# Determining Absolute Age

**Strand** Geology

**Topic** Investigating Absolute Dating and Half-life

**Primary SOL** ES.9 The student will investigate and understand that many aspects of the history and evolution of Earth and life can be inferred by studying rocks and fossils. Key concepts include

c) absolute and dating have different applications but can be used together to determine the age of rocks and structures.

**Related SOL** ES.1 The student will plan and conduct investigations in which

e) variables are manipulated with repeated trials;

f) current applications are used to reinforce Earth science concepts.

ES.2 The student will demonstrate an understanding of the nature of science and scientific reasoning and logic. Key concepts include

a) science explains and predicts the interactions and dynamics of complex Earth systems;

c) observation and logic are essential for reaching a conclusion.

**Background Information**

The most accurate method known for determining the absolute age of rocks and fossils is based on the radioactive decay of certain elements. During radioactive decay, radioactive elements gradually become new elements by giving off energy and particles. Each radioactive element has a fixed rate at which it decays. This rate is expressed as its *half-life*—the amount of time it takes for half of its radioactive atoms to decay. This is a constant rate unaffected by outside factors, such as temperature and pressure. Therefore, if a rock or fossil contains a radioactive element, the decay process can be used to determine the age of the item.

Radioactivity occurs because some isotopes of a particular element may be unstable, having nuclear forces that cause it to decay spontaneously to more stable isotopes of the same or some other element. This process can be very complex. For example, through a 14-step chain reaction, uranium-238 (U-238) decays to form the stable isotope lead-206 (Pb-206). The steps, or links, in this decay chain include eight different steps (though a few are different isotopes of the same element), each unstable until the last, Pb-206.

Carbon-14 (C-14) presents a special challenge. C-14 is produced in the upper atmosphere, the product of a reaction started when solar radiation strikes nitrogen. It is important to understand that C-14 is constantly entering our bodies through eating, drinking, and respiration, while it simultaneously decays back to stable nitrogen. The concentration of C-14 remains constant while an organism is alive. However, once death occurs, no new C-14 is introduced, but the C-14 already present continues to decay. Because nitrogen is a gas, it leaves the organic remains; thus, it is impossible to measure the parent/daughter isotope ratio directly. Fortunately, there is a very simple way to determine the concentration of C-14 remaining in a sample of organic matter. Radioactive decay releases decay products or particles. Measuring the varying amounts of these decay particles over a period of time provides an indirect measure of the amount of C-14 present in the material.

The concepts of radioactivity and half-life are easy to define and model; yet they remain a challenge for students to grasp fully at a deep conceptual level. In this activity, students will use pennies to learn how to determine the half-life of a sample and then the age of the sample. The activity intends to model the process of radioactive decay by illustrating the probabilistic nature of decay and the concept of half-life; however, the "tails is unstable" and "heads is stable" decay analogy may lead students to conclude that the process of decay occurs in a single step. Make sure they understand that tails represents the beginning of the chain reaction (U-238 or C-14) and heads represents the decay product (Pb-206 or nitrogen) at the end of the reaction. The concept of half-life is similarly easy to define, but it is harder for students to grasp conceptually without some familiarity with probability and statistics.

**Materials**

- Plastic shoeboxes with lids
- Pennies
- Data Tables handout (attached)
- Class data table
- Graph paper

**Vocabulary**

*absolute dating, relative dating, decay, half-life, isotope, radioactivity*

**Student/Teacher Actions (what students and teachers should be doing to facilitate learning)**

*Introduction*

1. Lead a discussion on the meaning of the term *decay*, writing students' ideas on chart paper or on the board.
2. Have students complete the Dating Methods Activity.

*Procedure*

3. Tell students they are going to model the radioactive decay of unstable atoms using a box of pennies. Emphasize that the lab model is limited because the only parts of the decay chain present in the model are the original parent isotope (tails up pennies) and final daughter isotope (heads up pennies).
4. To prepare students for the results they will observe, ask, "Would you expect to see all of the pennies in the box turn *tails up* if you shook the box? How likely is it that all the pennies would turn *heads up* after shaking the box?" (Students will have no trouble answering these questions because they intuitively know that both extreme results are not likely.) Ask, "If both extreme outcomes are highly unlikely, then what do you think is most likely?" (This question intentionally leads students to reply "fifty-fifty." They may not understand why, but it seems like the most reasonable answer, and it is. Still, many students react to the post-shake results, in which typically half the pennies are heads up and the other half tails up, as if they are seeing a magic trick. They still ask, "Why does it do

that?" Often students will not be satisfied with the answer because either all heads or all tails are equally unlikely, a balanced mix of both is most likely.)

5. Give each pair of students a shoebox containing 100 pennies and a copy of the attached Data Tables handout. Have each pair count the pennies in their box to make sure they have exactly 100.
6. Have pairs put the lids on their boxes and shake the boxes well once or twice. Then, have them open the boxes and remove and count all of the pennies that have flipped to *heads*. These pennies represent radioactive atoms that have decayed. Have them set these "decayed" pennies aside and record the number of decayed atoms in Data Table 1. Have them subtract the number of "decayed" pennies from 100 to find the number of pennies remaining in their boxes. Direct them to record this number as the "number of pennies before shaking" for the *next* shake.
7. Have pairs repeat step 5 over and over until there are no more pennies in the box—i.e., all the pennies have "decayed." They may not complete the entire table depending on how many shakes are required for all of the pennies to "decay."
8. Have pairs use the following formula to calculate the percent that decayed after each shake and then record their data in Data Table 1.

$$\text{percent decayed} = \frac{\text{number of pennies decayed after shaking}}{\text{number of pennies before shaking}} \times 100$$

