ScienceNews
IN HIGH SCHOOLS | EDUCATOR GUIDE

Michael Studinger/NASA

November 25, 2017

Mosses Tell Story of Retreating Ice

SOCIETY FOR SCIENCE & THE PUBLIC

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EDUCATOR GUIDE

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About the Issue

***Science News* article(s):** "Mosses tell story of retreating ice"

Readability score: 11.2

***Science News for Students* article(s):** "Thawing mosses tell a climate change tale"

Readability score: 7.6

The article "Mosses tell story of retreating ice" describes how radioactive carbon-14 dating of newly exposed mosses in the Arctic shows that summers are the warmest they have been in at least the last 40,000 years. Students can focus on details reported in the article, follow connections to earlier articles about frozen mosses, carbon-14 dating and global warming, and pursue cross-curricular connections to other major science topics in physics, chemistry, biology, Earth science and engineering. In a related activity, students can explore exponential radioactive decay and half-life with a simulation using pennies, a chemical reaction using food coloring and bleach, and through students' own calculations.

The 2016 Shattered Earth's Heat Record Educator Guide is another great resource for teaching about environmental change. This guide links to several relevant *Science News* and *Science News for Students* articles and provides questions that explore other climate data. The included activity requires students to research and collect data to investigate a claim about a climate change topic.

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Article-based observation: Questions focus on how scientists measured the age of newly thawed mosses in the Arctic and the implications of the findings.

Quest through the archives: Use this short section to explore other articles about frozen mosses, radioactive carbon-14 dating and global warming as reported by *Science News* since 1924.

Cross-curricular discussion:

Physical and Chemical Sciences questions address the physics and chemistry of carbon-14 and radioactive dating techniques.

Biological and Earth Sciences questions discuss the effects of climate change on the environment and on different species.

Engineering and Experimental Design questions deal with various ways of measuring radioactive carbon to date an object.

Activity: Exploring half-life

Purpose: To understand the meaning and implications of radioactivity, exponential decay and half-life.

Procedural overview: Simulate the exponential radioactive decay and half-life of carbon-14 with pennies and a food coloring/bleach chemical reaction.

Approximate class time: 30–50 minutes.

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Standards

Next Generation Science	Common Core ELA
Matter and its Interactions: HS-PS1-1, HS-PS1-2, HS-PS-1-8	Reading Informational Text (RI): 1, 2, 4, 5, 7
Ecosystems: Interactions, Energy, and Dynamics: HS-LS2-1, HS-LS2-2, HS-LS2-4, HS-LS2-5, HS-LS2-6, HS-LS2-7	Writing (W): 1, 2, 3, 4, 6, 7, 8, 9
Biological Evolution: Unity and Diversity: HS-LS4-5, HS-LS4-6	Speaking and Listening (SL): 1, 2, 4, 5, 6
Earth's Systems: HS-ESS2-2, HS-ESS2-3, HS-ESS2-4, HS-ESS2-5, HS-ESS2-6, HS-ESS2-7	Reading for Literacy in Science and Technical Subjects (RST): 1, 2, 3, 4, 5, 7, 8, 9
Earth and Human Activity: HS-ESS3-1, HS-ESS3-2, HS-ESS3-4, HS-ESS3-5	Writing Literacy in History/Social Studies and Science and Technical Subjects (WHST): 1, 2, 4, 7, 8, 9
Engineering Design: HS-ETS1-1, HS-ETS1-2, HS-ETS1-3	

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Article-Based Observation: Q&A

Directions: Read the article "Mosses tell story of retreating ice" and then answer these questions.

1. In one sentence, what is the main idea of the article?

Possible student response: Analysis of frozen mosses in the Arctic shows that summers are now warmer than they have been in at least 40,000 years.

2. Where in the Arctic did paleoclimatologist Gifford Miller and his team find the mosses, and how were the mosses exposed?

Possible student response: Miller and his team studied mosses on Baffin Island in the northeastern Canadian Arctic. The mosses were found along the edges of diminishing ice sheets and were exposed as those ice sheets melted and retreated.

3. How were the mosses originally covered?

Possible student response: Earlier in geologic time, as conditions grew colder and ice sheets formed and advanced, live mosses were covered by the ice and remained frozen until now.

4. How many different samples were analyzed? How do you know this?

Possible student response: The article states that Miller's team has identified 370 mosses with distinct ages, so at least 370 plant samples must have been collected and analyzed.

