CHAPTER

9

# Radioactivity and Nuclear Reactions

The Sun gives off tremendous amounts of energy from day to day, year to year. Almost all of the Sun's energy comes from nuclear reactions in which the nuclei of atoms are fused together. In this chapter, you will learn about unstable nuclei and how they emit different types of radiation. You will also learn how this radiation can be used to determine the age of objects, produce energy, or treat diseases.

## What do you think?

**Science Journal** Look at the picture below with a classmate. Discuss what you think this is or what is happening. Here's a hint: *There's probably one of these on the ceiling.* Write your answer or best guess in your Science Journal.

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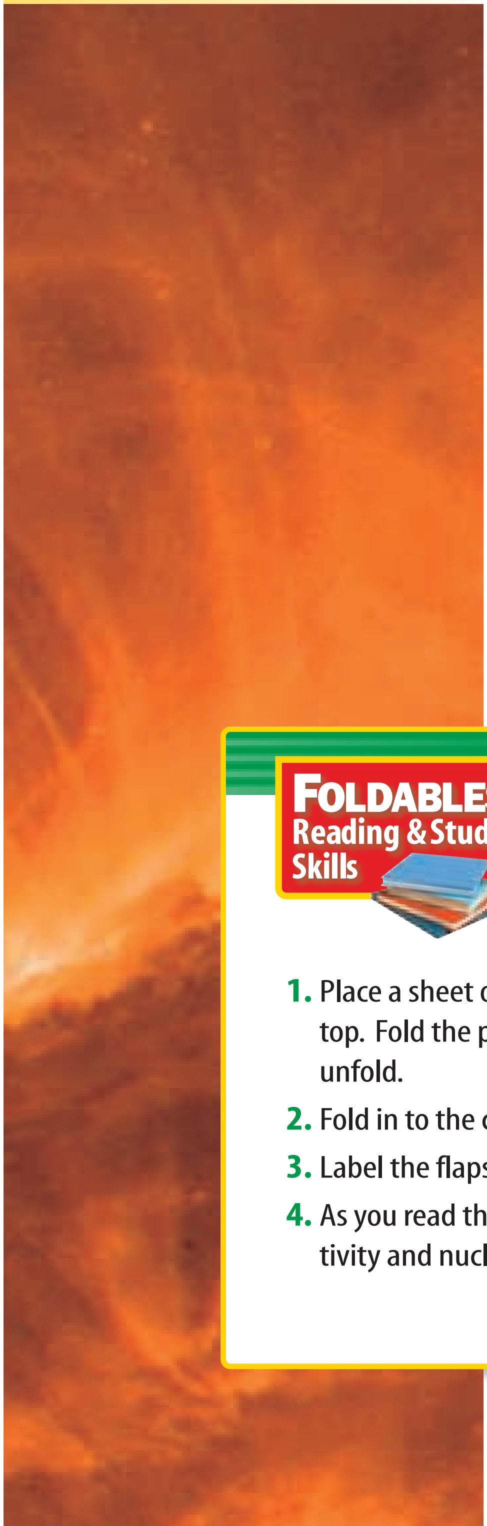


## EXPLORE ACTIVITY

Do you realize you are made up mostly of empty space? Your body is made of atoms, and atoms are made of electrons whizzing around a small nucleus of protons and neutrons. The size of this region of space in which the electrons are moving is the same as the size of the atom. An atom is much larger than its nucleus. During this activity you will find out just how small a nucleus is.

### Model the space inside an atom

1. Go outside and pour several grains of sugar onto a sheet of paper.
2. Choose a tiny grain of sugar with a diameter equal to the width of one of the lines on a ruler. This sugar grain represents the nucleus of an atom.
3. Brush the rest of the sugar off the paper and place the sugar grain in the center of the paper.
4. Use a meterstick to measure a 10 m distance away from the sugar grain.

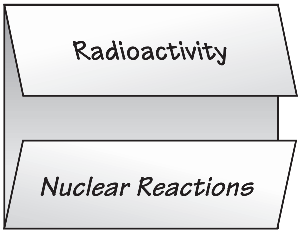
### Observe

In your Science Journal, explain why an atom contains mostly empty space. Use the fact that an electron is much smaller than the nucleus of an atom.

## Before You Read

**FOLDABLES Reading & Study Skills**

**Making a Main Ideas Study Fold** **Make the following Foldable to help you identify the major topics about radioactivity and nuclear reactions.**



1. Place a sheet of paper in front of you so the short side is at the top. Fold the paper in half from top to bottom and then unfold.
2. Fold in to the centerfold line to divide the paper into fourths.
3. Label the flaps *Radioactivity* and *Nuclear Reactions.*
4. As you read the chapter, write what you learn about radioactivity and nuclear reactions under the flaps.

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SECTION

# 1 Radioactivity

**As You Read**

### What You'll Learn

- **Describe** the structure of an atom and its nucleus.
- **Explain** what radioactivity is.
- **Contrast** properties of radioactive and stable nuclei.
- **Discuss** the discovery of radioactivity.

