Archaeo-Tech: Radiocarbon Dating

Cultural Resources Education

Created by Jacob Hamill, SCDNR Heritage Trust Program Public Information Coordinator (2019). Adapted from Half-Life Coins by Scientific American.

Grade Levels
High School Chemistry, Earth Science, and Physics

Estimated Time
Approximately 45 minutes for Part 1: Half-Life and Radioactive Decay. Approximately 45 minutes to 1 hour for Part 2: Radiocarbon Dating.

Goal
Students will learn how atoms with the same number of protons can vary in the number of neutrons they carry, which are called isotopes. Some isotopes are unstable and will kick out subatomic particles, giving off energy, to reach a stable form in a process called radioactive decay. Students will learn how scientists use the concept of half-life to measure an isotope's rate of decay. Students will then watch the short film, *Archaeo-Tech: Radiocarbon Dating*, and learn how archaeologists can use the half-life of carbon-14 to date archaeological remains.

Objectives
After completion of the activity and the viewing of the *Archaeo-Tech: Radiocarbon Dating* short film, students will be able to:

1. *Define* key terms, such as isotope, radioactive decay, half-life, and radiocarbon dating.
2. *Record* numerical data in a table and *model* that data as a graph.
3. *Discuss* the process of radioactive decay and *relate* this concept to the activity of flipping a penny.
4. *Explain* how and why unstable isotopes undergo radioactive decay.
5. *Recognize* trends or shapes in graphed data and *derive* information from the shape of the graph.
6. *Observe* the application of half-life and radioactive decay in the field of archaeology.
7. *Understand* how radiocarbon dating works, as well as its limitations.
8. *Using* the formula for exponential decay, *apply* algebra skills, as well as knowledge of half-life and radiocarbon dating, to *solve* different variables in an equation.
9. *Summarize* the limitations of radiocarbon dating, and *evaluate* radiocarbon dating as a scientific tool in the field of archaeology.

South Carolina Academic Standards

Science

H.C.1 The student will use the science and engineering practices, including the processes and skills of scientific inquiry, to develop understandings of science content.

H.C.2 The student will demonstrate an understanding of atomic structure and nuclear processes.

- **H.C.2B.2** Develop models to exemplify radioactive decay and use the models to explain the concept of half-life and its use in determining the age of materials (such as radiocarbon dating or the use of radioisotopes to date rocks).

H.E.1 The student will use the science and engineering practices, including the processes and skills of scientific inquiry, to develop understandings of science content.

H.E.4 The student will demonstrate an understanding of the dynamic relationship between Earth's conditions over geologic time and the diversity of organisms.

- **H.E.4A.5** Develop and use models of various dating methods (including index fossils, ordering of rock layers, and radiometric dating) to estimate geologic time.
- **H.E.4A.6** Use mathematical and computational thinking to calculate the age of Earth materials using isotope ratios (actual or simulated).
- **H.E.4A.7** Develop and use models to predict the effects of an environmental change (such as the changing life forms, tectonic change, or human activity) on global carbon cycling.

H.P.1 The student will use the science and engineering practices, including the processes and skills of scientific inquiry, to develop understandings of science content.

H.P.3 The student will demonstrate an understanding of how the interactions among objects can be explained and predicted using the concept of the conservation of energy.

- **H.P.3G.1** Develop and use models to represent the basic structure of an atom (including protons, neutrons, electrons, and the nucleus).
- **H.P.3G.4** Use mathematical and computational thinking to predict the products of radioactive decay (including alpha, beta, and gamma decay).
- **H.P.3G.5** Obtain information to communicate how radioactive decay processes have practical applications (such as food preservation, cancer treatments, fossil and rock dating, and as radioisotopic medical tracers).

Activity Type: In-Class / Optional Out-of-Class Component

This lesson is to be done as an in-class activity. The teacher will provide the required materials and necessary instructions. Students can access online resources for the optional out-of-class component.

Materials

- Activity 1:
    - o Half-Life & Radiocarbon Dating Worksheet (one for every student)
    - o 100 pennies per group
    - o One zip-lock plastic bag per group
- Activity 2:
    - o One scientific calculator per student

Radiocarbon Dating Background Information

- The number of protons an atom has determines what element it is (for example, an atom of carbon always has six protons, while an atom of gold always has seventy-nine protons). While all atoms of an element have the same number of protons, the number of neutrons they carry can vary. Atoms that vary in the number of neutrons they carry are called **isotopes**.
- Isotopes with an equal number of protons and neutrons are stable, meaning those atoms have a binding energy that is strong enough to hold their nucleus together. In isotopes with more neutrons than protons, the binding energy may not be able to hold the nucleus together, making the atom unstable. Unstable isotopes will give off subatomic particles in order to reach a stable state. This change in an unstable isotope's nucleus also gives off energy, called **radiation**, and the isotope is said to be radioactive. The process of radioactive isotopes releasing energy and particles to reach a stable form is called **radioactive decay**.
- Not all atoms of a radioactive isotope decay at the same time. They do, however, decay at a fixed rate specific to the isotope. The term **half-life** refers to the amount of time it takes for a radioactive isotope in a sample to decay to half its original value.
- Because some isotopes can take thousands of years to decay, measuring the half-life of these long-lived radioisotopes is an effective way to estimate how old something is. Measuring half-life and radioactive decay is particularly useful in the field of archaeology, the study of past humans and cultures through material remains.
- Archaeologists use a variety of techniques when dating archaeological remains. Different techniques can be broadly categorized as either relative dating methods or absolute dating methods.
- **Relative dating** methods determine the age of an artifact by examining its relation to other artifacts. Relative dating methods can help archaeologists create chronologies and typologies, but specific dates are unknown.
- Conversely, **absolute dating** methods provide either specific dates or an estimated date range in calendar years for archaeological finds. **Radiocarbon dating**, which uses the concepts of radioactive decay and half-life, is a commonly used method of absolute dating.
- Radiocarbon dating is effective because of the **carbon cycle**. All living things are made of carbon and carbon atoms are constantly moving between living organisms and the biosphere. Unstable **carbon-14** isotopes are continuously

