12.3 Dating with Radioactivity

Reading Focus

Key Concepts

- What is radioactivity?
- What is half-life?
- What is radiometric dating?
- How is carbon-14 used in radiometric dating?

Vocabulary

- radioactivity
- half-life
- radiometric dating
- radiocarbon dating

Reading Strategy

Monitoring Your Understanding Preview the key concepts, topics, headings, vocabulary, and figures in this section. Copy the chart below. List two things you expect to learn about each. After reading, state what you learned about each item you listed.

What I expect to learn	What I learned
1. a. ?	b. ?
2. c. ?	d. ?

Today, it is possible to obtain reliable numerical dates for events in the geologic past. For example, we know that Earth is about 4.56 billion years old and that the last dinosaurs became extinct about 65 million years ago. Although these great spans of time are hard to imagine, the vast expanse of geologic time is a reality. In this section you will learn how scientists measure time using radioactivity and radiometric dating.

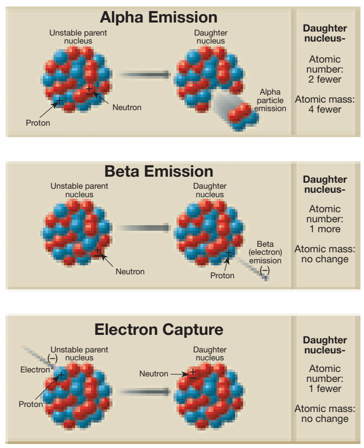
Basic Atomic Structure

Recall from Chapter 2 that each atom has a nucleus containing protons and neutrons and that the nucleus is orbited by electrons. Electrons have a negative electrical charge and protons have a positive charge. A neutron has no charge. The atomic number of an element is the number of protons in its nucleus. Different elements have different atomic numbers, but atoms of the same element always have the same atomic number. An atom's mass number is the number of protons and neutrons in an atom's nucleus. The number of neutrons can vary, and these variants, or isotopes, have different mass numbers.

Radioactivity

The forces that bind protons and neutrons together in the nucleus are usually strong. However, in some isotopes, the forces binding the protons and neutrons together are not sufficiently strong and the nuclei are unstable. When nuclei are unstable, they spontaneously break apart, or decay, in a process called **radioactivity.** An unstable or radioactive isotope of an element is called the parent. The isotopes that result from the decay of the parent are called the daughter products.

Figure 12 Common Types of Radioactive Decay In each case, the number of protons (atomic number) in the nucleus changes, thus producing a different element.



Section 12.3

1 FOCUS

Section Objectives

12.8 **Define** radioactivity and half-life.
12.9 **Explain** radiometric dating.
12.10 **Describe** how carbon-14 is used in radiometric dating.

Reading Focus

Build Vocabulary L2

Vocabulary Rating Chart Have students make a four-column chart with the headings "Term," "Can Define or Use It," "Heard or Seen It," and "Don't Know." Have them write *radioactivity*, *half-life*, *radiometric dating*, and *radiocarbon dating* in the first column. Students should then rate their knowledge of each term by putting a checkmark in one of the other columns. Ask them to revise their charts after they have read the section.

Reading Strategy L2

Sample answers include:
a. What is radioactivity? **b.** the breakdown of unstable nuclei; **c.** What is half-life? **d.** the time required for one half of the nuclei in a sample to decay to its stable isotope

2 INSTRUCT

Basic Atomic Structure

Build Science Skills L2

Using Models Have students draw models of atoms. Student models should show protons (positive charge) and neutrons (neutral charge) in the nucleus. Electrons (negative charge) should orbit outside the nucleus.
Kinesthetic, Logical

Radioactivity

Use Visuals L1

Figure 12 Ask: **What happens to the number of protons in each case?** *(It either increases or decreases.)*
Visual

Section 12.3 (continued)

Half-Life

Use Visuals L1

Figure 13 Have students predict how much of the radioactive parent will remain after six half-lives. *(1/64)* Ask: **At which point is the parent/daughter ratio 1:1?** *(after one half-life)*
Visual

