AP BIOLOGY · UNIT 7 · TOPIC 7.12

# Origins of Life on Earth

*Learning objective 7.12.A Describe the scientific evidence that supports models of the origin of life on Earth.*

Name: Date: Period:

Use the tool **Four Billion Years, One Window**. Parts 1 and 2 use **The window**, Part 3 uses **Four steps**, and Parts 4 and 5 use **Why RNA**. This topic is about **the evidence**, not the story, and the two are different things. Some of what follows is as firm as anything in biology, and some of it is a set of partially supported hypotheses that scientists still debate. The point of this handout is to tell which is which, so for each claim, ask how anyone could know it.

## Part 1 · What the rocks bracket

The tool lists five dates from the history of Earth, and only one of them comes from a fossil. On The window, click each date and record its age, its kind of evidence and what the evidence is. The tool also marks the **window**: the interval between the time the surface of Earth became survivable and the earliest evidence of life. Everything in this topic happened inside the window.

| Event | Billion years ago | Geological or fossil? | What the evidence is |
|---|---|---|---|
| Earth forms | | | |
| Oldest surviving minerals | | | |
| Oldest surviving rocks | | | |
| Conditions become survivable | | | |
| Earliest widely accepted evidence of life | | | |

**1. (a) Using the Part 1 table, identify the time interval in which life on Earth most likely began.**

**(b) Describe how geological evidence and fossil evidence set the start and the end of this interval.**

**2. The dates in the Part 1 table come from radiometric dating of rocks and minerals. They indicate when life began but not how it began. Explain why the dates are more firmly supported than any model of how life began.**

## Part 2 · Five clocks, one rock

A single date from a single measurement would not be very convincing. Scroll down to the panel headed “Five clocks, one rock,” and copy what each decay system shows for the same **4.55-billion-year-old** sample. Compare the fourth column (parent isotope left) with the fifth (age it gives): the parent isotope left differs greatly between the five systems, and the age does not. Then open “The clock that cannot be used, and why that matters,” below the table.

| Decay system | Half-life (billions of years) | Half-lives elapsed | Parent isotope left | Age it gives |
|---|---|---|---|---|
| Uranium-238 → Lead-206 | | | | |
| Uranium-235 → Lead-207 | | | | |
| Potassium-40 → Argon-40 | | | | |
| Thorium-232 → Lead-208 | | | | |
| Rubidium-87 → Strontium-87 | | | | |

**3. Five decay systems with very different half-lives give the same age for the sample. Explain why this agreement is stronger evidence for the age than any single measurement.**

**4. A student claims that radiometric dating cannot be trusted for the age of Earth because carbon-14 dating works only for samples up to about 50,000 years old. Explain why the student's claim is incorrect.**

**5. (a) Describe the fossil evidence for the earliest life on Earth.**

**(b) Identify the approximate age of this evidence.**

## Part 3 · Four steps, and how well each is supported

Go to **Four steps**. Every model of the origin of life has to get from simple chemistry to something that reproduces and inherits, and the route is usually drawn as four steps. They are **not** equally well supported. Click Step 1 to Step 4 in turn, and record what each step produces, the strength of the evidence and what is still open. Note which step is marked weakest. For question 6, read “The two experiments worth knowing by name” lower on the same tab; it also describes protobionts.

| Step | What it produces | Strength of evidence | What is still open |
|---|---|---|---|
| 1. Small organic molecules form from inorganic precursors | | | |
| 2. Small molecules join into polymers | | | |
| 3. Polymers become enclosed in membranes | | | |
| 4. A molecule appears that can both store information and be copied | | | |

**6. (a) Describe the Miller–Urey experiment.**

**(b) Describe what the Miller–Urey experiment demonstrated.**

**7. (a) Describe what protobionts are.**

**(b) Explain how protobionts provide evidence for one of the four steps in the Part 3 table.**

**8. (a) Identify the step in the Part 3 table that is supported by the weakest evidence.**

**(b) Explain why this step is also the most important step in the origin of life.**

## Part 4 · Three requirements, three candidates

Go to **Why RNA**. Whatever the first genetic material was, it had to do three things. The tool scores the three molecules against the three requirements. Click each molecule and record yes or no for each requirement, and the total. Only one molecule meets all three, and that is the main argument for the RNA world: it rests on chemistry, not on preference. For question 10, read “The problem RNA solves” below the grid; it also answers question 11.