### Vocabulary

strong force
radioactivity

### Why It's Important

The characteristics of atomic nuclei determine whether or not they will undergo radioactive decay.

## The Nucleus

Every second you are being bombarded by energetic particles. Some of these particles come from unstable atoms in soil, rocks, and the atmosphere. What types of atoms are unstable? What type of particles do unstable atoms emit? The answers to these questions begin with the nucleus of an atom.

You remember that atoms are composed of protons, neutrons, and electrons. The nucleus of an atom contains the protons, which have a positive charge, and neutrons, which have no electric charge. The total amount of charge in a nucleus is determined by the number of protons, which also is called the atomic number. You might remember that an electron has a charge that is equal but opposite to a proton's charge. Atoms usually contain the same number of protons as electrons. Negatively charged electrons are electrically attracted to the positively charged nucleus and swarm around it.

**Protons and Neutrons in the Nucleus** Protons and neutrons are packed together tightly in a nucleus. The region outside the nucleus in which the electrons are located is large compared to the size of the nucleus. As **Figure 1** shows, the nucleus occupies only a tiny fraction of the space in the atom. If an atom were enlarged so that it was 1 km in diameter, its nucleus would have a diameter of only a few centimeters. But the nucleus contains almost all the mass of the atom, because the mass of one proton or neutron is almost 2,000 times greater than the mass of an electron.

**Figure 1**
**The size of a nucleus in an atom can be compared to a marble sitting in the middle of an empty football stadium.**

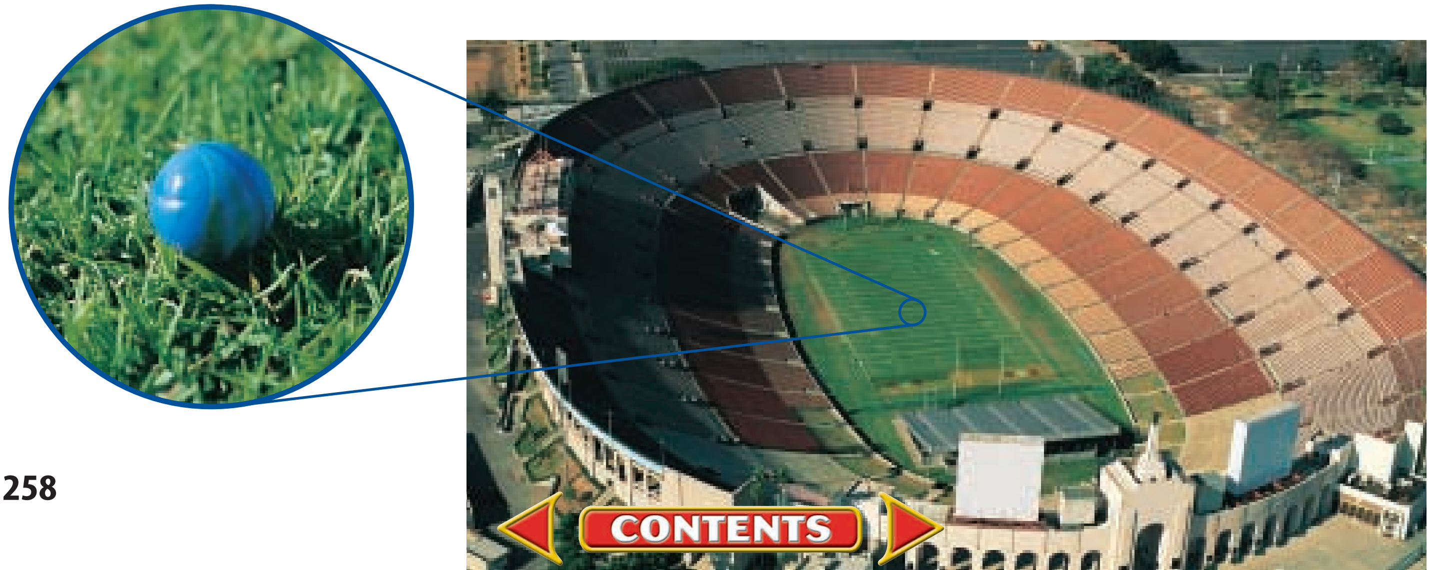

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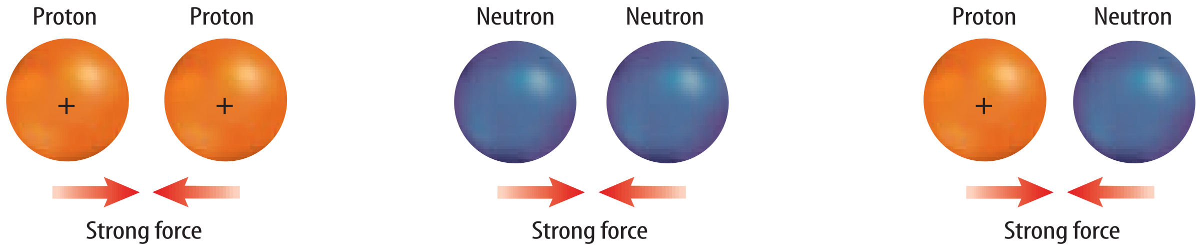
**Figure 2**
**The particles in the nucleus are attracted to each other by the strong force.**