Radiometric Dating

Build Science Skills L2

Applying Concepts Have students review Figure 12 on p. 347. Tell them that the element thorium has an atomic number of 90 and a mass number of 232. Ask: **If a radioactive isotope of thorium emits six alpha particles and four beta particles during radioactive decay, what are the atomic number and mass number of the stable daughter product?** *(Each time beta decay occurs, the atomic number increases by one; mass number does not change. Each alpha decay decreases the atomic number by two and the mass number by four. Thus, for six alpha decays and four betas, the atomic number of the daughter would be $90 - (6 \times 2) + 4 = 82$. The mass number of the daughter would be $232 - (6 \times 4) = 208$).*
Logical

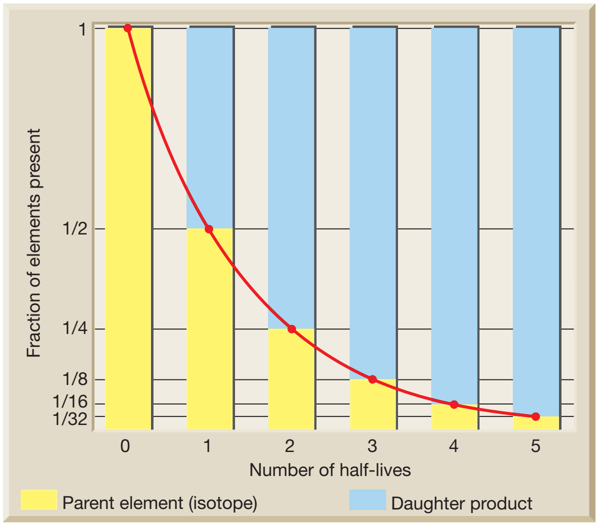


Figure 13 The Half-Life Decay Curve The radioactive decay curve shows change that is exponential. Half of the radioactive parent remains after one half-life. After a second half-life, one quarter of the parent remains, and so forth. **Interpreting Graphs** ***If $\frac{1}{32}$ of the parent material remains, how many half-lives have passed?***

What happens when unstable nuclei break apart? Radioactive decay continues until a stable or non-radioactive isotope is formed. A well-documented decay series is uranium-238, which decays over time to form the stable isotope lead-206. Three common types of radioactive decay are shown in Figure 12 on page 347.

Half-Life

A **half-life** is a common way of expressing the rate of radioactive decay. **A half-life is the amount of time necessary for one half of the nuclei in a sample to decay to its stable isotope.** Figure 13 illustrates what occurs when a radioactive parent decays directly into its stable daughter product. If the half-life of a radioactive isotope is known and the parent/daughter ratio can be measured, the age of the sample can be calculated. For example, if the half-life of an unstable isotope is 1 million years, and the parent/daughter ratio is 1:16, the ratio indicates that four half-lives have passed. The sample must be 4 million years old.

Reading Checkpoint *what is a half-life?*

Radiometric Dating

One of the most important results of the discovery of radioactivity is that it provides a way to calculate the ages of rocks and minerals that contain certain radioactive isotopes. The procedure is called **radiometric dating.** The rates of decay for many isotopes have been precisely measured and do not vary under the physical conditions that exist in Earth's outer layers. **Each radioactive isotope has been decaying at a constant rate since the formation of the rocks in which it occurs.** The products of decay have also been accumulating at a constant rate. For example, when uranium is incorporated into a mineral that crystallizes from magma, lead isn't present from previous decay. The radiometric "clock" starts at this point. **As the uranium decays, atoms of the daughter product are formed, and measurable amounts of lead eventually accumulate.**

Reading Checkpoint *What is a radiometric dating?*

Customize for English Language Learners

Give ELL students opportunities to interact verbally with non-ELL classmates. Place students in cooperative groups to discuss key concepts or chapter activities. Do not place all ELL students in one group—the goal is to help them improve their English skills in an informal setting. Encourage all students to be supportive during the discussions. For example, if a student easily grasps a difficult concept, he or she can attempt to simplify the concept for others in a relaxed manner.