being formed in the atmosphere by nitrogen-14 atoms bombarded by cosmic rays. The unstable carbon-14 isotopes enter the carbon cycle when they combine with oxygen to form carbon dioxide.

- When an organism dies, it stops exchanging carbon with the biosphere. The amount of carbon-12 and carbon-13 present in the organism at the time of death will remain the same because these isotopes are stable. However, the amount of carbon-14 will slowly diminish due to radioactive decay. In all living organisms, the ratio of carbon-12 and carbon-13 to carbon-14 is the same. That ratio will change, however, when an organism dies because it is no longer exchanging carbon. In a sample used for radiocarbon dating, scientists measure the ratio of carbon-12 and carbon-13 to carbon-14, and compare it to the ratio in living organisms. From there, scientists can estimate how many half-lives carbon-14 has undergone and approximate the sample's age. The half-life of C_{14} is approximately 5,730 years.
- Only **organic materials** can be dated using radiocarbon dating. Wood, bone, charcoal, shell, plant materials, and blood residue all contain carbon and can be dated. However, stone and metal artifacts cannot. Some inorganic artifacts, like pottery, can be radiocarbon dated if the artifacts have organic residue on them (such as food residue).
- Radiocarbon dating is only effective within a certain date range; artifacts outside this range must be dated using other methods. Because radiocarbon dating measures the ratio between C_{12} and C_{14} isotopes, there comes a point when the remaining amount of unstable C_{14} is so miniscule that it is impossible to measure. Radiocarbon dating is only effective for artifacts less than 50,000 years old.
- The amount of C_{14} in the atmosphere and its ratio to C_{12} and C_{13} has not always been the same. Natural changes in the Earth's climate over thousands of years has caused the amount of C_{14} to fluctuate. Furthermore, the mass burning of fossil fuels has drastically offset the ratio of carbon in the atmosphere. The testing of atomic bombs in the mid-twentieth century has also increased the present amount of radiocarbon. All of these factors skew the results from radiocarbon dating, reducing its effectiveness as a dating method.

Pockoy Shell Ring Background Information

- Pockoy Island (pronounced Pock-ee) is a remote South Carolina sea island and a part of the Department of Natural Resource's Botany Bay Heritage Preserve / Wildlife Management Area. The property is located on the northeastern corner of Edisto Island in Charleston County.
- Botany Bay is one of the largest relatively undeveloped wetland ecosystems on the Atlantic Coast, providing a critical habitat for numerous wildlife species.
- The **cultural resources** of Botany Bay are equally important, with sites dating from approximately 4,000 years ago to the nineteenth century. Several sites are listed on the National Register of Historic Places, including the outbuildings from

Bleak Hall Plantation, granite markers from the 1850 Alexander Bache U.S. Coast Survey, and the Fig Island Shell Rings.

- The shell ring on Pockoy Island was first identified in early 2017 by analysts studying Hurricane Matthew's effect on South Carolina's coastline. When studying maps produced by aerial light detection and ranging, or **LIDAR**, the analysts noticed strange circular features on the coast of Pockoy Island, indicating the presence of a shell ring. **Shovel testing** began in the summer of 2017, which confirmed the ring's existence. **Radiocarbon dating** conducted on recovered animal bone revealed that the site was approximately 4,300 years old, making it the oldest known shell ring in South Carolina.
- Testing continued in late 2017, and large-scale **excavations** were conducted in May and December of 2018.
- **Shell rings** are structures found along the coasts of South Carolina, Georgia, Florida, and Mississippi, dating to the **Late Archaic** period (roughly 5,000 – 3,000 years ago). Dating suggests that the shell ring on Pockoy Island was built over a relatively short period of time, around 20 – 30 years.
- As the name indicates, shell rings are large circular or semi-circular structures made from piled shell. Some are C-shaped and U-shaped, while others are irregularly shaped or made up of multiple shapes. Pockoy is doughnut-shaped. Shell rings are primarily composed of oyster shell, but cockles, periwinkles, clams, and whelk shells are also commonly found. Shell rings range in size from 30 to 250 meters in diameter and are between 1 and 6 meters high. The Pockoy shell ring is approximately 60 meters in diameter.
- Another key feature of a shell ring is a central area called a **plaza**, which is devoid of shell. **Archaeologists** speculate that this area was maintained for ceremonial purposes or contained a structure.
- Archaeologists have been studying shell rings for decades but there is still a lot we do not know.
- Archaeologists are unsure if shell rings were intentionally built or not. Some argue that shell rings were inadvertently created from piles of discarded shell following meals over a long period of time. Others believe shell rings were planned structures built from leftover shells from feasts and other quarried shell.
- Archaeologists are also unsure what shell rings were used for. Some believe shell rings were sites of general human occupation, while others theorize shell rings were ceremonial structures only used for specific purposes at specific times.
- Archaeologists have recovered thousands of **artifacts** from Pockoy and other shell rings. The most common artifacts are pottery, shell, and animal bone.
- What archaeologists do not find at a site can also tell them a lot about the people that lived there. Very little stone has been found at Pockoy, telling archaeologists that the people that once lived there did not rely primarily on stone tools. Some archaeologists interpret this as evidence that the shell ring was not a site of human occupation, but others propose that this is reflective of the environment –