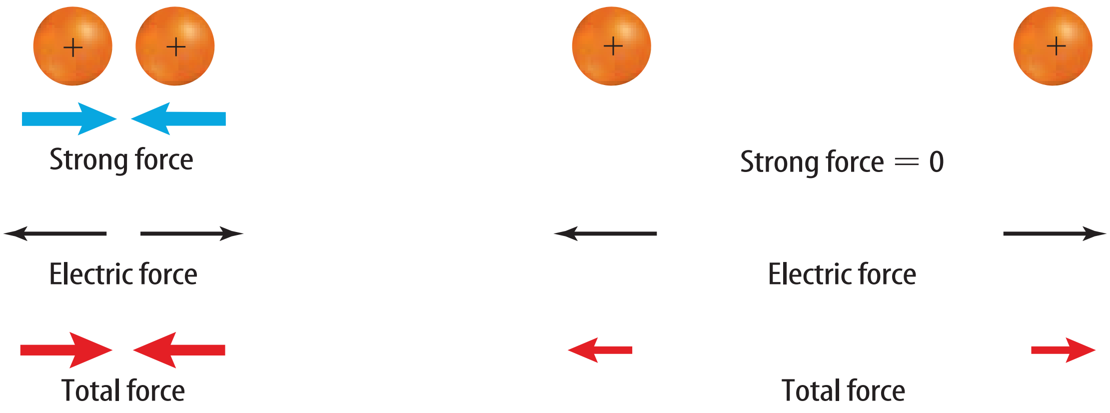
## The Strong Force

How do you suppose protons and neutrons are held together so tightly in the nucleus? Positive electric charges repel each other, so why don't the protons in a nucleus push each other away? Another force, called the **strong force,** causes protons and neutrons to be attracted to each other, as shown in **Figure 2.**

The strong force is one of the four basic forces and is about 100 times stronger than the electric force. The attractive forces between all the protons and neutrons in a nucleus keep the nucleus together. However, protons and neutrons have to be close together, like they are in the nucleus, to be attracted by the strong force. The strong force is a short-range force that quickly becomes extremely weak as protons and neutrons get farther apart. The electric force is a long-range force, so protons that are far apart still are repelled by the electric force, as shown in **Figure 3.**

**Reading Check** *What causes the attraction between protons and neutrons?*

**Figure 3**
**The total force between two protons depends on how far apart they are.**



**A** When protons are close together, they are attracted to each other. The attraction due to the short-range strong force is much stronger than the repulsion due to the long-range electric force.

**B** When protons are too far apart to be attracted by the strong force, they still are repelled by the electric force between them. Then the total force between them is repulsive.

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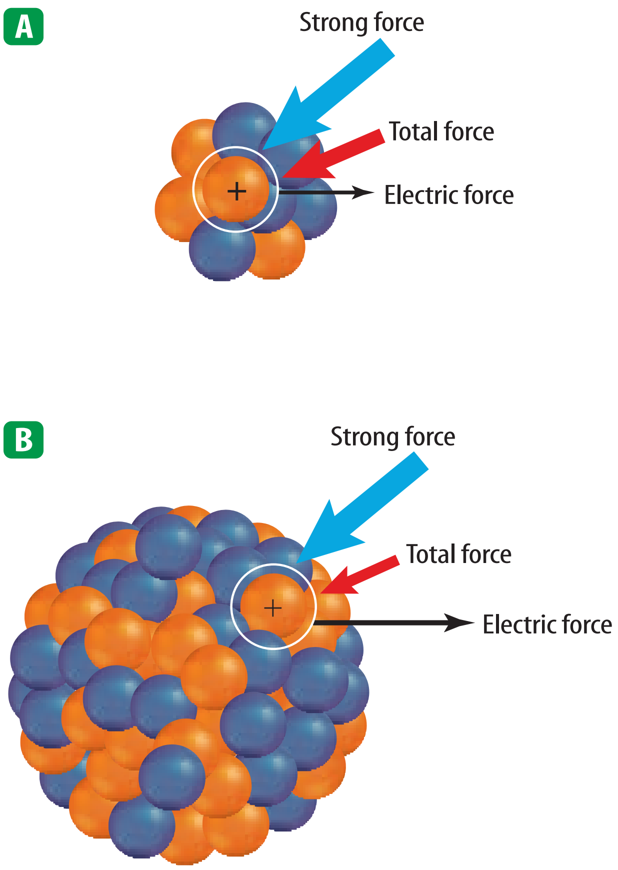

**Figure 4**
**Protons and neutrons are held together less tightly in large nuclei. The circle shows the range of the attractive strong force. A Small nuclei have few protons, so the repulsive force on a proton due to the other protons is small. B In large nuclei, the attractive strong force is exerted only by the nearest neighbors, but all the protons exert repulsive forces. The total repulsive force is large.**

**Attraction and Repulsion** Some atoms, such as uranium, have many protons and neutrons in their nuclei. These nuclei are held together less tightly than nuclei containing only a few protons and neutrons. To understand this, look at **Figure 4A.** If a nucleus has only a few protons and neutrons, they are all close enough together to be attracted to each other by the strong force. Because only a few protons are in the nucleus, the total electric force causing protons to repel each other is small. As a result, the overall force between the protons and the neutrons attracts the particles to each other.

