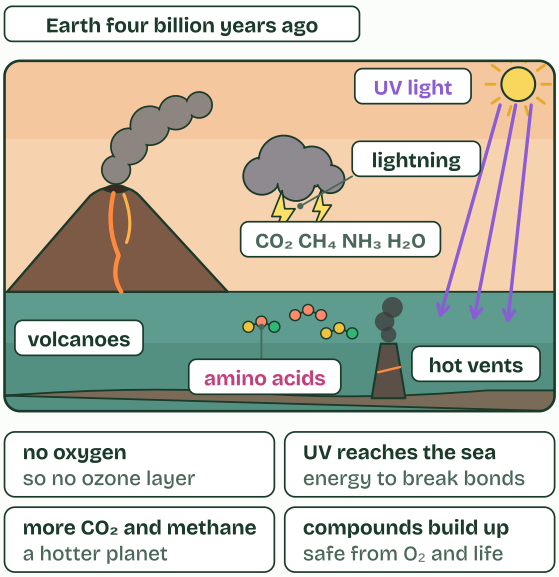
A2.1.1 HL CONDITIONS ON EARLY EARTH AND THE PRE-BIOTIC FORMATION OF CARBON COMPOUNDS

Four billion years ago Earth was a different planet. Its atmosphere held no free oxygen, so there was no ozone layer either, and ultraviolet light from the Sun reached the surface and the sea. The air held far more carbon dioxide and methane than today, and with these greenhouse gases the planet was hotter. Volcanoes erupted water vapour and gases, lightning was frequent, and hot water poured from vents on the sea floor.

Under those conditions, carbon compounds could have formed by chemical reactions that no longer happen on Earth. Energy from ultraviolet light, lightning and heat could break the bonds in simple molecules such as methane, ammonia and water, and the fragments could join into larger ones such as amino acids and sugars. With no oxygen to react with them and no living things to eat them, these compounds could build up in the sea. Today oxygen breaks them down and organisms consume them, which is one reason life does not keep arising afresh.

KEY POINTS

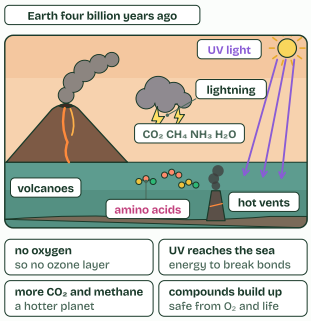
- Early Earth: no free oxygen, no ozone, more CO_2 and methane, hotter.
- UV light, lightning and heat gave energy for reactions.
- Carbon compounds may have formed spontaneously, by chemistry that does not happen now.



SWITCH IT

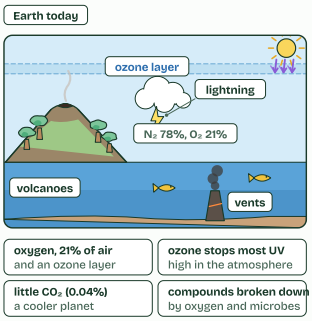
2 SETTINGS

1



Four billion years ago

2



Today

WATCH OUT

No ozone is a consequence of no oxygen: ozone (O_3) is made from oxygen. They are not two separate facts.

PREDICT

Why could amino acids build up in the early sea but not in today's?

(A) The early sea was much colder, so the amino acids that formed in it were not broken down by heat

(B) There was no oxygen to break them down and no living things to consume them as food

(C) There was an ozone layer to shield them, so ultraviolet light did not break up their bonds

Decide before you look. Answer on page 17.

03 Lightning in a *flask*

A2.1.4 HL EVIDENCE FOR THE ORIGIN OF CARBON COMPOUNDS

In 1952 Stanley Miller and Harold Urey tested whether early Earth's conditions could make the compounds of life. A sealed loop of glass held water and a mixture of methane, ammonia and hydrogen, their model of the early atmosphere. The water was boiled so its vapour carried the gases round, past a spark between two electrodes in a large flask, standing in for lightning. A condenser cooled the vapour so it rained back into a trap. After a week the liquid had turned brown, and chromatography showed amino acids in it, glycine and alanine most of all.