5. What happens over time to a radioactive element? Define and give an example of a half-life mentioned in the article?

Possible student response: As unstable radioactive elements decay over time, they can give off radioactive particles, which transforms the element into a different one. The half-life of a radioactive element is the amount of time it takes for half of a radioactive sample to decay into another element. The half-life of carbon-14 is about 5,730 years.

6. How long does it take for radioactive carbon to completely "die" or decay? How is radioactive carbon generally used for radioactive dating?

Possible student response: Radioactive carbon almost completely decays in approximately 40,000 to 50,000 years. Because you know carbon-14's rate of decay, by measuring how much carbon-14 an object contains and comparing that with the amount of decay by-products, you can estimate the time since that object was formed.

7. What is a limitation of radiocarbon dating?

After approximately 40,000–50,000 years, virtually all of the radioactive carbon has decayed away, so radioactive carbon dating cannot be used to estimate ages older than that.

8. Based on radioactive carbon dating, when were groups of moss buried on the island?

Possible student response: Some of the moss was frozen around 570 years ago, some around 900 years ago, some around 3,700 years ago and some at least 40,000 years ago (those moss samples did not have enough radioactive carbon left to get an age estimate).

9. What additional evidence can be used to estimate the age of the mosses that lack measurable radioactive carbon?

Possible student response: An ice core collected in nearby Greenland suggests that the planet experienced continuous cold from 40,000 to about 115,000 years ago, when the last warm interglacial period ended. Thus, some mosses might be as old as 115,000 years if they were buried and frozen as ice advanced at the end of the last warm interglacial period.

10. Why do you think this study is important for the modern world?

Possible student response: Summers are now the warmest they have been in 40,000 years, and summertime Arctic ice has retreated the furthest it ever has since that time. The world is warming rapidly due to human production of greenhouse gases, and will continue to warm unless we take dramatic action. Without action, the climate will be much warmer than it has ever been during human civilization, making it challenging to provide enough food, water and housing for everyone on the planet.

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Article-Based Observation: Q

Directions: Read the article "Mosses tell story of retreating ice" and then answer these questions.

1. In one sentence, what is the main idea of the article?

2. Where in the Arctic did paleoclimatologist Gifford Miller and his team find the mosses, and how were the mosses exposed?

3. How were the mosses originally covered?

4. How many different samples were analyzed? How do you know this?

5. What happens over time to a radioactive element? Define and give an example of a half-life mentioned in the article?

6. How long does it take for radioactive carbon to completely "die" or decay? How is radioactive carbon generally used for radioactive dating?

7. What is a limitation of radiocarbon dating?

8. Based on radioactive carbon dating, when were groups of moss buried on the island?

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10. Why do you think this study is important for the modern world?

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Quest Through the Archives: Q&A

1. Can you find another recent article about global warming and vanishing sea ice but from a different year? How do the records for different years compare?

Possible student response: The article "For three years in a row, Earth breaks heat record," published 1/18/2017, recounts how 2016, 2015 and 2014 were the hottest years since record keeping began in 1880. As of the date of that article, the first 16 years of the 21st century were among the 17 hottest years on record, with the highest temperatures in the last three successive years. The article included a very informative graph of the changes in total global sea ice (millions of square kilometers) over a year, from 1978–2017. The total sea ice for 2016 and the beginning of 2017 was dramatically lower than in previous years.

2. Can you find other articles about "ancient" items that were dated with radioactive carbon (carbon-14)? Describe the items.

Possible student response: The article "Ancient Maya codex not fake, new analysis claims," published 10/29/2016, describes 10 surviving pages of a hand-drawn, bark-paper book that was apparently produced by the Maya in the 13th century, making it the earliest known surviving manuscript from ancient America. The article "Ancient text gives Judas heroic glow," published 4/29/2006, describes a 1,700-year-old Coptic Egyptian manuscript of the Gospel of Judas that was produced by a group of early Gnostic Christians. The article "Tailored Egyptian dress is the oldest ever found," published 4/2/2016, describes a woven and tailored dress that was recovered from an Egyptian cemetery, which carbon dating revealed to be between 5,100 and 5,400 years old. (Students might find articles with many other examples.)

3. Can you find an article about bringing frozen Arctic moss back to life? How are the scientific techniques in that article similar to or different from those described in the article from the November 25, 2017 issue?

Possible student response: The article "Mosses frozen in time come back to life," published 5/27/2013, discusses how scientists recovered moss samples that, until recently, had been buried under ice on a different Canadian island, Ellesmere Island. As with this week's article, the scientists used carbon-14 dating to determine the mosses' age, and found that the mosses lived approximately 400 years ago. Unlike in this week's article, however, the scientists tried to revive the old, "dead" mosses by giving them fresh nutrients, water and light. Four different moss types sprung to life.