**Forces in a Large Nucleus** However, if nuclei have many protons and neutrons, each proton or neutron is attracted to only a few neighbors by the strong force, as shown in **Figure 4B.** The other protons and neutrons are too far away. Because only the closest protons and neutrons attract each other in a large nucleus, the strong force holding them together is about the same as in a small nucleus. However, all the protons in a large nucleus exert a repulsive electric force on each other. Thus, the electric repulsive force on a proton in a large nucleus is larger than it would be in a small nucleus. Because the repulsive force increases in a large nucleus while the attractive force on each proton or neutron remains about the same, protons and neutrons are held together less tightly in a large nucleus.

## Radioactivity

In many nuclei the strong force is able to keep the nucleus permanently together, and the nucleus is stable. When the strong force is not large enough to hold a nucleus together tightly, the nucleus can decay and give off matter and energy. This process of nuclear decay is called **radioactivity.**

Large nuclei tend to be unstable and can break apart or decay. In fact, all nuclei that contain more than 83 protons are radioactive. However, many other nuclei that contain fewer than 83 protons also are radioactive. Even some nuclei with only a few protons are radioactive.

Almost all elements with more than 92 protons don't exist naturally on Earth. They have been produced only in laboratories and are called synthetic elements. These synthetic elements are unstable, and decay soon after they are created.

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**Stable and Unstable Nuclei** The atoms of an element all have the same number of protons in the nucleus. For example, the nucleus of all carbon atoms contains six protons. However, not all naturally occurring carbon nuclei have the same numbers of neutrons. Some carbon nuclei have six neutrons, some have seven, and some have eight neutrons. Nuclei that have the same number of protons but different numbers of neutrons are called isotopes. The element carbon has three isotopes that occur naturally. The atoms of all isotopes of an element have the same number of electrons, and have the same chemical properties.

Isotopes of elements differ in the ratio of neutrons to protons, as shown in **Figure 5.** This ratio is related to the stability of the nucleus. In less massive elements, an isotope is stable if the ratio is about 1 to 1. Isotopes of the heavier elements are stable when the ratio of neutrons to protons is about 3 to 2. However, the nuclei of any isotopes that differ much from these ratios are unstable, whether the elements are light or heavy. In other words, nuclei with too many or too few neutrons compared to the number of protons are radioactive. Radioactive isotopes are sometimes called radioisotopes.

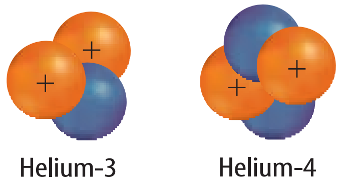

**Figure 5**
**These two different isotopes of helium each have the same number of protons, even though they have different numbers of neutrons.** *What is the ratio of protons to neutrons in each of these isotopes of helium?*

**Nucleus Numbers** A nucleus can be described by the number of protons and neutrons it contains. The number of protons in a nucleus is called the atomic number. Because the mass of all the protons and neutrons in a nucleus is nearly the same as the mass of the atom, the number of protons and neutrons is called the mass number.

A nucleus can be represented by a symbol that includes its atomic number, mass number, and the symbol of the element it belongs to, as shown in **Figure 6.** The symbol for the nucleus of the stable isotope of carbon is shown as an example.

$$\begin{matrix}\text{mass number} \rightarrow \\ \text{atomic number} \rightarrow\end{matrix} {}^{12}_{6}\text{C} \leftarrow \text{element symbol}$$

This isotope is called carbon-12. The number of neutrons in the nucleus is the mass number minus the atomic number. So the number of neutrons in the carbon-12 nucleus is $12 - 6 = 6$. Carbon-12 has six protons and six neutrons. Now, compare the isotope carbon-12 to this radioactive isotope of carbon:

$$\begin{matrix}\text{mass number} \rightarrow \\ \text{atomic number} \rightarrow\end{matrix} {}^{14}_{6}\text{C} \leftarrow \text{element symbol}$$

The radioactive isotope is carbon-14. How many neutrons does carbon-14 have?