good stone is hard to find on the coast so the people living there relied on tools made out of shell and bone.
- Due to Pockoy's location on the coast, the site is vulnerable to coastal erosion and rising sea levels. With a rate of 9.5 meters of coastline lost per year, Pockoy is expected to be completely engulfed by the ocean by 2024.
- Climate change, or "heritage at risk", poses a serious challenge to archaeologists, and Pockoy is not the only site facing destruction. According to a report by DINAA (The Digital Index of North American Archaeology), a one-meter rise in sea level would result in the loss of 13,583 archaeological sites across the Southeastern United States. It is imperative to salvage, protect, and study these vulnerable sites before they are gone.

Vocabulary

- **Absolute Dating:** Determining the age of an object or feature on a specific time scale.
- **Archaeological Site**: A place where human activity occurred, and material remains were deposited.
- **Archaeologist**: A scientist who studies the material remains of past human activity.
- **Archaeology**: The scientific study of past human cultures by analyzing the material remains (sites and artifacts) that people left behind.
- **Artifact**: Any object made, modified, or used by people.
- **Carbon Cycle**: The continuous movement of carbon between living organisms and the biosphere.
- **Carbon-14 (C_{14})**: A radioactive carbon isotope that contains six protons and eight neutrons. For every one trillion atoms of carbon-12 and approximately the same number of carbon-13, there is one atom of carbon-14.
- **Cultural Resources**: Evidence of past human activity. They include archaeological sites, historic homes, battlefields, burial grounds, shipwrecks, historic and prehistoric artifacts.
- **Excavation**: The systematic digging and recording of an archaeological site.
- **Half-Life**: The time it takes for a radioactive isotope in a sample to decay to half of its original value.
- **Isotope**: Atoms with the same number of protons but a different number of neutrons.
- **LIDAR (Light Detection and Ranging)**: A detection system that works on the principle of radar but uses light from a laser. It is a remote sensing method used to examine the surface of the Earth.
- **Organic Material**: Any substance containing carbon-based compounds, especially produced by or derived from living organisms. Bones, wood, and leather are examples of organic material.
- **Plaza (Shell Ring)**: The central area of a shell ring that is devoid of shell.

- **Radiation**: Energy given off by matter in the form of rays or high-speed particles. For this lesson, specifically energy from unstable isotopes when subatomic particles are released in order to reach a stable form.
- **Radioactive Decay**: A process in which radioactive isotopes release subatomic particles and energy over time to reach a stable form.
- **Radiocarbon Dating**: An absolute dating technique that measures the amount of radioactive carbon (C_{14}) in organic material such as wood, bone, or shell. When living organisms die, they lose the radioactive carbon they contain in measurable amounts. The smaller the amount of C_{14} that is found, the older the object is. The half-life of carbon is 5,730 years. This means that radiocarbon dating is not particularly helpful for very recent objects and objects more than 50,000 years old.
- **Relative Dating**: Determining the age of an object compared to other objects.
- **Shell Ring**: Large circular or semi-circular prehistoric structures made from piled shell, typically found on the coasts of South Carolina, Georgia, Florida and Mississippi.
- **Shovel Testing**: a survey method where archaeologists dig a series of test holes using shovels to determine the presence and location of cultural resources. Shovel testing precedes large-scale excavations.

Lesson

1. If necessary, review the structure and characteristics of atoms and their subatomic particles. Students should have a firm understanding of these basic concepts before starting this lesson.
2. Distribute the "How Old Is It? Understanding Radiocarbon Dating" Lesson and Worksheet. Introduce the concepts of isotopes and radioactivity to your class. Students can follow along in the worksheet as they listen to the lecture.
3. Transition into a discussion on radioactive decay and half-life. Instruct your students that they will be simulating radioactive decay through a short activity involving pennies (you don't have to use pennies – any object with two distinguishable sides will work).
4. Divide your class into pairs or small groups, assign each group a number, and have your students complete "Activity 1" in their worksheet. On the board create a table for averaging the class results (see example below). As your students finish filling out their "Activity 1 Table", have them submit their results to the class table and create a class average.