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Quest Through the Archives: Q

Directions: After reading the article "Mosses tell story of retreating ice," log in to your *Science News* in High Schools account and use the Search page to answer these questions. Make sure you adjust the filters to include articles written before 1999, if the question requires you to do so.

1. Can you find another recent article about global warming and vanishing sea ice but from a different year? How do the records for different years compare?

2. Can you find other articles about "ancient" items that were dated with radioactive carbon (carbon-14)? Describe the items.

3. Can you find an article about bringing frozen Arctic moss back to life? How are the scientific techniques in that article similar to or different from those described in the article from the November 25, 2017 issue?

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Cross-Curricular Discussion: Q&A

Directions: After students have had a chance to review the article "Mosses tell story of retreating ice," lead a classroom discussion based on the questions that follow.

PHYSICAL AND CHEMICAL SCIENCES

Discussion questions:

1. What are isotopes, and what are the isotopes of carbon? What carbon isotopes are radioactive?

Isotopes are atoms of the same element with different masses — they have the same numbers of protons and same numbers of electrons, but different numbers of neutrons. Most of the naturally occurring carbon on Earth is carbon-12 or ^{12}C (its nucleus contains 6 protons and 6 neutrons). Approximately 1 percent is carbon-13 or ^{13}C (its nucleus contains 6 protons and 7 neutrons). Both of those carbon isotopes are stable — they do not radioactively decay to become another element. If certain other elements are exposed to radiation, they can temporarily form other carbon isotopes that are radioactive. Carbon-11 or ^{11}C (its nucleus contains 6 protons and 5 neutrons) decays with a half-life of approximately 20 minutes to become stable boron-11 or ^{11}B (its nucleus contains 5 protons and 6 neutrons). Carbon-14 or ^{14}C (its nucleus contains 6 protons and 8 neutrons) decays with a half-life of approximately 5,730 years to become nitrogen-14 or ^{14}N (its nucleus contains 7 protons and 7 neutrons).

2. What is beta decay? Write the decay equation for carbon-14.

Beta particles are electrons (which have negative electric charge) and positrons (the positively charged antimatter version of an electron). In beta-minus decay, a neutron turns into a positively charged proton plus an electron (along with a neutral particle called an anti-neutrino). In beta-plus decay, a proton turns into a neutron plus a positron (and a neutrino). Beta decay occurs when an atom trades a neutron for a proton or vice versa, in order to reach a more stable, lower-energy state.

The beta-minus decay equation for carbon-14 is: $^{14}C \rightarrow {}^{14}N + e^-$ *(and an anti-neutrino)*

3. How is carbon-14 formed in the atmosphere?

High-energy cosmic rays from the sun or other sources in space hit atoms in the upper atmosphere, knocking loose neutrons. Most of the atmosphere is made of ^{14}N (its nucleus contains 7 protons and 7 neutrons). If a neutron generated by a cosmic ray knocks a proton out of ^{14}N and takes its place, carbon-14 (its nucleus contains 6 protons and 8 neutrons) is formed:

$$^{14}N + n^0 \rightarrow {}^{14}C + p^+$$

Carbon in the atmosphere combines with oxygen to form carbon dioxide or CO_2. Roughly 1×10^{-12} of the carbon in atmospheric CO_2 is carbon-14.

4. How does carbon dating work?

Living organisms acquire carbon from atmospheric CO_2 either directly for plants or indirectly for other organisms (herbivorous animals eat plants that have acquired atmospheric carbon, and carnivorous animals eat herbivorous animals that have eaten plants that acquired atmospheric carbon). Approximately 1 atom out of every 10^{12} newly acquired carbon atoms is carbon-14. As long as an organism is living and exchanging carbon with the environment, the percentage of carbon-14 in an organism should remain approximately equal to that of the environment. Carbon-14, which has a half-life of approximately 5,730 years, decays at a rate of about 13.5 atoms/minute per gram of total carbon. After the organism has been dead for about 5,730 years, it should contain $1/2^1 = 1/2$ of that original amount of carbon-14. After the organism has been dead for 11,460 years (5,730 x 2), it should contain $1/2^2 = 1/4$ of the original amount of carbon-14. After the organism has been dead for 17,190 years (5,730 x 3), it should contain $1/2^3 = 1/8$ of the original amount of carbon-14. And so forth.

