SN EDUCATOR GUIDE

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How Earth Got its Moon

Cross-Curricular Discussion

After students have had a chance to review the article "How Earth got its moon," lead a classroom discussion based on the questions that follow. You can copy and paste only the questions that apply to your classroom into a different document for your students.

Here is other relevant *Science News* journalism that your students can explore:

Science News articles:

- Two-stage process formed moon, simulations suggest
- Fast-spinning young Earth pulled the moon into a yo-yo orbit
- Moon's origins revealed in rocks' chemistry
- Moon material on Earth

Science News for Students articles:

- Student programs computer to predict path of space trash (6.4 readability score)
- Comet probe may shed light on Earth's past (7.5 readability score)

EARTH AND SPACE SCIENCES

Discussion Questions:

1. **List as many possible hypotheses as you can think of for how the moon formed and how it ended up in its current orbit around Earth. Discuss the evidence that would support or refute each hypothesis.**

   [*Students may have other ideas, or variations or combinations of the ideas listed below.*]
   a. ***The moon formed far away from Earth and was later captured by Earth's gravity.*** *The moon's composition is similar to that of Earth, so the moon would have coalesced from material extremely similar to that from which Earth coalesced. On the other hand, some scientists think that Theia and/or asteroids that hit Earth could have mostly been formed from the same type of material. It is also very challenging to imagine that the incoming moon would not pass by Earth without being captured, and not collide with Earth, or that it would end up where it is today.*

   b. ***The moon and Earth coalesced from the same localized clump of debris orbiting the recently formed sun, with the moon and Earth orbiting together.*** *This would account for the nearly identical composition,* *but how would a debris clump have so much angular momentum that it would divide into two objects and not form one?*

c. ***While a clump of debris orbiting the sun was still combining to form Earth, it was disrupted by something else (like a passing planet), causing the debris to combine into two bodies (Earth and the moon) instead of just one.*** *This idea might account for the very similar compositions, the coalescence into two bodies and not one, and the lack of evidence for a collision. On the other hand, it does presume that a planet happened along at exactly the right time and on exactly the right trajectory to perturb the still-coalescing proto-Earth.*

d. ***Earth formed and was spinning so fast that it flung off part of itself to form the moon.*** *As will be calculated in the activity later, Earth would have to have been spinning far faster than it is now, and in fact so fast that it would have torn itself apart or never would have coalesced in the first place.*

e. ***Earth formed and then was hit by a large object (the protoplanet Theia); the collision produced the current Earth and moon.*** *As noted in the article, to make Earth and the moon so similar to each other in composition, Theia would have to have been extremely similar to Earth. Alternatively, the Theia-Earth collision would have to have mixed the contents of those two initial bodies so well that the resulting moon and Earth ended up with nearly identical ratios of the same materials, instead of having one that was more like Theia and one that was more like proto-Earth.*

f. ***Earth formed and then was hit by a succession of impactors that gradually skimmed off enough material that combined to form the moon.*** *As noted in the article, this could account for the extreme similarity of Earth and the moon. On the other hand, if Earth got hit that many times, why didn't Mercury, Venus and Mars? And why did all of Earth's mini moons combine into just one moon?*

Extension Prompts:

2. **How did Earth form?** [*Scientists believe that Earth formed at the beginning of the Hadean Eon, beginning about 4.5 billion years ago. Collisions occurred between cosmic objects — such as asteroids and larger planetesimals — within a spinning cloud of dust and gases called an accretion disk. At the center of this spinning disk was the previously formed sun. Other pieces in the mix continued to collide, forming early molten planets including Earth. As the molten material cooled, the iron in the mix sank to the center of the mass and formed a core, while lighter elements floated to the surface. The oldest known zircon crystals on Earth date back about 4.4 billion years.*]

3. **What are the three main types of rocks on Earth and how are they formed?** [*Rocks are formed during what's known as the rock cycle. Specifically, there are three types of rocks that are formed by different processes. Igneous rocks form from cooled lava or magma. Depending on whether the molten material cools inside the Earth or above the surface, the rock will have different characteristics. Sedimentary rocks are formed from particles of shell, sand and other sediments that get compressed in layers over time. Fossils are commonly found in sedimentary rock. Metamorphic rocks form inside the Earth when igneous, sedimentary or other metamorphic rocks undergo physical and chemical changes due to pressure and exposure to*

extreme heat. Metamorphic rocks frequently have ribbon-like layers and may have crystals growing as part of their composition. Through processes such as weathering and erosion, the rock cycle explains how rock masses are moved around, and eventually melt back into magma when edges of the Earth's plates move and sink into the mantle.]

4. **How do plate tectonics on Earth differ from geologic activity on the moon?** [*Pieces of the Earth's crust and upper mantle, together called the lithosphere, move over time. The movement of these plates, known as tectonic plates, slowly changes the surface of the planet. As convection currents occur in the molten material of the mantle, causing hot rocks to rise and cooler rocks to sink, the tectonic plates move. Larger terrestrial planets, including Earth, Venus and Mars, have active inner molten layers, so their surfaces continue to deform (though not all have plate tectonics). Mercury and our moon, however, are smaller and have cooled enough to be considered tectonically inactive. It is believed that the moon has been tectonically inactive for the last 3 billion years.*]

5. **How do geologic layers help create a timeline?** [*A basic law of geology called the Law of Superposition, or geochronology, says that in undisturbed layers of rock, the oldest layer or strata will be laid down first. Since the rock that forms on Earth's surface is mostly sedimentary, the rocks are in layers that were laid down at different times. These layers can give clues about geologic events, like volcanic eruptions, faults and folds; show the results of climatic changes, such as floods and freezes; and give us fossils that reveal clues to biological events. Since the placement of the layer relatively dates its formation (with older rocks buried deeper), these layers can serve as a timeline of the geologic history of the planet.*]

Earth and Space Sciences Question Bank

List as many possible hypotheses as you can think of for how the moon formed and how it ended up in its current orbit around Earth. Discuss the evidence that would support or refute each hypothesis.

