Radiometric dating techniques make use of unstable radioactive isotopes to measure the ages of objects from the geologic past. Isotopes are atoms of an element that have different numbers of neutrons in their nuclei. The neutrons and protons in the nucleus of an atom are usually held together by strong forces. In some isotopes, however, the forces are not strong enough to hold the nucleus together, and it breaks apart, or decays. This process is called radioactivity.

When an atom of an element decays, an atom of a different element is often formed. For example, an unstable uranium atom decays to form a stable lead atom. The uranium atom is called the parent, and the lead atom is called the daughter. Every radioactive isotope decays at a constant rate that is characteristic of that isotope.

Suppose a rock contains atoms of radioactive uranium (U-238). The parent uranium atoms have been decaying and daughter lead atoms have been accumulating at a constant rate since the rock was formed. The time required for one-half of the nuclei in a sample to decay is called the half-life of the isotope. It takes 4.5 billion years for half the U-238 atoms in a rock to decay into lead atoms. After one half-life, the numbers of U-238 atoms and lead atoms in the rock are equal. After two half-lives, there is one U-238 atom for every three lead atoms.

### Part A: Radiocarbon Dating

High-energy radiation from the Sun causes atoms of a radioactive isotope of carbon, carbon-14 (C-14), to form in the atmosphere. These atoms combine with oxygen to form radioactive carbon dioxide, which is taken in by plants and incorporated into plant tissue. Thus, C-14 enters the food chain and carbon cycle along with common C-12 atoms. There is little radioactive carbon in living things—about one atom of C-14 to one trillion atoms of stable C-12. When an organism dies, carbon no longer is taken into its body, and any C-14 present continues to decay, forming a nonradioactive isotope, nitrogen-14 (N-14). Because the half-life of C-14 is relatively short, it can be used only to date material that is less than 100,000 years old.

Suppose that an ancient human once lit a campfire in a cave dwelling and that you analyze some charcoal from that fire. The charcoal contained 100 g of C-14 when the fire was lit. The half-life of C-14 is 5730 y.

1. Complete Table 1. Note that C-14 and N-14 have the same atomic mass.
2. On the grid below, graph the data in your table to show the relationship between the passage of time and the amount of C-14 in the charcoal sample. Time 0 is the point at which radioactive decay begins. The 28,650-year point is the present time.

### Table 1

<table>
<thead>
<tr>
<th>Amount of Parent Material (C-14) in Charcoal Sample (grams)</th>
<th>Amount of Daughter Material (N-14) in Charcoal Sample (grams)</th>
<th>Number of Years that Have Passed</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5730</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11,460</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17,190</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22,920</td>
</tr>
<tr>
<td>3.125</td>
<td>96.875</td>
<td>28,650</td>
</tr>
</tbody>
</table>

### Years Passed v. Amount of C-14

![Graph](graph.png)
Analyze and Conclude

Respond to each question or statement.

1. **Explain** whether carbon-14 can be used to find the ages of rocks.

2. **Evaluate** Why is radiometric dating more accurate than relative dating, which uses the law of superposition?

---

**Part B: Dating Ötzi, the Iceman**

On September 19, 1991, an amazing discovery was made in the mountains between Austria and Italy. Two hikers found an ancient mummified body that was partially embedded in melting glacial ice. The Iceman, as he was called first, was later nicknamed Ötzi after the mountain range in which he died. At first, Ötzi was believed to be about 500 years old, but when scientists saw the tools that were found near the body, they realized that he was older. Radiometric analysis of Ötzi’s bones and hair and the grass in his shoes showed that their carbon-14 content was 53 percent of what it would have been before death.

Using a mathematical equation, scientists determined that Ötzi died between 5200 and 5500 years ago at the end of the Stone Age. Analysis of Ötzi’s body and tools is still going on to determine how he died, where he lived, and what he ate.

**Table 2**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium-238</td>
<td>4.5 billion years</td>
</tr>
<tr>
<td>Potassium-40</td>
<td>1.25 billion years</td>
</tr>
<tr>
<td>Carbon-14</td>
<td>5730 years</td>
</tr>
<tr>
<td>Radon-222</td>
<td>3.82 days</td>
</tr>
</tbody>
</table>

---

**Analyze and Conclude**

Use Table 2 to respond to each question or statement.

1. **Identify** the geologic era in which Ötzi lived.

2. **Calculate** If a sample of wood from one of Ötzi’s tools is found to contain only one-fourth as much carbon-14 as a sample from a living tree, what is the estimated age of the wood in the tool?

3. **Infer** Why did scientists use carbon-14 to establish Ötzi’s age instead of using the other isotopes listed in Table 2?

---

**CAREERS IN BIOLOGY**

**Paleontology** Visit biologygmh.com for information on paleontologists. What are the responsibilities of a paleontologist?
2. Possible answer: If different layers contained the same materials, I would conclude that the environment did not change over a long period of time. If some layers didn’t overlap, I would look for disturbances in the strata and compare the strata to other sites in the area.