5. How is carbon-14 measured?

For younger and/or larger samples that contain more carbon-14, the carbon-14 content can generally be measured by a radiation counter to directly detect beta decay of carbon-14 into nitrogen-14. For older and/or smaller samples with very little carbon-14, a mass spectrometer can be used, distinguishing the charge and mass of different ions vaporized from the sample.

Extension prompts:

6. What are the limitations of carbon-14 dating?

After 45,840 years (5,730 x 8), only $1/2^8 = 1/256$ of the original amount of carbon-14 is left. Because the original amount of carbon-14 was very small to begin with, it is very difficult to carbon-date an object that is older than 40,000–50,000 years. Also, carbon dating is only useful for determining the age of something that was once alive and absorbing carbon. That is great for remains of humans, animals and plants, as well as human tools that were made from plants or animals. However, it is not useful for stone or metal tools, rocks and minerals, and other objects that were never alive.

7. What other radioactive decays are useful for dating objects?

Longer-lived isotopes can be used to date rocks and estimate the age of Earth, the moon, meteorites and other objects that are older than 50,000 years. One useful isotope is potassium-40, which has a half-life of approximately 1.25 billion years. Potassium-40 beta-decays to calcium-40. It can also decay through a process called electron capture into argon-40. Argon-40 is a gas that easily escapes from hot molten rock, but not cooled solid rock. So newly formed igneous rocks should have virtually no argon-40, and older igneous rocks can be dated by how much of their potassium-40 has decayed to trapped argon-40.

Another useful isotope is uranium-238, which undergoes a series of several decays to ultimately become lead-206. Uranium-238 has a half-life of approximately 4.47 billion years. And radioactive isotope uranium-235, also undergoes a series of several decays to ultimately become lead-207. Uranium-235 has a half-life of approximately 710 million years.

BIOLOGICAL AND EARTH SCIENCES

Discussion questions:

1. How do plants use photosynthesis to incorporate atmospheric carbon?

The chloroplasts in plant cells absorb energy from sunlight (using chlorophyll molecules), use that energy to break up water (H_2O) and atmospheric carbon dioxide (CO_2) and combine their components one step at a time to produce sugars (containing C, H and O) and oxygen (O_2). In further steps, plant cells use those sugars to form a wide variety of other biological molecules. Those sugars and the biological molecules made from them are thus built from atmospheric carbon.

2. What are the major greenhouse gases and why are they called greenhouse gases? How has the level of carbon dioxide changed in recent history?

Carbon dioxide, methane, water vapor, nitrous oxide and ozone are all greenhouse gases. They are called greenhouses gasses because they trap heat in Earth's atmosphere, similar to how a greenhouse traps heat. Short wavelengths of sunlight enter through the atmosphere and are absorbed by Earth's surface. Some of the sunlight is re-emitted by Earth as thermal radiation, or heat. Greenhouse gasses in the atmosphere then absorb some of that heat and reflect some back to Earth's surface, so Earth gets warmer. Atmospheric carbon dioxide has increased from approximately 300 to over 400 parts per million (ppm) over the last century.

3. How has the global average temperature and sea level changed in recent history?

Global average temperature has risen by about 1° Celsius, or about 1.8° Fahrenheit, over the last century. As a result, global ice melts and ocean temperatures warm (water expands as it becomes warmer), contributing to sea level rise. Sea levels have risen by about 20 centimeters over the last century.

Extension prompts:

4. How have human activities affected the climate? How does the speed of the environmental changes today contrast the speed of changes in the past?

Most changes in Earth's climate have occurred slowly over millions of years, allowing species to adapt. But greenhouse gas emissions from human activities have increased the rate of climate change over the last century. Millions of years ago, relatively quick, drastic changes in the environment resulted in mass extinctions. There have been five mass extinctions in Earth's history. During the last mass extinction event, 66 million years ago, about 75 percent of all species disappeared, including non-avian dinosaurs.

ENGINEERING AND EXPERIMENTAL DESIGN

Discussion questions:

1. What types of sensors could detect radiation from carbon-14, and how do they work?

A Geiger-Mueller tube is filled with a gas between high-voltage electrodes. If a beta particle from carbon-14 (or some other type of radiation) passes through the gas, it will ionize some of the atoms in the gas, conducting current between the electrodes and giving an electrical signal.

A scintillation material, such as zinc sulfide, emits light when a beta particle (or other type of radiation) passes through it. The radiation boosts electrons in the material to higher energy levels, and they give off photons when they drop back down to lower energy levels.