Trial No.	Group 1	Group 2	Group 3	Group 4	Group 5	Avg.
0	100	100	100	100	100	100
1	54	60	56	49	62	56.2
2	22	42	24	25	30	28.6
3	11	27	12	11	15	15.2
4	6	13	5	6	8	7.6
5	3	7	3	2	5	4
6	1	4	3	1	2	2.2
7	1	2	1	1	2	1.4
8	0	1	1	0	1	0.6
9	0	0	0	0	1	0.2

5. Graph the class average on the board. Have your students compare their group's results to the class results.
6. Have your students complete the "Questions for Discussion" under "Activity 1" in their worksheet. Then discuss the activity as a class, emphasizing how this activity represents the concept of half-life. Explain that in the real world, the half-lives of radioactive isotopes can vary from less than a second to millions of years. Instruct your students that because half-life is a fixed rate of decay over time, it can used to measure how old something is.
7. Next, direct your student's attention to "Part 2" of the worksheet. This part focuses on the application of radioactive decay and half-life in the field of archaeology. Show your students the *Archaeo-Tech: Radiocarbon Dating* film and have them answer the questions in their worksheet.
8. Discuss the film and the science behind radiocarbon dating. Students can follow along in their worksheets as they listen to the lecture / discussion. Have your students move on to "Activity 2: Radiocarbon Dating Exercises". Introduce the formula for exponential decay, explaining each variable and how we can use this formula to model the decay of radiocarbon using our understanding of half-life. You can adjust the math skills used in this activity for different classes. Students in advanced classes can apply concepts learned from pre-calculus and calculus courses. Have your students solve the radiocarbon dating problems in their worksheet. This activity can be expanded to other isotopes and rates of decay.
9. Read and discuss the limitations of radiocarbon dating. Show your students the film *Challenges in Radiocarbon Dating Aquatic Specimens* via the link: (https://ajkoelker.wixsite.com/theringpeople/big-bites) and have them answer the following questions. Conclude the lesson by discussing the merits of radiocarbon dating.
10. Optional. For homework have your students read the article "The Shell Rings of Pockoy: A Window into the Past" by Cindy Thompson for the *South Carolina Wildlife* magazine. The article is available online at http://www.scwildlife.com/articles/septoct2018/TheShellRingsofPockoy.html. Discuss how radiocarbon dating was used by archaeologists studying the Pockoy Island Shell Ring and what information it revealed.

Archaeo-Tech: Radiocarbon Dating Film Answers

1. Carbon
2. Carbon-12 / Carbon-13 / Carbon-14
3. 1 Trillion
4. Ratio / Did Not Change / Reduced / Older

Activity 2 Answers

To find the rate of decay of C_{14} using the formula for exponential decay, knowing that the half-life of C_{14} is 5,730:

$N(t) = N_0 e^{kt}$

→ $N(5730) = N_0 e^{k(5730)}$

Because the half-life of C_{14} is 5,730 years, we know that when t = 5,730, half the initial amount (N_0) of carbon remains. Therefore, we can say that $N(5730) = (N_0 / 2)$.

→ $(N_0 / 2) = N_0 e^{k(5730)}$

→ Simplify to $(1 / 2) = e^{k(5730)}$

→ $\ln (1 / 2) = \ln (e^{k(5730)})$

→ $\ln (1 / 2) = k (5730)$

→ $k = (\ln (1 / 2) / 5730)$

→ **$k \approx -0.000121$**

1. $4 = 13 e^{-0.000121 (t)}$

   → $(4 / 13) = (e^{-0.000121 (t)})$

   → $\ln (4 / 13) = -0.000121 (t)$

   → $(-1.1787 / -0.000121) = t$

   → **$t \approx 9{,}741.32$ years**

2. $N(t) = 18 e^{-0.000121 (2250)}$

   → $N(t) = 18 e^{-0.27225}$

   → $N(t) = (18 . 0.7617)$

   → **$N(t) \approx 13.71$ grams**

3. $0.0124 = N_0 e^{-0.000121 (4700)}$

   → $0.0124 = N_0 e^{-0.5687}$

   → $0.0124 = N_0 . 0.5667$

   → $N_0 = (0.0124 / 0.5667)$

   → **$N_0 \approx 0.0219$ grams**

4. $N(t) = .022 \cdot N_0$ → $(0.22)\, N_0 = N_0 \cdot e^{-0.000121\,(t)}$
→ $0.22 = e^{-0.000121\,(t)}$
→ $\ln(0.22) = -0.000121\,(t)$
→ $(-1.5131 / -0.000121) = t$
→ **$t \approx 12{,}513.45$ years**
→ **$(12{,}513.45 / 5{,}730) \approx 2.18$ Half-Lives**

References

Atomic number, atomic mass, and isotopes. (n.d.). *Khan Academy*. Retrieved from https://www.khanacademy.org/science/biology/chemistry--of-life/elements-and-atoms/a/atomic-number-atomic-mass-and-isotopes-article

Carbon dating (2005). *University of Arizona, The Biology Project*. Retrieved from http://www.biology.arizona.edu/biomath/tutorials/applications/carbon.html

Challenges in radiocarbon dating aquatic specimens. (n.d.). *Koelker & Associates*. Retrieved from https://ajkoelker.wixsite.com/theringpeople/big-bites.