BioLab

Page 7 • Is spontaneous generation possible?

1. Answers will vary.
2. Microorganisms grew in the broth exposed to microorganisms in the environment.
3. Verification can prove that experimental results are not due to a chance occurrence.
4. If organisms could be produced from nonliving material, microorganisms would have grown in both the sterile broth that was exposed to air and in the sterile broth that was sealed completely.
5. Answers will vary. The sterile broth might have been contaminated after boiling.

Real-World Biology: Analysis

Page 9 • Dating the Iceman

Planning the Activity
This activity should be used after students have studied the concepts of relative and absolute dating in Chapter 14 of the text. It can be used to reinforce the concept of the geologic time scale.

Purpose
Students explore radiometric dating technology and how it was used to determine the age of a mummified body.

Career Applications
Paleontologists are scientists who study fossils, preserved evidence of organisms that lived in the past. Paleontologists do more than just dig through ancient rock layers looking for fossils. Most of the analysis of Ötsi’s body and tools was done by paleontologists who specialize in artifacts from the Stone Age.

Teaching Strategies
• To review concepts from the chapter, ask students “What is radiometric dating?” “What is a half-life?”

• To reinforce the concept of half-life, place 100 white beans in a box. Tell students that the white beans have a half-life of five minutes. Every five minutes, remove half of the white beans in the box and replace them with red beans. Have students count the numbers of red beans and white beans in the box each time.

• Have students learn about other methods of absolute age dating, such as dendrochronology (the analysis of tree rings).

• Below Level: If students are having trouble with the table and/or graph in Part A, work through the first few time periods with them. Also, make sure to explain that the table and graph are two different ways to show the same information.

• Above Level: Have students use their completed graph from Part A to estimate Ötsi’s age based on a carbon-14 content of 53 percent of what it would have been before death.

Answers to Student Worksheet

Part A: Radiocarbon Dating

1. Table 1

<table>
<thead>
<tr>
<th>Amount of Parent Material (C-14) in Charcoal Sample (in grams)</th>
<th>Amount of Daughter Material (N-14) in Charcoal Sample (in grams)</th>
<th>Number of Years That Have Passed</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>5730</td>
</tr>
<tr>
<td>25</td>
<td>75</td>
<td>11,460</td>
</tr>
<tr>
<td>12.5</td>
<td>87.5</td>
<td>17,190</td>
</tr>
<tr>
<td>6.25</td>
<td>93.75</td>
<td>22,920</td>
</tr>
<tr>
<td>3.125</td>
<td>96.875</td>
<td>28,650</td>
</tr>
</tbody>
</table>

2. Years Passed v. Amount of Radioisotope

![Graph showing the decrease in radioisotope over time](image-url)
Chapter 14  Teacher Guide and Answers

Analyze and Conclude
1. The half-life of carbon-14 is too short to be used to date rocks. The use of carbon-14 is limited to material that is less than 100,000 years old. Most rocks are millions or billions of years old.
2. Radiometric dating uses the decay of radioactive isotopes to find the age of a rock. Relative dating by superposition depends on undisturbed rock layers. Also, relative dating does not give the actual ages of the rocks.

Part B: Dating Ötzi, the Iceman
Analyze and Conclude
1. Cenozoic Era
2. 11,460 years
3. Ötzi’s body contains carbon-14, which has a relatively short half-life and is appropriate for dating present-day humans. It is not likely that Ötzi’s body contains either uranium-238 or radon-222. Also, the half-lives of uranium-238 and potassium-40 are too long to date human remains, and the half-life of radon-222 is too short.

Careers in Biology
Paleontologists study fossils, preserved evidence of organisms that lived in the past.

Enrichment
Page 11 • The Fossil Record
Student presentations may vary but should be accurate and complete. Photographs of fossils would be useful illustrations. Presentations should include information about the habitat of the fossil organism and its evolutionary history. Groups should explain the fossil organism’s relationship to living groups.

Concept Mapping
Page 12 • Fossils
1. Fossils
2. sediment
3. relative dating
4. radiometric dating
5. organisms
6. rock layers
7. radioactive isotopes
8. minerals
9. age
10. fossils

Study Guide
Page 13 • Section 14.1
1. false
2. true
3. true
4. false
5. false
6. Precambrian
7. Cenozoic Era
8. Mesozoic Era
9. Paleozoic Era
10. Mesozoic Era
11. Paleozoic Era
12. Paleozoic Era
13. Precambrian

Note: Student answers for questions 14–18 are interchangeable.
14. trace fossils—footprints, burrows, fossilized feces
15. molds and casts—impression of an organism, can be filled with minerals
16. replacement—detailed mineral replicas
17. petrified or permineralized—wood pores filled with minerals
18. original material—mummified or frozen remains

Page 15 • Section 14.2
1. C
2. D
3. B
4. A
5. C
6. A
7. D