Of the many radioactive isotopes that exist in nature, five have proved particularly useful in providing radiometric ages for ancient rocks. The five radioactive isotopes are listed in Table 1.

Table 1 Radioactive Isotopes Frequently Used in Radiometric Dating

Radioactive Parent	Stable Daughter Product	Currently Accepted Half-Life Values
Uranium-238	Lead-206	4.5 billion years
Uranium-235	Lead-207	713 million years
Thorium-232	Lead-208	14.1 billion years
Rubidium-87	Strontium-87	47.0 billion years
Potassium-40	Argon-40	1.3 billion years

An accurate radiometric date can be obtained only if the mineral remained in a closed system during the entire period since its formation. If the addition or loss of either parent or daughter isotopes occurs, then it is not possible to calculate a correct date. For example, an important limitation of the potassium-argon method stems from the fact that argon is a gas. Argon may leak from minerals and throw off measurements. Cross-checking of samples, using two different radiometric methods, is done where possible to ensure accuracy. Although the basic principle of radiometric dating is simple, the actual procedure is quite complex. The analysis that determines the quantities of parent and daughter must be painstakingly precise. In addition, some radioactive materials do not decay directly into the stable daughter product. Uranium-238, for example, produces thirteen intermediate unstable daughter products before the fourteenth and final daughter product, the stable isotope lead-206, is produced.

Reading Checkpoint *Why is a closed system necessary in radiometric dating?*

Dating with Carbon-14

To date recent events, carbon-14 is used in a method called **radiocarbon dating.** Carbon-14 is the radioactive isotope of carbon. Carbon-14 is continuously produced in the upper atmosphere. It quickly becomes incorporated into carbon dioxide, which circulates in the atmosphere and is absorbed by living matter. As a result, all organisms—including you—contain a small amount of carbon-14.

Q&A

Q *In radioactive decay, is there ever a time when all of the parent material is converted into the daughter product?*

A Theoretically, no. During a half-life, half of the parent material is converted into the daughter product. Then half of the remaining parent material is converted to the daughter product in another half life, and so on. By converting only half of the parent material with each half-life, there is never a time when all the parent material would be converted. However, after many half-lives, the parent material can exist in such small amounts that it is essentially undetectable.

Go Online SCI LINKS NSTA

For: Links on radioactive dating
Visit: www.SciLinks.org
Web Code: cjn-4124

Dating with Carbon-14

Build Reading Literacy L1

Refer to **p. 246D** in **Chapter 9**, which provides the guidelines for relating cause and effect.

Relate Cause and Effect Remind students that a cause makes something happen; the effect is what happens because of the cause. After students have read about dating with carbon-14, ask: **Why do all organisms contain a small amount of carbon-14?** *(It circulates in the atmosphere and is absorbed by living matter.)* **Why is the ratio of carbon-14 to carbon-12 constant during an organism's lifetime?** *(Carbon-14 is continually replaced.)* **At what point does the amount of carbon-14 in an organism began to decrease?** *(when the organism dies and starts to decay)*
Verbal, Logical

Go Online NSTA SCI LINKS

Download a worksheet on radioactive dating for students to complete, and find additional teacher support from NSTA SciLinks.

Facts and Figures

In a sample of uranium-238, unstable nuclei decay and produce a variety of daughter products, including radon—a colorless, odorless, invisible gas. Radon itself decays, having a half-life of only about four days. Its decay products are mainly radioactive solids that stick to dust particles, many of which are inhaled by people. During prolonged exposure to a radon-contaminated environment, some decay will occur while the gas is in the lungs, thereby placing the radioactive radon in direct contact with delicate lung tissue. Growing evidence indicates that radon is a significant cause of lung cancer, second only to smoking.

Answer to . . .

Figure 13 *Five half-lives have passed.*

Reading Checkpoint *the amount of time necessary for one half of the nuclei in a sample to decay to its stable isotope*

Reading Checkpoint *the process of using radioactivity to calculate the ages of rocks and minerals that contain certain radioactive isotopes*

Reading Checkpoint *An accurate radiometric date can be obtained only if the mineral remained a closed system since its formation.*

Section 12.3 (continued)

Importance of Radiometric Dating

Teacher Demo

Modeling Half-Lives

L2

Purpose Students will recognize how a radioactive parent isotope decays into its daughter product.