Half-life coins (2015). *Scientific American*. Retrieved from https://www.scientificamerican.com/article/half-life-coins/

How does carbon dating work? (n.d.). *Beta Analytic*. Retrieved from https://www.radiocarbon.com/about-carbon-dating.htm

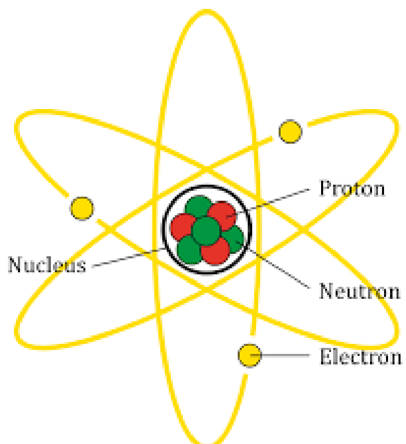
How does radiocarbon-14 dating work? (n.d.). *Environmental Science*. Retrieved from https://www.environmentalscience.org/how-radiocarbon-14-dating-works

Thompson, Cindy. “The shell rings of Pockoy: A window into the past.” *South Carolina Wildlife*, September / October, 2018. Accessed March 29, 2019. http://www.scwildlife.com/articles/septoct2018/TheShellRingsofPockoy.html

How Old Is It?
Understanding Radiocarbon Dating
Lesson and Worksheet

Part One: Half-life and Radioactive Decay

Reading for Understanding
As you know, all matter is made up of very, very tiny particles called atoms. Atoms are composed of three subatomic particles: protons, neutrons, and electrons. The number of protons an atom has determines its chemical properties, telling us what element it is. For example, all oxygen atoms have eight protons. The number of protons each element has is referred to as its atomic number.



Unlike protons, however, the number of neutrons in an atom can vary, meaning that atoms with the same atomic number can have different masses. Atoms with the same number of protons but a different number of neutrons are called **isotopes**.

Many elements have multiple isotopes that occur naturally. For example, the element carbon has three main isotopes: carbon-12 (C_{12}), carbon-13 (C_{13}), and carbon-14 (C_{14}). These three isotopes have the same number of protons (in this case six), but a different number of neutrons (carbon-12 has six neutrons, carbon-13 has seven, and carbon-14 has eight).

In the space below draw an example of a carbon-12 and carbon-14 isotope

Some isotopes are stable, while other isotopes are unstable. What does this mean? An atom's nucleus, which is made up of protons and neutrons, is held together by a force called binding energy. Stable atoms have a binding energy that is strong enough to hold its protons and neutrons together. Isotopes with an equal number of protons and neutrons are the most stable. In isotopes with more neutrons than protons, the binding energy may not be able to hold the nucleus together, making the atom unstable. Unstable isotopes will give off subatomic particles in order to reach a stable state. This change in an unstable isotope's nucleus also gives off energy, called radiation, and the isotope is said to be **radioactive**. The process of a radioactive isotope releasing energy and particles to reach a stable form is called **radioactive decay**.

Not all atoms of a radioactive isotope decay at the same time, but they do decay at a fixed rate specific to the isotope. The term **half-life** refers to the amount of time it takes for the radioactive isotopes in a sample to decay to half its original value.

The following activity will exemplify the concepts of radioactive decay and half-life.

Activity 1: Modeling Radioactive Decay & Half-Life

Introduction

In this activity you will be using pennies to simulate radioactive decay. Each penny represents a radioactive isotope. Heads represents an unstable isotope, in other words it has yet to decay. Tails represents an isotope that has decayed to a stable form by releasing subatomic particles and energy.