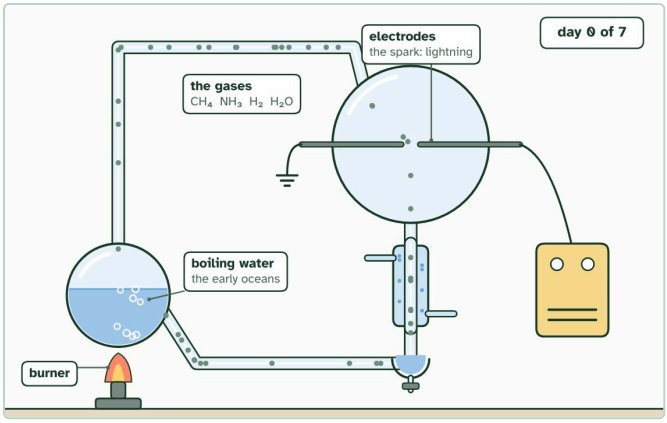
Evaluating it means weighing both sides. It showed that amino acids can form from simple molecules with no life present, and with a run without the spark as a control, that the energy was needed. Later analysis of Miller's stored samples found more than twenty amino acids. But geologists now think the early atmosphere was mostly carbon dioxide and nitrogen, which give far less; the gases in the apparatus were chosen to work. And amino acids are a long way from a cell: the experiment makes no proteins, no nucleic acids and no membranes.

KEY POINTS

- Gases plus a spark plus water, cycled for a week, gave amino acids.
- Strength: organic compounds of life can form without life, from energy and simple molecules.
- Limits: the atmosphere may have been wrong, and amino acids are far from a cell.

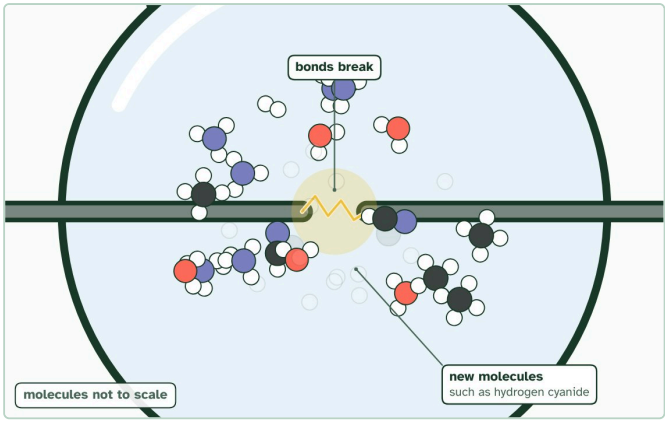
ANIMATION · THE MILLER-UREY EXPERIMENT
6 MOMENTS

1 HEATING



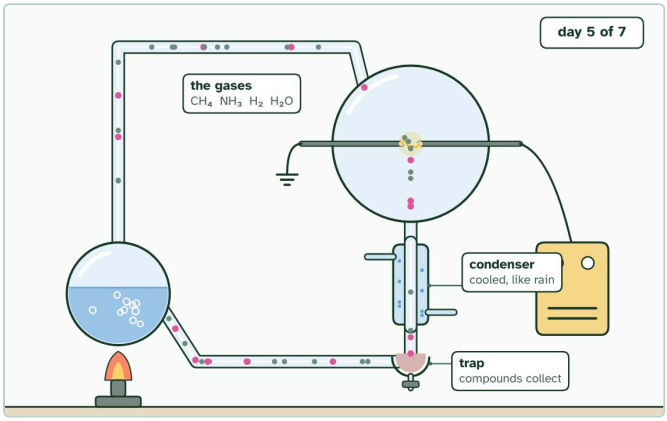
Heat: water boils in the small flask, standing in for the early oceans. Its vapour carries methane, ammonia and hydrogen round a sealed loop of glass.

2 SPARK



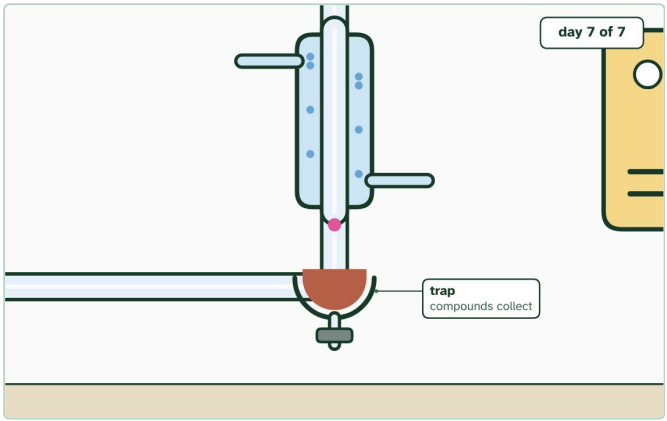
The gases pass a **spark** between two electrodes, standing in for lightning. Its energy breaks bonds, and new, reactive molecules form, such as hydrogen cyanide (going deeper).