| | Stores information in a sequence | Can be copied from a template | Can catalyze chemical reactions | Total |
|---|---|---|---|---|
| DNA | | | | |
| Protein | | | | |
| RNA | | | | |

**9. (a) Describe the RNA world hypothesis.**

**(b) Using the Part 4 table, identify the property of RNA that DNA does not have.**

**10. In living cells, DNA cannot be copied without proteins, and proteins cannot be made without the information in DNA.**
**(a) Explain why this dependence makes it unlikely that either DNA or protein was the first genetic molecule.**

**(b) Explain how RNA resolves this problem.**

**11. Describe one piece of evidence from living organisms, not from rocks, that supports the RNA world hypothesis.**

## Part 5 · The objection, and the arithmetic

The most common objection to the origin of life by natural processes is a probability calculation, and it deserves a careful answer. Scroll down to the panel headed “The objection, and the arithmetic behind it,” and copy its table. Read the third column carefully: the first calculation is **correct**, so the reply to the objection has to be about something other than the arithmetic. For question 13, open “And the limit of that answer, which is real” below the table.

| The calculation | Result | Is the arithmetic correct? |
|---|---|---|
| A specific 100-residue protein in one random draw | | |
| Random trials available in the whole window | | |
| The same target reached by cumulative selection | | |

**12. A student argues that life cannot have arisen by chance because the probability of a specific protein forming in one random draw is extremely small.**
**(a) Using the Part 5 table, describe what is correct about the student's argument.**

**(b) Explain what is incorrect about the student's argument.**

**13. Cumulative selection answers the student's argument in question 12.**
**(a) Identify what cumulative selection requires that it cannot itself explain.**

**(b) Explain how your answer to part (a) relates to the step marked weakest in the Part 3 table.**

## What the model simplifies

The dates are rounded to the nearest hundred million years, which is roughly the precision at which they are usefully quoted rather than the precision of any individual measurement. The age of the Earth is known considerably more precisely than the date at which the surface became survivable, and the date of the earliest fossil life is the least secure of the three.

The five decay systems are used to make one point (that independent clocks with very different rates agree), and the arithmetic assumes a closed system with no initial daughter isotope. Real dating corrects for both, and the correction is most of what the technique consists of. The isochron method, which handles initial daughter isotope without assuming it away, is beyond this course but is the reason the assumption is not a weakness.

The four steps are presented as a sequence because that is how the models present them. There is no requirement that they happened in that order, and some proposals reverse steps 2 and 3: compartments first, chemistry inside them afterwards. The ordering is a convenience for teaching rather than a finding.

The Miller–Urey experiment is described as it was performed. The gas mixture it used is no longer thought to be a good match for the early atmosphere, and later repeats with more realistic mixtures produce smaller yields. This does not undo the result, because organic monomers are also found in meteorites, which settles the point independently of any assumption about Earth's atmosphere.

Scoring DNA as unable to catalyze is a simplification. Catalytic DNA molecules have been made in the laboratory; none is known to occur in nature, and DNA's catalytic range is far narrower than RNA's. The scoring reflects the biological situation, not an absolute chemical impossibility.

The cumulative-selection simulation uses a fixed target sequence, which is a real weakness in it: evolution has no target. It is used only for one comparison (how many trials a step-by-step process needs against how many a single draw needs), and that comparison does not depend on the target being fixed. If anything a fixed target makes the problem harder than the real one, in which very many different sequences would do.

The 2025 course framework asks students to describe the scientific evidence that supports models of the origin of life. This handout therefore marks how strong the evidence for each step is, and states what is unresolved, rather than presenting the four steps as a single settled account. That is a deliberate choice about how to teach the topic, and it is worth being explicit with students that it is one.