A junction diode, or semiconductor detector, senses electrical signals produced when beta particles (or other type of radiation) deposit enough energy to raise electrons in the semiconductor to higher energies.

2. What types of sensors could detect carbon-14 directly (without measuring its radiation), and how do they work?

A mass spectrometer can be used to directly detect carbon-14. Carbon-14, carbon-12 and other atoms from a sample can be vaporized, fully ionized (their charge will depend on the number of protons they contain) and accelerated to a known high energy state in a small particle accelerator that creates brief pulses. The pulsed beam of ionized atoms can be passed through a magnetic field of known strength. By the Lorentz force, the trajectories of ions with different charges and different masses will be bent by different amounts. If all the ions have the same amount of energy, but different masses, they will also have different speeds — smaller ions with less mass will have higher velocities and reach their destination more quickly, whereas larger ions with more mass will have lower velocities and reach their destination more slowly. If an array of sensors detects where and when the ions from the beam arrive on the other side of the magnetic field, the charge (number of protons) and mass (number of protons + neutrons) of each ion can be determined.

Extension prompts:

3. How might you design a portable carbon-14 dating device that could rapidly determine the age of a fragile, valuable object such as an ancient manuscript?

Student answers will vary, but students should consider nondestructive measurement of beta particles from carbon-14 (and estimating how much total carbon is in the object) versus destructive measurement of carbon-14 in a mass spectrometer (or how to minimize how much of a sample is needed for a mass spectrometer).

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Cross-Curricular Discussion: Q

Directions: The following list of discussion questions is provided to help you take notes, brainstorm ideas and test your thinking in order to be more actively engaged in class discussions related to this article. All questions in this section are related to topics covered in "Mosses tell story of retreating ice."

PHYSICAL AND CHEMICAL SCIENCES

Discussion questions:

1. What are isotopes, and what are the isotopes of carbon? What carbon isotopes are radioactive?

2. What is beta decay? Write the decay equation for carbon-14.

3. How is carbon-14 formed in the atmosphere?

4. How does carbon dating work?

5. How is carbon-14 measured?

Extension prompts:

6. What are the limitations of carbon-14 dating?

7. What other radioactive decays are useful for dating objects?

BIOLOGICAL AND EARTH SCIENCES

Discussion questions:

1. How do plants use photosynthesis to incorporate atmospheric carbon?

2. What are the major greenhouse gases and why are they called greenhouse gases? How has the level of carbon dioxide changed in recent history?

3. How has the global average temperature and sea level changed in recent history?

Extension prompts:

4. How have human activities affected the climate? How does the speed of the environmental changes today contrast the speed of changes in the past?

ENGINEERING AND EXPERIMENTAL DESIGN

Discussion questions:

1. What types of sensors could detect radiation from carbon-14, and how do they work?

2. What types of sensors could detect carbon-14 directly (without measuring its radiation), and how do they work?

Extension prompts:

3. How might you design a portable carbon-14 dating device that could rapidly determine the age of a fragile, valuable object such as an ancient manuscript?

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Activity Guide for Teachers: Exploring half-life

Purpose: To understand the meaning and implications of radioactivity, exponential decay and half-life.

Procedural overview: Simulate exponential radioactive decay and half-life with pennies and a food coloring/bleach chemical reaction to understand the exponential radioactive decay of carbon-14.

Approximate class time: 30–50 minutes.

Materials:

- Activity Guide for Students: Exploring half-life
- Pennies (16 per group; try to have the number of student groups be some power of 2, like 8 or 16)
- Cell phones with video recording capabilities and timers
- Gloves
- Goggles
- Test tubes (at least 8 per group)
- Test tube racks
- Blue food coloring
- Bleach
- Sink
- Disposable pipettes
- Scientific calculators

Notes to the teacher:

If you have a spectrophotometer available for your class to use, you can make the chemical reaction portion of this activity more precise by recording absorbance over time. If you don't have access to a spectrophotometer, encourage students to create control solutions so they can try to match the color of the test tube at a particular point during the reaction — just eyeballing it is good enough for students to get the idea.

This activity uses these basic concepts, so if necessary please review them in advance with your students:

- Scientific notation
- Exponentials and e
- Logarithms and ln

Questions for students, with suggested answers:

Before beginning the activity, create your own data table for the entire activity, dividing it up by parts. You will need to read through the entire procedure for this part to determine what observations you are trying to collect. If you are working in a pair, individually read through the procedure and decide all key information before collaborating with your partner on a data table.