3 CONDENSING



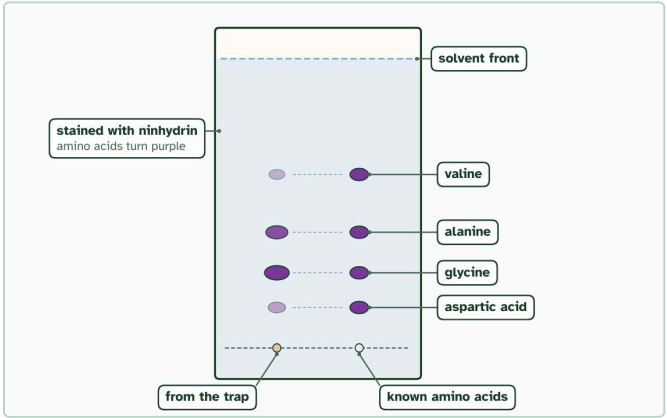
The **condenser** cools the vapour, like rain. Water, and anything dissolved in it, drips into the trap, and the cycle goes round again.

4 A WEEK ON



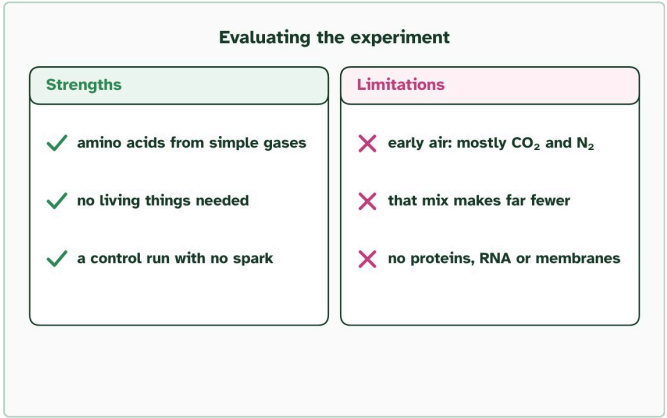
A week on, the liquid in the trap has turned pink, then brown, as new compounds build up.

5 TESTED



Tested by chromatography beside known amino acids, the liquid holds **amino acids**, glycine and alanine most of all: carbon compounds of life, made with no life present.

6 EVALUATING



Evaluating it: amino acids formed from simple molecules with no life present. But the early air was probably mostly carbon dioxide and nitrogen, and amino acids are a long way from a cell.

Watch it move, and change it as it runs: biologybybradford.com/guides/ib-biology-a2-1-origins-of-cells#miller

NATURE OF SCIENCE

A claim in science must be testable. The origin of life is hard to test: the conditions on pre-biotic Earth cannot be replicated exactly, and the first protocells did not fossilize. Scientists test the parts they can, such as whether amino acids form, whether fatty acids make vesicles and whether RNA can copy itself, and treat the whole story as a set of hypotheses still being tested.

PREDICT

The experiment is repeated with nitrogen, carbon dioxide and water instead of methane, ammonia and hydrogen. What would you predict?

(A) The same amino acids in the same amounts, because the spark supplies all the energy either way

(B) Far fewer amino acids, because those gases are less ready to react when given the spark's energy

(C) No change in the liquid at all, because nitrogen and carbon dioxide cannot be broken by a spark

Decide before you look. Answer on page 17.

A2.1.5 HL SPONTANEOUS FORMATION OF VESICLES BY COALESCENCE OF FATTY ACIDS INTO SPHERICAL BILAYERS

04 The first *bubbles*

A cell needs an inside. Without a boundary, any useful molecules made by chance would drift away, and the chemistry in one place could never differ from that around it. A membrane-bound compartment lets the inside build up its own concentrations and its own reactions.