Materials scissors, adding machine tape, metric ruler

Procedure Begin with a piece of adding machine tape approximately 1 m long. Cut the paper in half. Set the two equal pieces aside. Take another 1-m long piece of paper and fold it into four equal pieces. Cut off one-fourth of the paper and set the two pieces aside. Ask students which two pieces of paper represent the parent/daughter ratio after one half-life. Ask which two represent the ratio after two half-lives.

Expected Outcomes Students will recognize that the two equal pieces of paper represent one half-life. The unequal pieces of paper, cut to represent one-quarter of the remaining parent isotope, represent two half-lives.
Visual

3 ASSESS

Evaluate Understanding

L2

Have students choose a radioactive isotope from Table 1 on p. 349 and make a graph showing its decay curve through several half-lives.

Reteach

L1

Use different-colored jelly beans to represent protons, neutrons, and electrons. Then model the common types of radioactive decay, using Figure 12 as a guide.

Connecting Concepts

Sample answer: Carbon-14 could be used to radiometrically date artifacts, assuming they are younger than 75,000 years.

Answer to . . .

Reading Checkpoint *the ratio of carbon-14 to carbon-12*

Figure 14 Carbon-14 is used to date recent events and objects.

While an organism is alive, the decaying radiocarbon is continually replaced. Thus, the ratio of carbon-14 to carbon-12—the stable isotope of carbon—remains constant. **When an organism dies, the amount of carbon-14 gradually decreases as it decays. By comparing the ratio of carbon-14 to carbon-12 in a sample, radiocarbon dates can be determined.**

Because the half-life of carbon-14 is only 5730 years, it can be used to date recent geologic events up to about 75,000 years ago. The age of the object shown in Figure 14 was determined using radiocarbon dating. Carbon-14 has become a valuable tool for anthropologists, archaeologists, and historians, as well as for geologists who study recent Earth history.

Reading Checkpoint *What is compared when dating with carbon-14?*

Importance of Radiometric Dating

Radiometric dating methods have produced thousands of dates for events in Earth's history. Rocks formed on Earth have been dated to be as much as 4 billion years old. Meteorites have been dated at 4.6 billion years old.

Radiometric dating has supported the ideas of James Hutton, Charles Darwin, and others who inferred that geologic time must be immense. Modern dating methods have proved that there has been enough time for the processes we observe to have accomplished tremendous tasks.

Section 12.3 Assessment

Reviewing Concepts

1. What happens to atoms that are radioactive?
2. Explain the concept of half-life.
3. What is needed to do radiometric dating?
4. Describe radiocarbon dating.

Critical Thinking

5. **Explaining Data** A grain of zircon in a sandstone is dated at 3 billion years. But the sandstone is from a unit of rock dated at 250 million years old. Explain how this can be.
6. **Understanding Concepts** How do scientists use half-lives in radiometric dating?

Connecting Concepts

Comparing and Contrasting Discuss the use of radiocarbon dating in determining the age of an ancient civilization. How can these two methods be used together?

Section 12.3 Assessment

1. The nuclei decay or react by emitting alpha or beta particles.
2. Half-life is the amount of time required for half of the nuclei of a radioactive substance to decay to form nuclei of a stable isotope.
3. radioactive isotopes and known decay rates for the isotopes
4. Materials containing carbon-14 are used. C-14 maintains a constant level in living organisms but not in dead organisms. So the ratio of C-14 to the stable isotope C-12 can be measured and a date of death determined.
5. Sandstone and other sedimentary rocks are made from sediments of pre-existing rocks. Therefore, the sediments can be much older than the rock itself.
6. If the half-life of a radioactive isotope is known and the parent/daughter ratio can be measured, the scientist can calculate the age of the sample.

understanding EARTH

Using Tree Rings to Date and Study the Recent Past

If you look at the top of a tree stump or at the end of a log, you will see that it is made of a series of concentric rings, like those shown in Figure 15. Every year in temperate regions trees add a layer of new wood under the bark. Each of these tree rings becomes larger in diameter outward from the center. During favorable environmental conditions, a wide ring is produced. During unfavorable environmental conditions, a narrow ring is produced. Trees growing at the same time in the same region show similar tree-ring patterns.