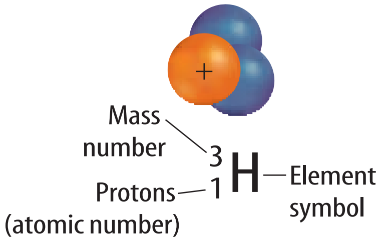

**Figure 6**
**A simple way to indicate the atomic mass of an isotope is to use a symbol like this one for hydrogen.** *How many neutrons are in this isotope?*

**✓ Reading Check** ***What is the atomic number of a nucleus?***

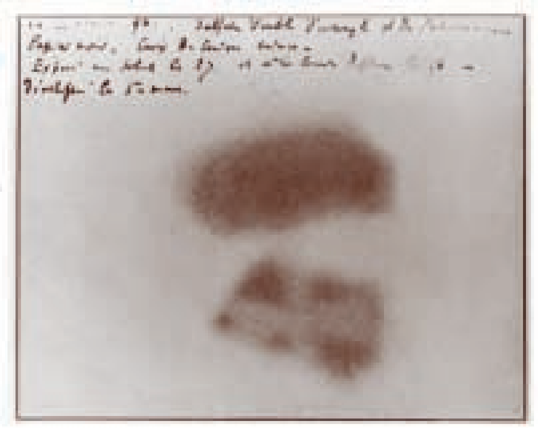

**Figure 7**
**Henri Becquerel found outlines of uranium salt on a photographic plate.**

## Discovery of Radioactivity

Look around the room. Can you detect any evidence of radioactivity? You can't see, hear, taste, touch, or smell radioactivity. Do you realize that small amounts of radioactivity are all around you, even inside your body? How was radioactivity first discovered if it can't be detected by your senses?

Henri Becquerel accidentally discovered radioactivity in 1896 when he left uranium salt in a desk drawer with a photographic plate. Later, when he removed the plate and developed it, he found an outline of the clumps of the uranium salt like in **Figure 7.** He hypothesized that the uranium had given off some invisible energy, or radiation, and exposed the film. Two years after Becquerel's discovery, Marie and Pierre Curie discovered the elements polonium and radium. These elements are even more radioactive than uranium. What are the atomic numbers of these elements?

CLICK HERE

**SCIENCE Online**

**Research** Visit the Glencoe Science Web site at **science.glencoe.com** for more information about the scientists who discovered and developed applications for radioactivity. Create a time line that shows key events and people in the use of radioactivity.

## Section 1 Assessment

1. What force keeps stable nuclei permanently together?
2. What is radioactivity?
3. Why are large nuclei unstable?
4. Identify the contributions of the three scientists who discovered the first radioactive elements.
5. **Think Critically** What is the ratio of protons to neutrons in lead-214? Explain whether you would expect this isotope to be radioactive or stable.

### Skill Builder Activities

6. **Comparing and Contrasting** Compare and contrast stable and unstable nuclei. **For more help, refer to the Science Skill Handbook.**
7. **Communicating** In your Science Journal, make a list of the first things you think of when you hear the word *radioactivity.* Write one paragraph describing your positive thoughts about radioactivity and another describing your negative thoughts. **For more help, refer to the Science Skill Handbook.**

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SECTION

2

# Nuclear Decay

**As You Read**

### What You'll Learn

- **Compare and contrast** alpha, beta, and gamma radiation.
- **Define** the half-life of a radioactive material.
- **Describe** the process of radioactive dating.

### Vocabulary

- alpha particle
- transmutation
- beta particle
- gamma ray
- half-life

### Why It's Important

Different types of nuclear radiation are used in medicine and for calculating the ages of artifacts.

## Nuclear Radiation

When an unstable nucleus decays, particles and energy are emitted from the decaying nucleus. These particles and energy are called nuclear radiation. The three types of nuclear radiation are alpha, beta (BAYT uh), and gamma radiation. Alpha and beta radiation are particles. Gamma radiation behaves like a wave that is similar to light but of much higher frequency.

## Alpha Particles

When alpha radiation occurs, an alpha particle is emitted from the decaying nucleus. An **alpha particle** is made of two protons and two neutrons, as shown in **Table 1.** Notice that the alpha particle is the same as a helium nucleus. The symbol for an alpha particle is the same as for the helium nucleus, $^{4}_{2}\text{He}$. An alpha particle has an electric charge of +2 and an atomic mass of 4.

**Reading Check** *What does an alpha particle consist of?*

**Damage from Alpha Particles** Compared to beta and gamma radiation, alpha particles are much more massive. They also have the most electric charge. As a result, alpha particles lose energy more quickly when they interact with matter than the other types of nuclear radiation do. When alpha particles pass through matter, they exert an electric force on the electrons in atoms in their path. This force pulls electrons away from atoms and leaves behind charged ions. Alpha particles lose energy quickly during this process. As a result, alpha particles are the least penetrating form of nuclear radiation. Alpha particles cannot even pass through a sheet of paper.

However, alpha particles can be dangerous if they are released by radioactive atoms inside your body. Biological molecules inside your body are large and easily damaged. A single alpha particle can damage many fragile biological molecules. Damage from alpha particles can cause cells in your body to no longer function properly, leading to illness and disease.