Part 1: Heads or Tails, a Penny Model

1. Put 16 pennies heads-up on a table. You will help the pennies undergo "radioactive exponential decay" to tails-up, with a half-life of 1 minute. Write down how many pennies are heads-up.

16

2. Start a timer. At around 1 minute, flip each of the 16 pennies in the air and let them randomly land heads-up or tails-up. Write down how many pennies are heads-up.

Probably around 8, with some random variation

3. At around 2 minutes, take only the pennies that are still heads-up, flip each of them in the air and let them randomly land heads-up or tails-up. Write down how many pennies are heads-up.

Probably around 4, with some random variation

4. At around 3 minutes, take only the pennies that are still heads-up, flip each of them in the air and let them randomly land heads-up or tails-up. Write down how many pennies are heads-up.

Probably around 2, with some random variation

5. At around 4 minutes, take only the pennies that are still heads-up, flip each of them in the air and let them randomly land heads-up or tails-up. Write down how many pennies are heads-up.

Probably around 1, with some random variation

6. At around 5 minutes, take only the pennies that are still heads-up, flip each of them in the air and let them randomly land heads-up or tails-up. Write down how many pennies are heads-up.

Probably 1 or 0, with some random variation

7. Repeat until all pennies are tails-up.

Coin flips are random. A few groups might experience a run of heads-up until they get a final tails-up.

8. Graph the number of heads-up pennies versus time in minutes. How does the graph compare with what you would ideally expect?

With some random variation, the graph should illustrate exponential decay.
For more ideal results, combine the results of all the student groups together and graph that in class.
Discuss how averaging over larger groups helps to smooth out random variations.

9. Instead of exponential decay, you could demonstrate exponential growth with pennies. Let's say one student in the class is a robber, who initially has one penny from their own group. In every round, the robber will steal until he or she doubles the number of pennies by taking pennies as necessary. How many rounds would it take for the robber to steal all the pennies from their own group? How many rounds does it take for the robber to steal all of the pennies from the class?

With 16 (2^4) pennies per group, assuming the robber has already stolen one penny from their own group, it would take four rounds for the robber to accumulate the remaining 15 pennies from their *group, or 16 pennies total. If there are eight groups or 8 x 16 = 128 (2^7) pennies, it would take seven rounds to accumulate them all.*

Part 2: Blues Fade Away, a Chemical Model

1. A chemical reaction can also demonstrate exponential decay. The chemical reaction of blue food coloring and sodium hypochlorite (the main ingredient in bleach) is a first-order reaction. Ever wonder how bleach works? You'll see it for yourself during this reaction. Use the following procedure to get set up.

- Obtain five identical clean and dry test tubes.
- Label test tubes 1 through 5.
- Fill test tubes 1 through 4 about two-thirds of the way with water (make sure the volume of water is the same for every test tube). Ideally, measure the water in the first test tube with a graduated cylinder, and then use that measurement to pour water into the other four test tubes.
- Add two drops of blue food coloring to test tubes 1, 2 and 3.
- Use a clean pipette to add two drops of bleach to test tube 4. Test tube 4 is a control to show a tube with no blue food coloring.
- Let the tubes sit until each has a uniform color, or cover them tightly and gently swirl them until a uniform color is reached.
- Add two additional drops of water to test tubes 1 and 2 and gently swirl. Test tube 2 is a control to show a tube with the maximum concentration of blue food coloring (or the initial concentration of blue food coloring at time=0 seconds)
- Pour exactly half of the solution in test tube 1 into test tube 5. Add water to test tube 5 until the total volume of solution matches the total volume of solution in test tube 4. Test tube 5 is a control test tube to show the color of the solution after half of the original blue food coloring has reacted.
- Set test tube 1 aside. Take a cell phone photo or otherwise note the color difference between your control test tubes 5, 2 and 4. Test tube 3 will be your experimental test tube.

Test tube 4 should be clear or nearly clear, test tubes 2 and 3 should be dark blue and test tube 5 should be about half as dark as test tube 2, since test tube 5 has half the concentration of food coloring as test tube 2.

2. Start a timer and start video recording the tubes as soon as you add drops of bleach to test tube 3. Add a few drops of bleach to test tube 3, and record how many drops you added.

Student answers will vary.

3. Record how long it takes for test tube 3 to become the color of test tube 5. This is the time that it takes for half of the original concentration of blue food coloring to react, analogous to the half-life of a radioactive elemental sample.

The half-life could be from a few seconds up to a minute or two, depending on how many drops of bleach the students added.

13. Keep video recording. At twice the time of the half-life, what do you notice about the color of test tube 3?

It should appear to have roughly one-fourth of its original blue color.