How did Earth form?

What are the three main types of rocks on Earth and how are they formed?

How do plate tectonics on Earth differ from geologic activity on the moon?

How do geologic layers help create a timeline?

PHYSICAL AND CHEMICAL SCIENCES

Discussion Questions:

1. **What are isotopes? What is meant by the term isotopic abundance? What does it mean when isotopes are called stable or unstable?** [*Isotopes are atoms of the same element that have the same number of protons but differing numbers of neutrons. Therefore, isotopes are atoms of the same element with a different atomic mass. Most elements in nature contain mixtures of different isotopes in relatively set percentages. The set percentage of an isotope with a specific atomic mass is called the isotopic abundance. Unstable isotopes undergo nuclear decay over time and emit radiation, while stable isotopes do not.*]

2. **What are the stable isotopes of oxygen? Name them and give their approximate abundances in Earth's atmosphere as a percent.** [*By definition, oxygen atoms contain 8 protons (and 8 electrons if they are not ionized or combined with other atoms). Different isotopes have different numbers of neutrons. The stable isotopes of oxygen (those that do not radioactively decay) are: Oxygen-16 (^{16}O, 8 protons + 8 neutrons = 16 amu), which makes up approximately 99.76% of oxygen in Earth's atmosphere. Oxygen-17 (^{17}O, 8 protons + 9 neutrons = 17 amu) makes up approximately 0.04% of oxygen in Earth's atmosphere. Oxygen-18 (^{18}O, 8 protons + 10 neutrons = 18 amu) makes up approximately 0.20% of oxygen in Earth's atmosphere.*]

3. **Why aren't radioactive oxygen isotopes relevant for comparing rock samples from different celestial bodies?** [*Oxygen isotopes other than ^{16}O, ^{17}O and ^{18}O are unstable with half-lives of minutes, seconds or even less, so they would not be found in ancient rock samples as they would have already undergone nuclear decay to become another element.*]

Extension Prompts:

4. **Why would rocks that have been through different processes, or formed on different celestial bodies, have different oxygen ratios?** [*Because of the extra neutrons, ^{17}O and ^{18}O are more massive than ^{16}O. That makes them, or molecules containing them, move at a slower relative average velocity and less likely to diffuse, evaporate or boil away when they are heated. Oxygen isotope ratios in a sample vary depending on what physical processes the sample has been through. Note that the article also mentions using the same general principle with isotopes of other elements such as zinc. Though isotopes of an element tend to have similar chemical properties (the same number of electrons, for instance), they have different physical properties.*]

PHYSICAL AND CHEMICAL SCIENCES QUESTION BANK

What are isotopes? What is meant by the term isotopic abundance? What does it mean when isotopes are called stable or unstable?

What are the stable isotopes of oxygen? Name them and give their approximate abundances in Earth's atmosphere as a percent.

Why aren't radioactive oxygen isotopes relevant for comparing rock samples from different celestial bodies?

Why would rocks that have been through different processes, or formed on different celestial bodies, have different oxygen ratios?

BIOLOGICAL SCIENCES AND ENGINEERING

Discussion Questions:

1. **What would be some biomedical applications of unstable oxygen isotopes?** [*Unstable isotopes would react chemically just like regular oxygen, but would be radioactive and emit detectable radiation. The longest-lived radioactive oxygen isotope is oxygen-15 (^{15}O, 8 protons + 7 neutrons = 15 amu), which has a*

half-life of 122 seconds and emits positrons (antimatter electrons). The positrons make ^{15}O very useful for positron emission tomography (PET), which uses positrons to produce three-dimensional images showing the activity of tissues and organs. Oxygen-15 could also be used to label and track various oxygen-containing biomolecules and their reactions, but due to its very short half-life, you would have to do an experiment quickly!]

2. **How can computer simulations reveal surprises in science?** [*Computer simulations reproduce the behavior of a system using programmed algorithms. Scientists can use computer simulations to test new drugs that are not ready for animal testing, for example, and gain insight on their effectiveness. Modeling systems with a computer allows scientists to watch how a process plays out based on different starting conditions, which can provide new and surprising information that wasn't in the original algorithms.*]

Extension Prompts:

3. **Generally, what technology is used to measure isotopes and their relative abundances in a sample?** [*Mass spectrometers are used to measure isotopic composition. These machines separate different isotopes based on their mass-to-charge ratio, typically by accelerating ions through an electric or magnetic field.*]

4. **Other than answering questions of planetary formation, what are other applications of measuring ratios of certain isotopes?** [*Answers will vary here due to the vast number of applications. Answers may include applications in the following fields: archaeology, forensic science, other geologic applications, climatology, hydrology and ecology.*]

Biological Sciences and Engineering Question Bank

What would be some biomedical applications of unstable oxygen isotopes?

How can computer simulations reveal surprises in science?

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Other than answering questions of planetary formation, what are other applications of measuring ratios of certain isotopes?