**Table 1 Alpha Particles**

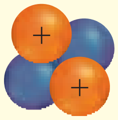
| | |
|---|---|
|  | |
| Symbol | $^{4}_{2}\text{He}$ |
| Mass | 4 |
| Charge | +2 |

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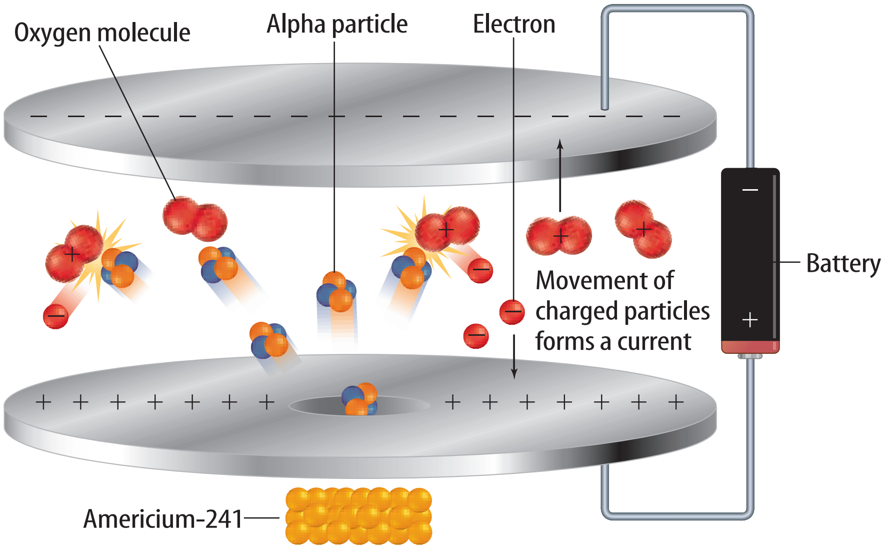
**Figure 8**
**When alpha particles collide with molecules in the air, positively-charged ions and electrons result. The ions and electrons move toward charged plates, creating a current in the smoke detector.**

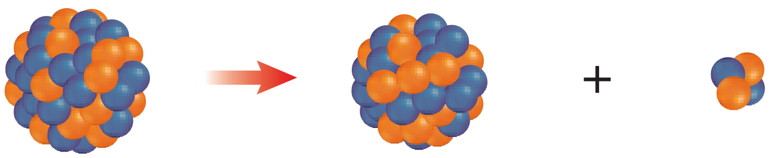


**Smoke Detectors** Some smoke detectors give off alpha particles that ionize the surrounding air. Normally, an electric current flows through this ionized air to form a circuit, as in **Figure 8.** But if smoke particles enter the ionized air, they will absorb the ions and electrons. The circuit is broken and the alarm goes off.

**Transmutation** When an atom loses an alpha particle, it no longer has the same number of protons, so it no longer is the same element. **Transmutation** is the process of changing one element to another through nuclear decay. In alpha decay, two protons and two neutrons are lost from the nucleus, so the new element formed has an atomic number two less than that of the original element. The mass number of the new element is four less than the original element. The nuclear equation in **Figure 9** shows a nuclear transmutation caused by alpha decay. Notice in the equation that the charge of the original nucleus equals the sum of the charges of the nucleus and the alpha particle that are formed.

**Figure 9**
**In this transmutation, polonium emits an alpha particle and changes into lead.** *Do the charges and mass numbers of the products add up to the charge and mass number of the polonium nucleus?*

$$^{210}_{84}\text{Po} \qquad ^{206}_{82}\text{Pb} + {}^{4}_{2}\text{He}$$



$$+84 \rightarrow +82 + +2$$

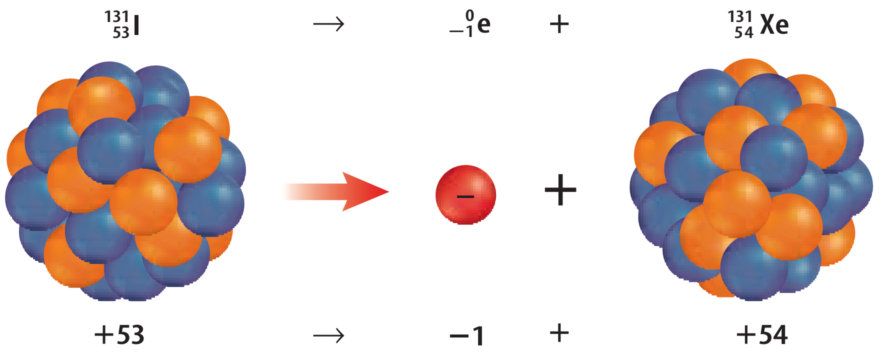


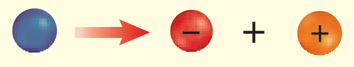
**Figure 10**
**Nuclei that emit beta particles undergo transmutation. In this process, iodine changes to xenon.** *Show how the charges and masses of the products add up to the charge and mass of the iodine nucleus.*

## Beta Particles

A second type of radioactive decay is called beta decay, which is summarized in **Table 2.** Sometimes in an unstable nucleus a neutron decays into a proton and emits an electron. The electron is emitted from the nucleus and is called a **beta particle.** Beta decay is caused by another basic force called the weak force.