14. Keep video recording. How long does it take for test tube 3 to become essentially the same color as test tube 4? How many half-lives is this?

Probably several times the half-life.

15. Remove test tube 3 and repeat the experiment at least two more times with a new, clean tube each time. Increase or decrease the number of drops of bleach for each trial. Record your results as before.

Student results will vary.

16. Graph your results for the half-life versus the number of drops of bleach you have added. What is the trend in your results?

The more drops of bleach, the shorter the half-life.

Part 3: Decaying Radioactively, Date the Carbon-14

1. You can use equations to calculate exponential decays. If t is the time since exponential decay began, $t_{1/2}$ is the half-life, k is the exponential rate constant, N_o is the initial number of carbon-14 atoms (or concentration), and N_t is the number of carbon-14 atoms remaining at time t (or concentration), the exponential decay may be written as:

$$\ln(N_t) = -kt + \ln(N_o)$$

$$t_{1/2} = \ln(2)/k$$

The half-life of carbon-14 is 5,730 years. What is the exponential rate constant for the decay of carbon-14? Don't forget to include units.

$k = \ln(2)/5730 \text{ years} = 1.21 \times 10^{-4} \text{ years}^{-1}$

2. At time t = 0, 1.00 x 10^{-12} percent by mass of the carbon in a newly deceased organism (plant or animal) is carbon-14. How much of the total carbon is carbon-14 after 1,000 years?

$\ln(N_{1000\text{ years}}) = -1.21 \times 10^{-4} \text{ years}^{-1} (1000 \text{ years}) + \ln(1.00\text{x}10^{-12}) = 8.86\text{x}10^{-13}$

3. How much of the carbon is carbon-14 after 10,000 years?

$\ln(N_{10000\text{ years}}) = -1.21 \times 10^{-4} \text{ years}^{-1} (10000 \text{ years}) + \ln(1.00\text{x}10^{-12}) = 2.98\text{x}10^{-13}$

4. How much of the carbon is carbon-14 after 100,000 years?

$\ln(N_{100000\text{ years}}) = -1.21 \times 10^{-4} \text{ years}^{-1} (100000 \text{ years}) + \ln(1.00\text{x}10^{-12}) = 5.58\text{x}10^{-18}$

5. Congratulations! You have just found a priceless ancient human artifact carved from mammoth bone. Analysis shows that 2.30x10^{-14} of its carbon is carbon-14. How old is the artifact?

$\ln(2.30\text{x}10^{-14}) = -1.21 \times 10^{-4} \text{ years}^{-1} (t) + \ln(1.00\text{x}10^{-12})$
t = 31,200 years old

6. Indiana Jones has just discovered King Tut's underwear, which is made of natural materials. Analysis shows that 6.67×10^{-13} percent by mass of its carbon is carbon-14. How old is the underwear?

$ln\ (6.67x10^{-13}) = -\ 1.21\ x\ 10^{-4}\ years^{-1}\ (t) + ln\ (1.00x10^{-12})$
t = 3,350 years old

7. What have you learned about exponential decay?

Student answers will vary.

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EDUCATOR GUIDE

November 25, 2017

Mosses Tell Story of Retreating Ice

Activity Guide for Students: Exploring half-life

Purpose: To understand the meaning and implications of radioactivity, exponential decay and half-life.

Procedural overview: Students can use simulate exponential radioactive decay and half-life with pennies and also with a food coloring/bleach chemical reaction. They can also calculate exponential decay and exponential growth processes.

Before beginning the activity, create your own data table for the entire activity, dividing it up by parts. You will need to read through the entire procedure for this part to determine what observations you are trying to collect. If you are working in a pair, individually read through the procedure and decide all key information before collaborating with your partner on a data table.

Part 1: Heads or Tails, a Penny Model

1. Put 16 pennies heads-up on a table. You will help the pennies undergo “radioactive exponential decay” to tails-up, with a half-life of 1 minute. Write down how many pennies are heads-up.

2. Start a timer. At around 1 minute, flip each of the 16 pennies in the air and let them randomly land heads-up or tails-up. Write down how many pennies are heads-up.

3. At around 2 minutes, take only the pennies that are still heads-up, flip each of them in the air and let them randomly land heads-up or tails-up. Write down how many pennies are heads-up.

4. At around 3 minutes, take only the pennies that are still heads-up, flip each of them in the air and let them randomly land heads-up or tails-up. Write down how many pennies are heads-up.