9. Have pairs use the data from Data Table 1 to plot the number of pennies before shaking vs. the number of shakes, and graph the line.
10. Next, use all students' data to complete Data Table 2 and then calculate the class average for each shake.
11. Using class data from Data Table 2, have students plot the class average vs. the number of shakes, and graph the line.
12. Have students answer the following application questions:
    - Compare the graph of your data with the graph of the class data. How are your results similar or different?
    - Using the class average graph, what is the half-life (in shakes) for the pennies? (Hint: How many shakes does it take for 100 penny atoms to decay? How many shakes does it take for 50 to decay to 25?)
    - Is the half-life affected by how many atoms (pennies) you start with? Why, or why not?
    - Using your data, what is the maximum age you could measure using the shaking method if each shake equaled 1,000 years? Why?
    - Carbon-14 cannot be used to accurately date objects older than 50,000 years. Explain why this is true, using your knowledge of half-life.
    - If you dig up a frozen woolly mammoth that has 1/8 of its original carbon-14, how long ago did the mammoth live? (Carbon-14 has a half-life of 5,730 years.) Show your work.

## Assessment

- **Questions**
  - Imagine you found another frozen woolly mammoth carcass, and this specimen has undergone five half-lives. Is this animal older, younger, or the same age as the first mammoth you found? Explain your answer and show your work.

- **Other**
  - Prepare sample decay curves for various isotopes useful to geologists. Give students assessment questions that require interpretation of the decay curves and/or comparison of the decay curves in order to answer.

## Extensions and Connections (for all students)

- Have students apply their understanding of half-lives to other practical applications of the concept, including many environmental and/or natural resource issues. Topics could include the following:
  - The hazards of nuclear waste disposal (long half-lives).
  - The ways scientists used the tools and clothing of the mummified Bronze Age man (The Ice Man) to determine his relative age and used radiocarbon dating to determine his absolute age.
  - The ways hydrologists use C-14 dating to determine how many years groundwater has been traveling through aquifers before it exited in a well or at a spring. (Determining the age of groundwater is useful for municipal and regional water resources planning.)

## Strategies for Differentiation

- As a follow up activity, complete the relative age activity from the Geologic Society of America found on their Website. This activity shows how to date using relative dating methods.
- As a class, discuss the need for absolute and relative dating methods. On the board or sheet of paper write down the pros and cons of each as well as good examples of each.

# Dating Methods Activity

**Instructions:**
From the list of items below, choose one item that can be dated with absolute methods and one that can be dated using relative dating methods. For each item be sure to indicate the following: age, how you determined its age, if there are better methods to date, why you used absolute and relative dating for each item as a proof.

**Dating Bank:**

- 1862 Indian head penny
- A note written on a small piece of paper found in someone's wallet
- The first edition of JRR Tolkien's "The Hobbit"
- The apple from a lunch pail
- 14th century pottery found in an archaeological dig
- The granite table top from your grandmother's bedside table
- Piece of petrified wood that you bought at a national park
- A picture of president Eisenhower holding the daily paper
- An antler knife handle found in the woods of New York
- Carved inscription on the desk that says "I was here Jan. 22, 1984"

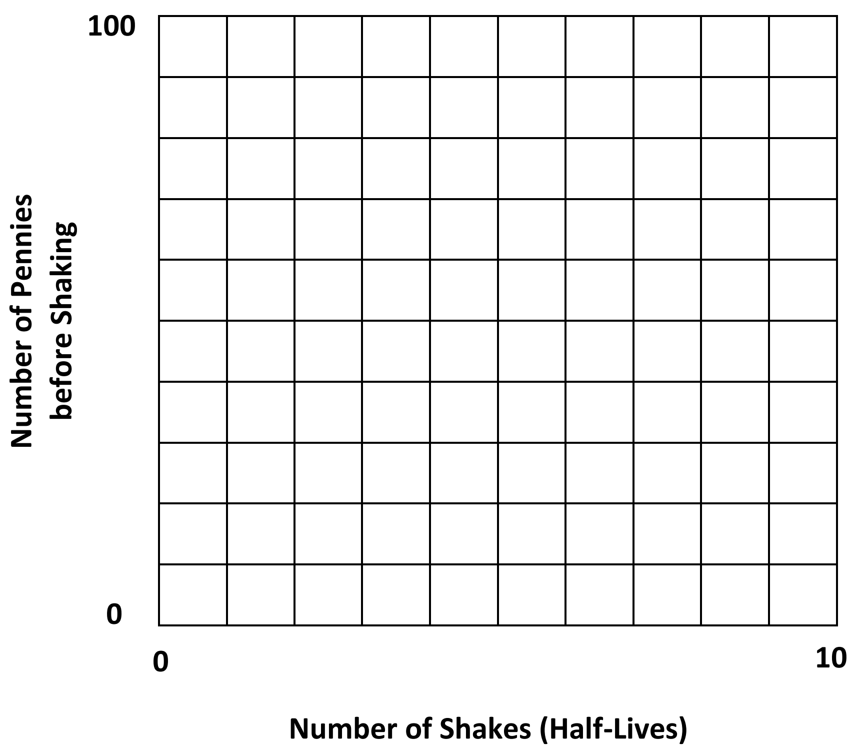
| Absolute item: | Relative Item: |
|---|---|
| | |

# Data Tables

**Data Table 1**

| Shake Number (Half-Life Number) | Number of Pennies before Shaking | Number of Pennies Decayed after Shaking | Percent (%) Decayed |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |

Using your data from Data Table 1, plot the number of pennies before shaking vs. the number of shakes, and graph.



**Data Table 2**

| Shake Number | Number of Pennies before Shaking | | | | | | | | | | | | Class Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Group Trials | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| 1 | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | |

Using class data from Data Table 2, plot the class average vs. the number of shakes, and graph the line.