Because the atom now has one more proton, it becomes the element with an atomic number one greater than that of the original element. Atoms that lose beta particles undergo transmutation. However, because the total number of protons and neutrons does not change during beta decay, the atomic mass number of the new element is the same as that of the original element. **Figure 10** shows a transmutation caused by beta decay.

**Table 2 Beta Particles**

| | |
|---|---|
|  | |
| **Symbol** | β |
| **Mass** | 0.0005 |
| **Charge** | −1 |

### Damage from Beta Particles

Beta particles are much faster and more penetrating than alpha particles. They can pass through paper but are stopped by a sheet of aluminum foil. Just like alpha particles, beta particles can damage cells when they are emitted by radioactive nuclei inside the human body.

## Gamma Rays

The most penetrating form of radiation is not made of protons, neutrons, or electrons. **Gamma rays** are a form of radiation called electromagnetic waves. Like water and sound waves, gamma rays carry energy. They have no mass and no charge, and they travel at the speed of light. They usually are released along with alpha or beta particles. The characteristics of gamma rays are summarized in **Table 3.**

Thick blocks of dense materials, such as lead and concrete, are required to stop gamma rays. However, gamma rays cause less damage to biological molecules as they pass through living tissue. Suppose an alpha particle and a gamma ray travel the same distance through matter. The gamma ray produces far fewer ions because it has no electric charge.

**Table 3 Gamma Radiation**

| | |
|---|---|
|  | |
| **Symbol** | γ |
| **Mass** | 0 |
| **Charge** | 0 |

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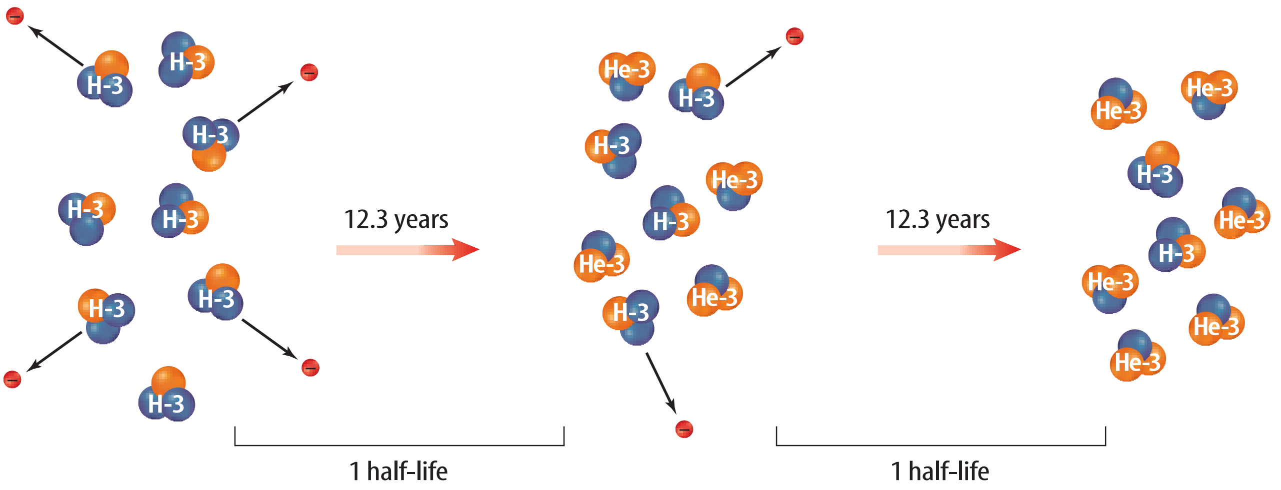

**Figure 11**
**The half-life of ${}^{3}_{1}\text{H}$ is 12.3 years. During each half-life, half of the atoms in the sample decay into helium.** *How many hydrogen atoms will be left in the sample after the next half-life?*

## Radioactive Half-Life

If an element is radioactive, how can you tell when its atoms are going to decay? Some radioisotopes decay to stable atoms in less than a second. However, the nuclei of certain radioactive isotopes require millions of years to decay. A measure of the time required by the nuclei of an isotope to decay is called the half-life. The **half-life** of a radioactive isotope is the amount of time it takes for half the nuclei in a sample of the isotope to decay. The nucleus left after the isotope decays is called the daughter nucleus. **Figure 11** shows how the number of decaying nuclei decreases after each half-life.