Fatty acids can make one by themselves. Like phospholipids they are amphipathic: a hydrophilic head and a hydrophobic tail. In water they first gather into small balls, **micelles**, with their tails hidden inside. At higher concentrations they coalesce into bilayers. A flat sheet of bilayer leaves tails exposed at its edges, so it curls round and closes into a sphere: a **vesicle**. Vesicles like these form readily in the laboratory, can trap molecules such as RNA inside, take in more fatty acids, grow and split.

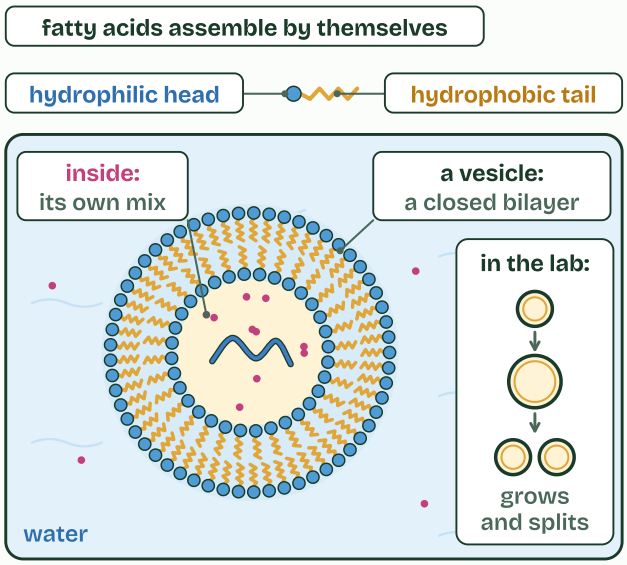
KEY POINTS

- A compartment lets the chemistry inside differ from that outside.
- Fatty acids are amphipathic: micelles, then bilayers.
- A bilayer closes into a vesicle so no tails are left exposed.

KEY TERMS

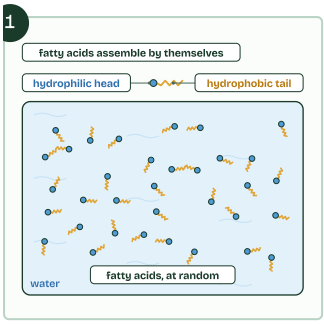
micelles
A small sphere of amphipathic molecules in water, hydrophobic tails inside and hydrophilic heads facing the water.

vesicle
A small closed sac bounded by a bilayer, with water inside and out.

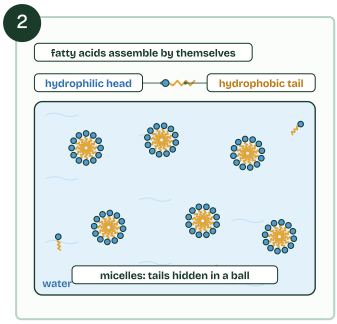


STEP BY STEP

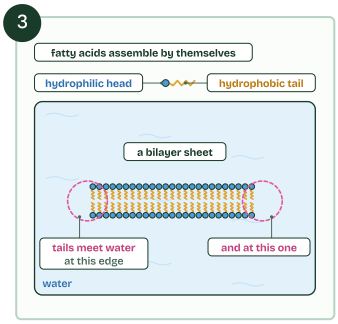
4 STEPS



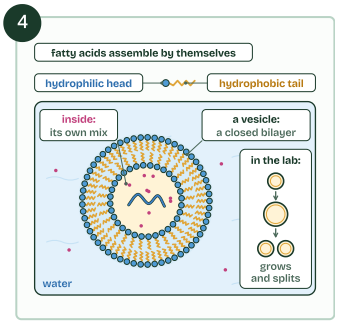
Fatty acids scattered in water.



They gather into **micelles**, tails inward.



At higher concentrations they form a **bilayer**, but its edges leave tails exposed.



The bilayer closes into a **vesicle**, and the inside can hold different molecules from the outside.

WATCH OUT

A vesicle of fatty acids is not a cell. It has a boundary but no genes, no enzymes and no metabolism. It is one of the four requirements, not all of them.

PREDICT

Why would a flat sheet of bilayer close up into a sphere?

(A) A sphere holds the most water inside, and water inside is what makes the vesicle stable

(B) Closing up removes the edges, where hydrophobic tails would otherwise be in contact with water

(C) The fatty acid heads attract each other strongly and pull the sheet round into a ball shape

Decide before you look. Answer on page 17.