Image acquired from Pixabay under Pixabay License

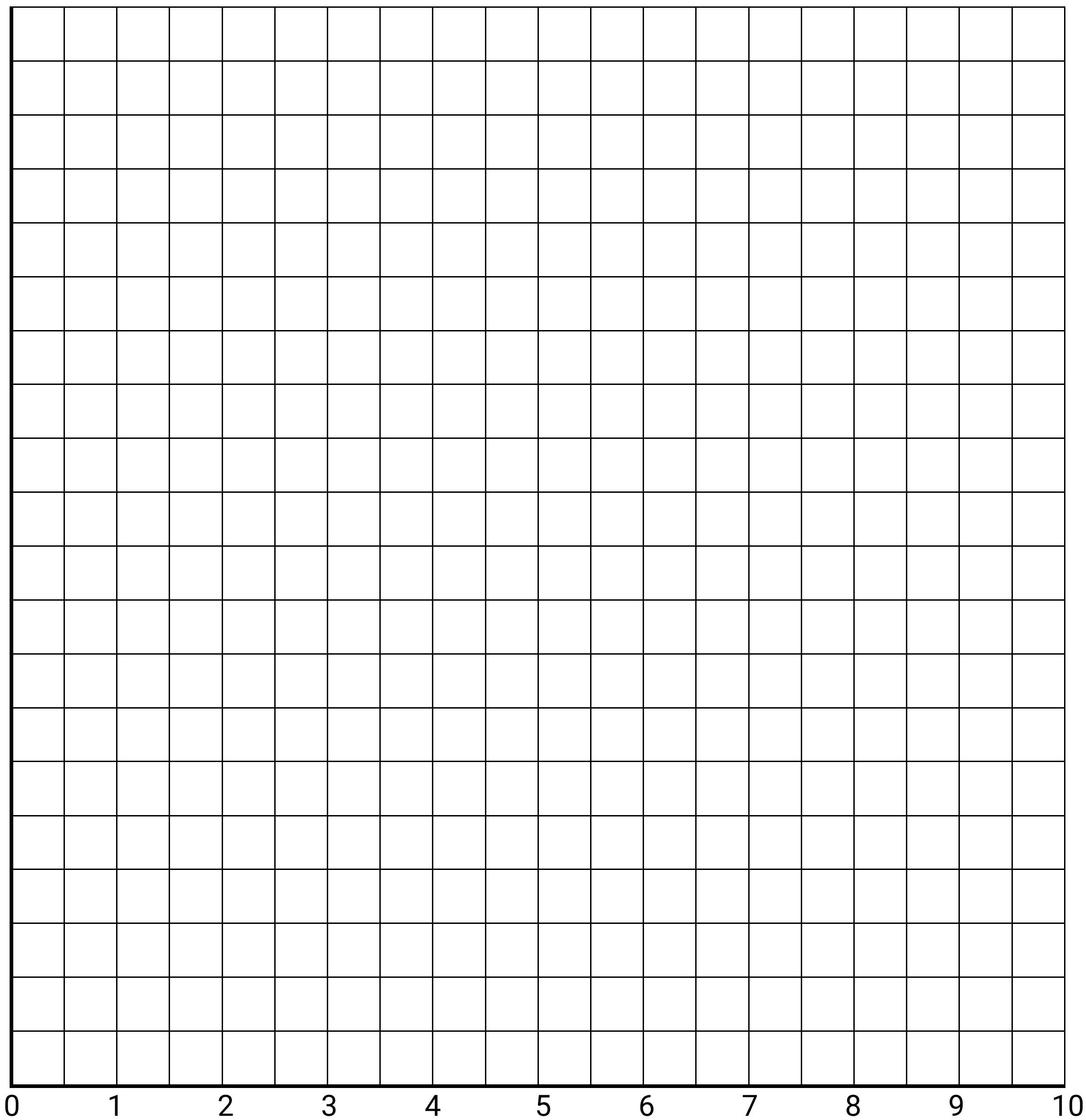
Instructions

For this activity your group will need 100 pennies and a large, resealable plastic bag. Place the pennies in the bag, seal, and shake. Empty the pennies from the bag onto a flat surface like a desk or the floor. Count the number of pennies that landed heads up and record your results in the table below. Place **only** the pennies that landed heads up back in the plastic bag (these isotopes are still radioactive). Remove all the pennies that landed on tails (these isotopes have experienced radioactive decay). Repeat this process until all the pennies have decayed or you reach trial #10.

Please note that at the start of this exercise all 100 pennies are considered radioactive.

Trial Number	Number of Radioactive Isotopes (Heads)
0	100
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Using your data from the table, graph your results in the space below. Have the x-axis represent the trial number and the y-axis represent the number of radioactive isotopes.



Questions for Discussion

Could you predict if a single penny was going to land on heads or tails? Why or why not?

On average, by what percent did the number of radioactive isotopes decrease every trial?

Describe the shape of your graph. Is it a straight line or a curve? What does this imply about radioactive decay?

Imagine if you doubled the number of pennies (isotopes) used in this exercise. Would the shape of your graph change, or would it remain the same?

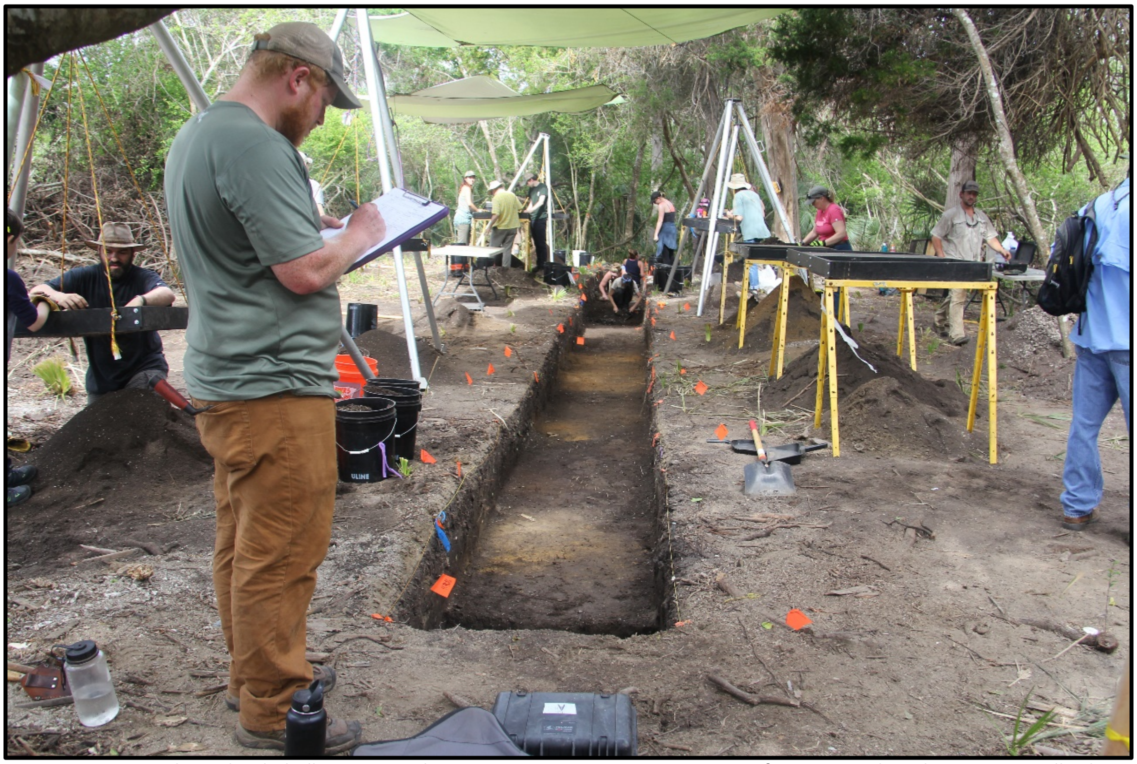
Using what you observed and learned in this activity, what is the half-life of pennies in terms of number of trials (or shakes)?