5. At around 4 minutes, take only the pennies that are still heads-up, flip each of them in the air and let them randomly land heads-up or tails-up. Write down how many pennies are heads-up.

6. At around 5 minutes, take only the pennies that are still heads-up, flip each of them in the air and let them randomly land heads-up or tails-up. Write down how many pennies are heads-up.

7. Repeat until all pennies are tails-up.

8. Graph the number of heads-up pennies versus time in minutes. How does the graph compare with what you would ideally expect?

9. Instead of exponential decay, you could demonstrate exponential growth with pennies. Let's say one student in the class is a robber, who initially has one penny from their own group. In every round, the robber will steal until he or she doubles the number of pennies by taking pennies as necessary. How many rounds would it take for the robber to steal all the pennies from their own group? How many rounds does it take for the robber to steal all of the pennies from the class?

Part 2: Blues Fade Away, A Chemical Model

1. A chemical reaction can also demonstrate exponential decay. The chemical reaction of blue food coloring and sodium hypochlorite (the main ingredient in bleach) is a first-order reaction. Ever wonder how bleach works? You'll see it for yourself during this reaction. Use the following procedure to get set up.

- Obtain five identical clean and dry test tubes.
- Label test tubes 1 through 5.
- Fill test tubes 1 through 4 about two-thirds of the way with water (make sure the volume of water is the same for every test tube). Ideally, measure the water in the first test tube with a graduated cylinder, and then use that measurement to pour water into the other four test tubes.
- Add two drops of blue food coloring to test tubes 1, 2 and 3.
- Use a clean pipette to add two drops of bleach to test tube 4. Test tube 4 is a control to show a tube with no blue food coloring.
- Let the tubes sit until each has a uniform color, or cover them tightly and gently swirl them until a uniform color is reached.
- Add two additional drops of water to test tubes 1 and 2 and gently swirl. Test tube 2 is a control to show a tube with the maximum concentration of blue food coloring (or the initial concentration of blue food coloring at time=0 seconds)
- Pour exactly half of the solution in test tube 1 into test tube 5. Add water to test tube 5 until the total volume of solution matches the total volume of solution in test tube 4. Test tube 5 is a control test tube to show the color of the solution after half of the original blue food coloring has reacted.

- Set test tube 1 aside. Take a cell phone photo or otherwise note the color difference between your control test tubes 5, 2 and 4. Test tube 3 will be your experimental test tube.

2. Start a timer and start video recording the tubes as soon as you add drops of bleach to test tube 3. Add a few drops of bleach to test tube 3, and record how many drops you added.

3. Record how long it takes for test tube 3 to become the color of test tube 5. This is the time that it takes for half of the original concentration of blue food coloring to react, analogous to the half-life of a radioactive elemental sample.

4. Keep video recording. At twice the time of the half-life, what do you notice about the color of test tube 3?

5. Keep video recording. How long does it take for test tube 3 to become essentially the same color as test tube 4? How many half-lives is this?

6. Remove test tube 3 and repeat the experiment at least two more times with a new, clean tube each time. Increase or decrease the number of drops of bleach for each trial. Record your results as before.

7. Graph your results for the half-life versus the number of drops of bleach you have added. What is the trend in your results?

Part 3: Decaying Radioactively, Date the Carbon-14

1. You can use equations to calculate exponential decays. If t is the time since exponential decay began, $t_{1/2}$ is the half-life, k is the exponential rate constant, N_o is the initial number of carbon-14 atoms (or

concentration), and N_t is the number of carbon-14 atoms remaining at time t (or concentration), the exponential decay may be written as:

$$\ln (N_t) = -kt + \ln (N_o)$$

$$t_{1/2} = \ln(2)/k$$

The half-life of carbon-14 is 5,730 years. What is the exponential rate constant for the decay of carbon-14? Don't forget to include units.

2. At time t = 0, 1.00×10^{-12} percent by mass of the carbon in a newly deceased organism (plant or animal) is carbon-14. How much of the total carbon is carbon-14 after 1,000 years?

3. How much of the carbon is carbon-14 after 10,000 years?

4. How much of the carbon is carbon-14 after 100,000 years?

5. Congratulations! You have just found a priceless ancient human artifact carved from mammoth bone. Analysis shows that 2.30×10^{-14} of its carbon is carbon-14. How old is the artifact?

6. Indiana Jones has just discovered King Tut's underwear, which is made of natural materials. Analysis shows that 6.67×10^{-13} percent by mass of its carbon is carbon-14. How old is the underwear?

7. What have you learned about exponential decay?

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