05 The *RNA* world

A2.1.6 HL RNA AS A PRESUMED FIRST GENETIC MATERIAL

In cells today, DNA stores genes and proteins do the catalysis, and each needs the other: proteins are made from the information in DNA, and DNA is copied by protein enzymes. So which came first? RNA offers a way out, because it can do both jobs.

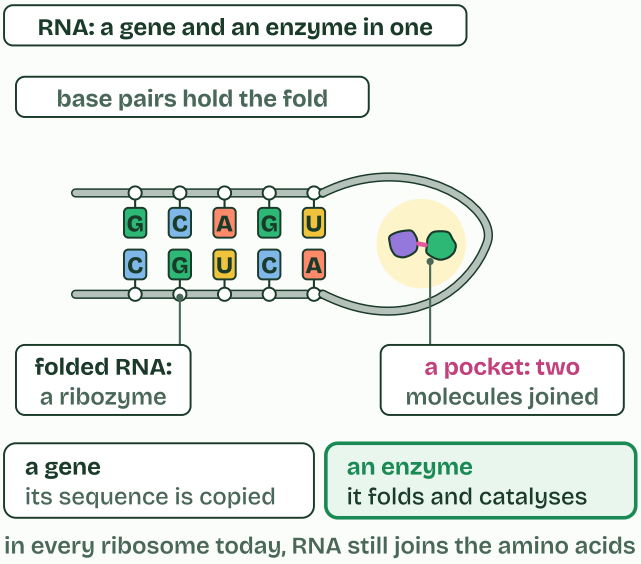
RNA stores information in its sequence of bases, and that sequence can be copied by complementary base pairing. RNA can also fold into shapes that catalyse reactions; such RNA catalysts are **ribozymes**. So the first living systems may have used RNA as both their genes and their enzymes: the RNA world hypothesis. A trace of it remains in every cell: in the ribosome, it is RNA, not protein, that catalyses the peptide bonds between amino acids during protein synthesis.

KEY POINTS

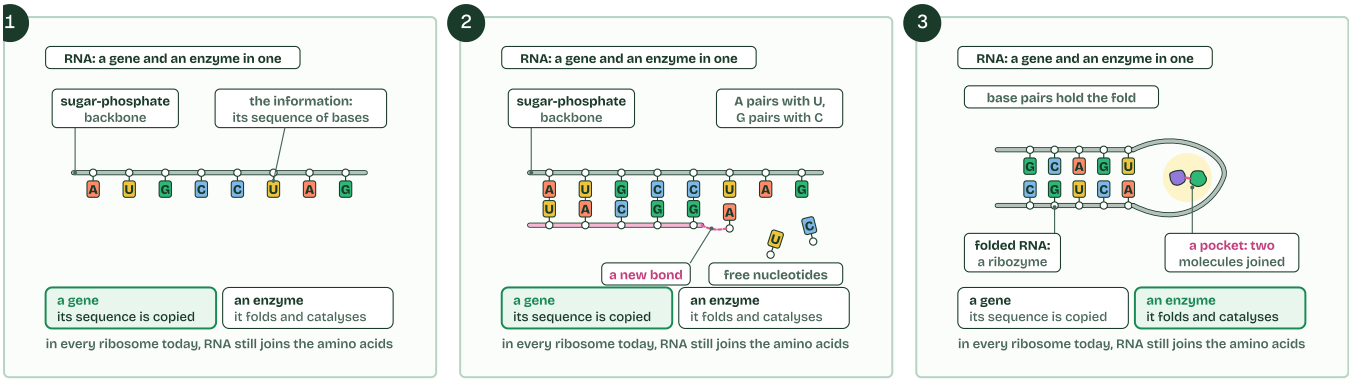
- RNA can store information and be copied by base pairing.
- RNA can catalyse reactions: ribozymes.
- The ribosome's peptide bonds are still made by RNA.

KEY TERMS

ribozymes
A molecule of RNA that acts as an enzyme, catalysing a chemical reaction.



STEP BY STEP
3 STEPS



A strand of RNA: information in its **sequence of bases**.

Free nucleotides pair with it to make a **complementary copy**.

Folded on itself, RNA can **catalyse** a reaction: a ribozyme.

WATCH OUT

The RNA world is a hypothesis. No self-replicating RNA from early Earth has been found; the evidence is what RNA can do today.

PREDICT

Why is the ribosome taken as evidence for the RNA world?