Imagine if the trial number represented a length of time. For example, imagine if one shake of the bag represented 16 years. In other words, what if the penny isotopes had a half-life of 16 years? How many penny isotopes of an unspecified amount would still be radioactive after 80 years? Express your answer as a fraction, as a percentage, and as a ratio.

Part Two: Archaeology and Radiocarbon Dating

Reading for Understanding

How can we tell how old something is? For **archaeologists**, scientists that study the material remains of past humans and cultures, this is a very important question. Knowing how old something is helps archaeologists incorporate their research into a broader understanding of human history and cultural change.



Pockoy Island Shell Ring Complex Excavation, May 2018. Courtesy of SCDNR Archaeologist Meg Gaillard. This image is owned by the South Carolina Department of Natural Resources (SCDNR).

Archaeologists use a variety of techniques when dating material remains. Different techniques can be broadly categorized as either relative dating methods or absolute dating methods. **Relative dating methods** determine the age of an artifact by examining its relation to other artifacts. Relative dating methods can help archaeologists create chronologies and typologies, but specific dates are unknown. Conversely, **absolute dating methods** provide either specific dates or an estimated date range in calendar years for archaeological materials. **Radiocarbon dating**, which uses the concepts of radioactive decay and half-life, is a commonly used method of absolute dating.

Archaeo-Tech: Radiocarbon Dating Film

The film *Archaeo-Tech: Radiocarbon Dating* shows how archaeologists use radiocarbon dating to estimate an archaeological site's age. As you watch the film, complete the sentences with the correct answer.

1. ________________ in the atmosphere is absorbed by plants and then by animals; it is present in every living thing.

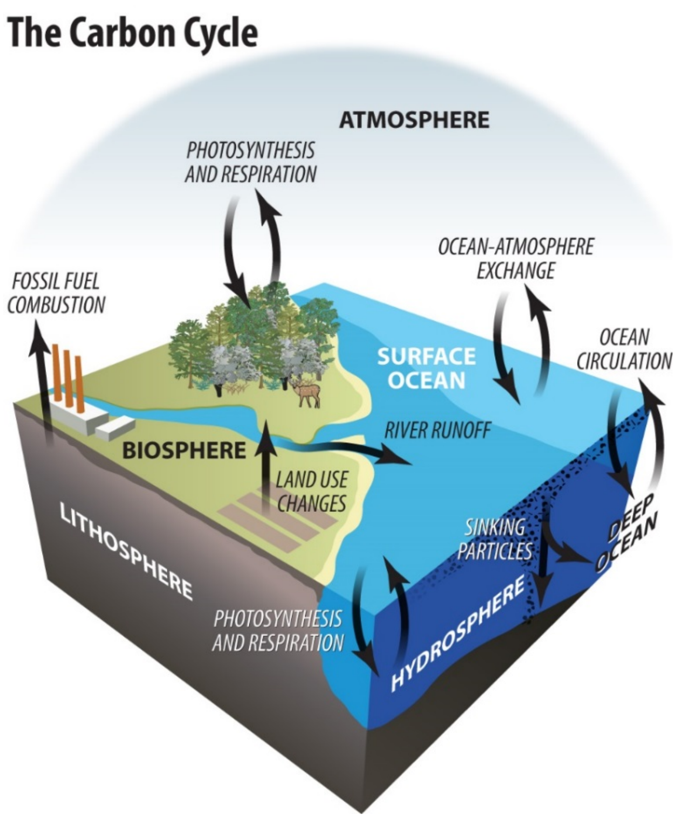
2. When a plant or animal stops growing, the ________________ and _________________ don't change, but ________________ begins to disappear in a process called radioactive decay.
3. For every ________________ atoms of carbon-12 and nearly the same amount of carbon-13, there is only one atom of carbon-14.
4. When the AMS (Accelerator Mass Spectrometer) data is processed the result is a ________________. When the sample stopped taking up carbon (when it died) it had the same ratio of carbon-13 to carbon-14. Since then, the amount of carbon-13 ________________, but radioactive decay ________________ the amount of carbon-14. The bigger the difference between carbon-13 and carbon-14, the ________________ the sample is.