Because a single growth ring is usually added each year, you can determine the age of the tree by counting the rings. Cutting down a tree to count the rings is not necessary anymore. Scientists can use small, non-destructive core samples from living trees. The dating and study of annual rings in trees is called dendrochronology.

To make the most effective use of tree rings, extended patterns known as ring chronologies are established. They are produced by comparing the patterns of rings among trees in an area. If the same pattern can be identified in two samples, one of which has been dated, the second sample can be dated from the first by matching the ring pattern common to both. This technique, called cross dating, is illustrated in Figure 16. Tree-ring chronologies extending back for thousands of years have been established for some regions. To date a timber sample of unknown age, its ring pattern is matched against the reference chronology.

Tree-ring chronologies have important applications in such disciplines as climate, geology, ecology, and archaeology. For example, tree rings are used to reconstruct long-term climate variations within a certain region. Knowledge of such variations is of great value in studying and understanding the recent record of climate change.

Dendrochronology provides useful numerical dates for events in the historic and recent prehistoric past. Because tree rings are a storehouse of data, they are a valuable tool in the reconstruction of past environments.

Figure 15 Each year's growth for a tree can be seen as a ring. Because the amount of growth (thickness of a ring) depends upon precipitation and temperature, tree rings are useful records of past climates.

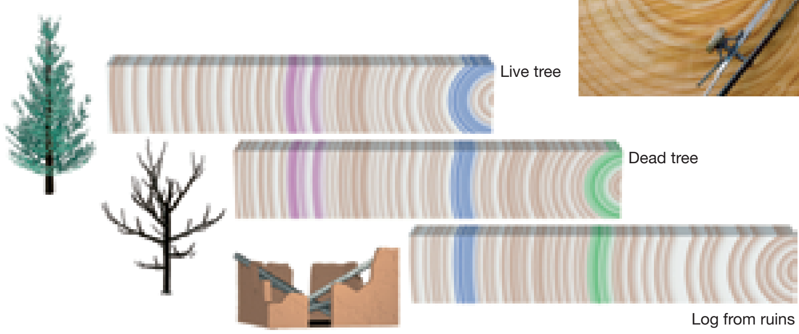


Figure 16 Using Tree Rings to Date Ancient Civilizations Cross dating is used to date an archaeological site by correlating tree-ring patterns using wood from trees of three different ages. First, a tree-ring chronology for the area is established using cores extracted from living trees. This chronology is extended further back in time by matching overlapping patterns from older, dead trees. Finally, cores taken from beams inside the ruin are dated using the chronology established from the other two sites.

understanding EARTH

Using Tree Rings to Date and Study the Recent Past L2

Background

One of the most basic principles of geology is also used in the study of dendrochronology—the principle of uniformitarianism, which states that the same processes at work today were also active in the past. The doctrine helps dendrochronologists to make inferences about ancient environmental conditions. It also allows them to predict future patterns based on evidence of past conditions. Other doctrines used by dendrochronologists include the principle of limiting factors, which states that life processes, such as growth, are constrained by the most limiting environmental factor of a particular area, such as precipitation. The principle of ecological amplitude states that trees located at the extremes of their species' geographic range will be most vulnerable to changing environmental factors. Other dendrochronologic principles cover site selection, cross-dating, and sampling techniques.

Teaching Tips

- Obtain several thin cross-sections of tree trunks. Allow students to examine the rings. Have them count the rings and try to establish the age of the tree.
- Tell students that clues to ancient environments can also be determined by examining ice cores. The cores are obtained by drilling through thick layers of ice, which are found in places such as Greenland and Siberia. By analyzing gases and other materials trapped in the layers of ice, scientists can reconstruct past climatic conditions.

Visual