(A) It is made only of protein, which shows that proteins took over every job from RNA long ago

(B) Its catalytic site is RNA, so one of life's most ancient reactions is still catalysed by RNA

(C) It copies RNA from DNA, which shows that DNA must have come before RNA in the first cells

Decide before you look. Answer on page 17.

A2.1.7 HL A2.1.8 HL A2.1.9 HL EVIDENCE FOR A LAST UNIVERSAL COMMON ANCESTOR APPROACHES USED TO ESTIMATE DATES OF THE FIRST LIVING CELLS AND THE LAST UNIVERSAL COMMON ANCESTOR EVIDENCE FOR THE EVOLUTION OF THE LAST UNIVERSAL COMMON ANCESTOR IN THE VICINITY OF HYDROTHERMAL VENTS

06 LUCA, the ancestor of *everything*

All living things share the same genetic code: the same codons stand for the same amino acids in bacteria, plants and people. All use DNA, RNA, ribosomes and ATP, and some genes are found, in recognisable versions, in every organism. The simplest explanation is that all life descends from one population of cells, the **last universal common ancestor** (LUCA). LUCA was not the first life: other forms probably evolved too, but went extinct, perhaps outcompeted by LUCA and its descendants.

Dates come from several approaches. Rocks are dated by the decay of radioactive isotopes, so fossils in them can be dated: stromatolites, layered mounds built by microbes, go back about 3.5 billion years, and possible microfossils are older. A **molecular clock** uses the differences between genes shared by all life, with a rate of change calibrated against dated fossils, to estimate when the lineages split; recent estimates put LUCA at around 4.2 billion years ago. Life has been evolving for almost all of Earth's 4.5 billion years.

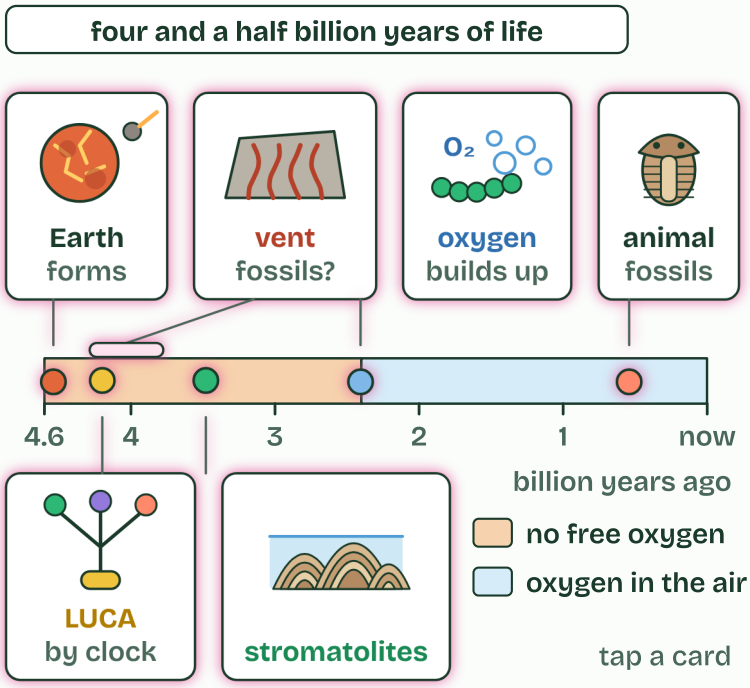
Where did LUCA live? Genes that are conserved across bacteria and archaea, and so were probably in LUCA, include ones for living without oxygen, at high temperature, and on hydrogen and carbon dioxide, which is how chemistry works at hydrothermal vents. And some of the oldest possible fossils are threads and tubes of iron minerals in rock that formed around ancient seafloor vents.

KEY POINTS

- One genetic code and shared genes: evidence for LUCA.
- Dates from fossils in dated rock and from molecular clocks.
- Vents: conserved genes for heat, no oxygen and H_2, and vent fossils.

KEY TERMS

last universal common ancestor
The last universal common ancestor: the most recent population of organisms from which all living things today are descended.



About 4.54 billion years ago: Earth forms. For its first few hundred million years it was hit by large impacts and may have had no lasting oceans.

About 2.4 billion years ago: oxygen made by photosynthesising bacteria builds up in the atmosphere. Chemistry like Miller-Urey stops working in the open air.