After watching the film, answer the following question: How do archaeologists use the concepts of radioactive decay and half-life to date artifacts using radiocarbon dating?

Activity 2: Radiocarbon Dating Exercises

Introduction

Crucial to the science behind radiocarbon dating is a process called the **carbon cycle**. As mentioned in the film, all living things are made of carbon, with carbon atoms constantly moving between living organisms and the biosphere. Unstable carbon-14 isotopes (C_{14}) are continuously being formed in the atmosphere when nitrogen-14 isotopes are bombarded by cosmic rays. The unstable C_{14} isotopes enter the carbon cycle when they combine with oxygen to form carbon dioxide.



When an organism dies, it stops exchanging carbon with the biosphere. The amount of C_{12} and C_{13} present in the organism at the time of death will remain the same because these carbon isotopes are stable. However, the amount of C_{14} will slowly diminish due to radioactive decay. In all living organisms, the ratio of C_{12} and C_{13} to C_{14} is the same. That ratio will change, however, when an organism dies because it is no longer exchanging carbon. In a sample used for radiocarbon dating, scientists measure the ratio of C_{12} and C_{13} to C_{14} and compare it to the ratio in living organisms. From there, scientists can estimate how many half-lives the carbon-14 as undergone and approximate the sample's age. The half-life of C_{14} is approximately 5,730 years.

Exponential Decay

As you observed in Activity 1, the radioactive decay of isotopes can be expressed as a negative exponential function, a concept you might recall from algebra.

Formula for Exponential Decay

$$N(t) = N_0 e^{kt}, \text{ where } k < 0$$

N represents the final amount after a given time (t).

N_0 represents the initial amount.

k represents growth / decay rate. Remember, if *k* is greater than zero, the amount is increasing (growth). If *k* is less than zero, the amount is decreasing (decay).

t represents the amount of time that has passed.

We can tweak this formula to model for radiocarbon decay. Using algebra, let's find the rate of decay for carbon-14. Remember, C_{14} has a half-life of 5,730 years. You will need to use a calculator for this exercise.

In the space below, find the equation for modeling the decay of carbon-14 using the formula for exponential decay.

Using this equation, solve the following problems.

1. Approximate the age of an artifact that contains 4 grams of C_{14} if it initially possessed 13 grams of C_{14}?

2. Suppose an artifact contained 18 grams of C_{14} at the time of death. How much C_{14} would remain after 2,250 years?

3. A team of archaeologists recovered an artifact containing 0.0124 grams of C_{14} that is dated to be 4,700 years old. How much C_{14} did the artifact originally contain?

4. If only 22% of the initial amount of C_{14} remains in a sample, how old is the sample? Approximately how many half-lives has the sample experienced?

Limitations of Radiocarbon Dating

Radiocarbon dating is a very useful tool that has revolutionized the field of archaeology since its invention in the mid-twentieth century. However, radiocarbon dating has its limitations.

1. Only organic materials can be dated using radiocarbon dating. Wood, bone, charcoal, shell, plant materials, and blood residue all contain carbon and can be dated. However, stone and metal artifacts cannot. Some inorganic artifacts, like pottery, can be radiocarbon dated if the artifacts have organic residue on them (such as food residue).
2. Radiocarbon dating is only effective within a certain date range; artifacts outside this range must be dated using other methods. According to the principle of half-life, after approximately every 5,730 years, the amount of C_{14} that was originally present in a sample is reduced by half. After 5,730 years there is 50%, after 11,460 years there is 25%, after 17,190 years there is 12.5%, and so on. Because radiocarbon dating measures the ratio between carbon-12 and carbon-14 isotopes, there comes a point when the remaining amount of unstable carbon-14 is so miniscule that it is impossible to detect. Radiocarbon dating is only effective for artifacts less than 50,000 – 60,000 years old.
3. The amount of carbon-14 in the atmosphere and its ratio to carbon-12 and carbon-13 has not always been the same. Natural changes in the Earth's climate over thousands of years has caused the amount of carbon-14 to fluctuate. Furthermore, the burning of fossil fuels starting at the end of nineteenth century and into today has offset the ratio of carbon in the atmosphere. The testing of atomic bombs in the mid-twentieth century has also drastically increased the amount of radiocarbon present. All of these factors skew the results from radiocarbon dating, reducing its effectiveness.

Thoms Creek pottery from the Pockoy Island Shell Ring Complex excavation, May 2019. Image courtesy of SCDNR Archaelgoist Meg Gaillard. This image is owned by the South Carolina Department of Natural Resources (SCDNR).

The film “Challenges in Radiocarbon Dating Aquatic Specimens” highlights another limitation of radiocarbon dating. After watching the film, answer the following questions, assessing your understanding of radiocarbon dating.

1. Discuss the positives of radiocarbon dating. How can it be used in archaeology and why is it useful?

2. Discuss the negatives of radiocarbon dating. What are some of its limitations and why are these issues a problem for scientists that rely on radiocarbon dating?

3. Besides archaeology, can you think of other scientific fields where dating materials via half-life would be a useful? How so?