A molecular clock, worked out from differences in genes shared by all life and calibrated with dated fossils, puts LUCA at roughly 4.2 billion years ago. Estimates vary a lot with the method.

Tubes and threads of iron minerals in rocks from Quebec that formed round hydrothermal vents on an ancient sea floor, between 3.77 and 4.28 billion years ago. If they are fossils of microbes, they are among the oldest evidence of life. Their origin is still debated.

About 540 million years ago: animals with hard parts appear in the fossil record. Life had been single cells for most of its history.

About 3.48 billion years ago: stromatolites, layered mounds built by mats of microbes, in rocks from Western Australia. Widely accepted as evidence of life.

WATCH OUT

LUCA was not the first living thing, and not the only life of its time. It is the last ancestor that everything alive today shares.

PREDICT

Which finding would most strongly challenge the idea of a single LUCA?

(A) A bacterium that lives at 110 °C in a vent on the sea floor, far hotter than any animal could stand

(B) A living organism whose codons code for completely different amino acids from all other life

(C) A fossil stromatolite even older than those found so far, from rocks dated at 3.7 billion years

Decide before you look. Answer on page 17.

Key terms

Every term this guide defines, A to Z, with the chapter it is in. Cover the right-hand side and test yourself.

last universal common ancestor 06
The last universal common ancestor: the most recent population of organisms from which all living things today are descended.

micelles 04
A small sphere of amphipathic molecules in water, hydrophobic tails inside and hydrophilic heads facing the water.

ribozymes 05
A molecule of RNA that acts as an enzyme, catalysing a chemical reaction.

vesicle 04
A small closed sac bounded by a bilayer, with water inside and out.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on A2.1 each time, marked as you go, and saved to your Exam practice progress when you are signed in. Scan the code, or type the link.

biologybybradford.com/exam-maker/sit?topics=A2.1&level=HL&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 Which feature of a virus is the strongest reason for calling it non-living?

B **It has no metabolism of its own and can only be copied by the machinery of a host cell**

Size is not the test, and many cells use RNA too. What a virus lacks is the self-sustaining part: no respiration, no protein synthesis, no growth, nothing at all until it is inside a cell.

02 Why could amino acids build up in the early sea but not in today's?

B **There was no oxygen to break them down and no living things to consume them as food**

Today oxygen reacts with and breaks down organic molecules, and any that form would soon be eaten by microbes. Early Earth had neither, so compounds made by lightning or UV could accumulate. The sea was warmer, not colder, and there was no ozone layer.

03 The experiment is repeated with nitrogen, carbon dioxide and water instead of methane, ammonia and hydrogen. What would you predict?

B **Far fewer amino acids, because those gases are less ready to react when given the spark's energy**

Repeats with a more neutral mixture give much lower yields. Methane, ammonia and hydrogen make a reducing mixture that readily forms organic compounds; with oxygen present, even more is broken down again. Try it in the film with Today's air.

04 Why would a flat sheet of bilayer close up into a sphere?

B **Closing up removes the edges, where hydrophobic tails would otherwise be in contact with water**

At an edge the tails meet water. A closed sphere has no edge, so every tail is hidden between the two layers. Nothing needs to pull it shut.

05 Why is the ribosome taken as evidence for the RNA world?

B **Its catalytic site is RNA, so one of life's most ancient reactions is still catalysed by RNA**

The ribosome is made of RNA and proteins, and the part that joins amino acids is RNA. Every cell on Earth makes proteins this way, so it looks like a leftover from a time when RNA did the catalysis. Copying DNA into RNA is transcription, done by RNA polymerase, not the ribosome.

06 Which finding would most strongly challenge the idea of a single LUCA?

B **A living organism whose codons code for completely different amino acids from all other life**

The universal genetic code is the key evidence for one common ancestor. An organism with an unrelated code would suggest a separate origin. A hot vent bacterium fits the vent idea, and an older fossil only moves the dates.

How this was made. The course structure, the activities and the teaching choices come from my own classroom, my presentations and my years of teaching IB and AP Biology. I use Claude, an AI, to help write and build the interactive guides, lesson plans, slides and practice questions, and to draw the diagrams and code the interactives. I direct the work and review it against the IB and AP specifications before it goes live.

Written and drawn for Biology by Bradford, biologybybradford.com. Free to print and share with a class.