Half-lives vary widely among the radioactive isotopes. For example, polonium-214 has a half-life of less than a thousandth of a second, but uranium-238 has a half-life of 4.5 billion years. The half-lives of some other radioactive elements are listed in **Table 4.**

**Table 4 Sample Half-Lives**

| Isotope | Half-Life |
|---|---|
| ${}^{3}_{1}\text{H}$ | 12.3 years |
| ${}^{212}_{82}\text{Pb}$ | 10.6 hr |
| ${}^{14}_{6}\text{C}$ | 5,730 years |
| ${}^{211}_{84}\text{Po}$ | 0.5 s |
| ${}^{235}_{92}\text{U}$ | $7.04 \times 10^{8}$ years |
| ${}^{131}_{53}\text{I}$ | 8.04 days |

✓ **Reading Check** *What is a daughter nucleus?*

## Radioactive Dating

Some geologists, biologists, and archaeologists, among others, are interested in the ages of rocks and fossils found on Earth. The ages of these materials can be determined using radioactive isotopes and their half-lives. First, the amounts of the radioactive isotope and its daughter nucleus in a sample of material are measured. Then, the number of half-lives that need to pass to give the measured amounts of the isotope and its daughter nucleus is calculated. The number of half-lives is the amount of time that has passed since the isotope began to decay. It is also usually the amount of time that has passed since the object was formed, or the age of the object. Different isotopes are useful in dating different types of materials.

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**Carbon Dating** The radioactive isotope carbon-14 often is used to find the ages of objects that were once living. Carbon-14 is found in molecules throughout the environment, including some carbon dioxide molecules plants take in as they carry out photosynthesis. Carbon-14 atoms behave chemically just like nonradioactive carbon-12 atoms, so all living plants contain some carbon-14. When animals eat plants, they ingest some of the radioactive carbon-14.

An atom of carbon-14 eventually will decay into nitrogen-14. The half-life of carbon-14 is 5,730 years. The amount of carbon-14 in living plants and animals remains fairly constant as decaying carbon-14 is replaced constantly by new carbon-14 when an animal eats or a plant makes food. However, when an organism dies, its carbon-14 atoms decay without being replaced. By measuring the amount of carbon-14 in a sample and comparing it to the amount of carbon-12, scientists can determine the approximate age of the material. Only the remains of plants and animals that lived within the last 50,000 years contain enough carbon-14 to measure.

**Uranium Dating** Radioactive dating also can be used to estimate the ages of rocks. Some rocks contain uranium, which has two radioactive isotopes with long half-lives. Each of these uranium isotopes decays into a different isotope of lead. The amount of these uranium isotopes and their daughter nuclei are measured. From the ratios of these amounts, the time since the rock was formed can be calculated.

TRY AT HOME Mini LAB

### Modeling the Strong Force

#### Procedure

1. Gather together **15 yellow candies** to represent neutrons and **13 red** and **two green candies** to represent protons.
2. Model a small nucleus by arranging one red and one green proton and two neutrons in a tight group.
3. Model a larger nucleus by arranging the remaining candies in a tight group.

#### Analysis

1. Compare the number of protons and neutrons touching the green proton in both nuclei. From this, compare the strong force on a proton in both nuclei.
2. How would the strong force on a proton change if the number of protons and neutrons in a nucleus were much larger?

## Section 2 Assessment

1. Describe three types of radiation.
2. Write a nuclear equation to show how radon-222 decays to give off an alpha particle and another element. What is the other element?
3. What is a half-life?
4. How is radioactivity useful in determining the age of material that was once part of a living organism?
5. **Think Critically** Is it possible for an isotope to decay to an element with a higher atomic number? Explain.

### Skill Builder Activities

6. **Using an Electronic Spreadsheet** Write a short program that allows you to input the mass and the half-life of a radioactive sample and calculate what mass remains after a certain number of half-lives. **For more help, refer to the Technology Skill Handbook.**
7. **Using Fractions** The half-life of iodine-131 is about eight days. Calculate how much of a 40-g sample will be left after eight days, after 16 days, and after 32 days. **For more help, refer to the Math Skill Handbook.**

SECTION 3

# Detecting Radioactivity

**As You Read**

### What You'll Learn

- **Describe** how radioactivity can be detected in cloud and bubble chambers.
- **Explain** how an electroscope can be used to detect radiation.
- **Explain** how a Geiger counter can measure nuclear radiation.

### Vocabulary

cloud chamber
bubble chamber
Geiger counter

### Why It's Important

Devices to detect and measure radioactivity are needed to monitor exposure to humans.

## Radiation Detectors

Because you can't see or feel alpha particles, beta particles, or gamma rays, you must use instruments to detect their presence. Some tools that are used to detect radioactivity rely on the fact that radiation forms ions in the matter it passes through. The tools detect these newly formed ions in several ways.

**Cloud Chambers** A **cloud chamber,** shown in **Figure 12,** can be used to detect alpha or beta particle radiation. A cloud chamber is filled with water or ethanol vapor. When a radioactive sample is placed in the cloud chamber, it gives off charged alpha or beta particles that travel through the water or ethanol vapor. As each charged particle travels through the chamber, it knocks electrons off the atoms in the air, creating ions. It leaves a trail of ions in the chamber. The water or ethanol vapor condenses around these ions, creating a visible path of droplets along the track of the particle. Beta particles leave long, thin trails, and alpha particles leave shorter, thicker trails.

✓ **Reading Check** *Why are trails produced by alpha and beta particles seen in cloud chambers?*

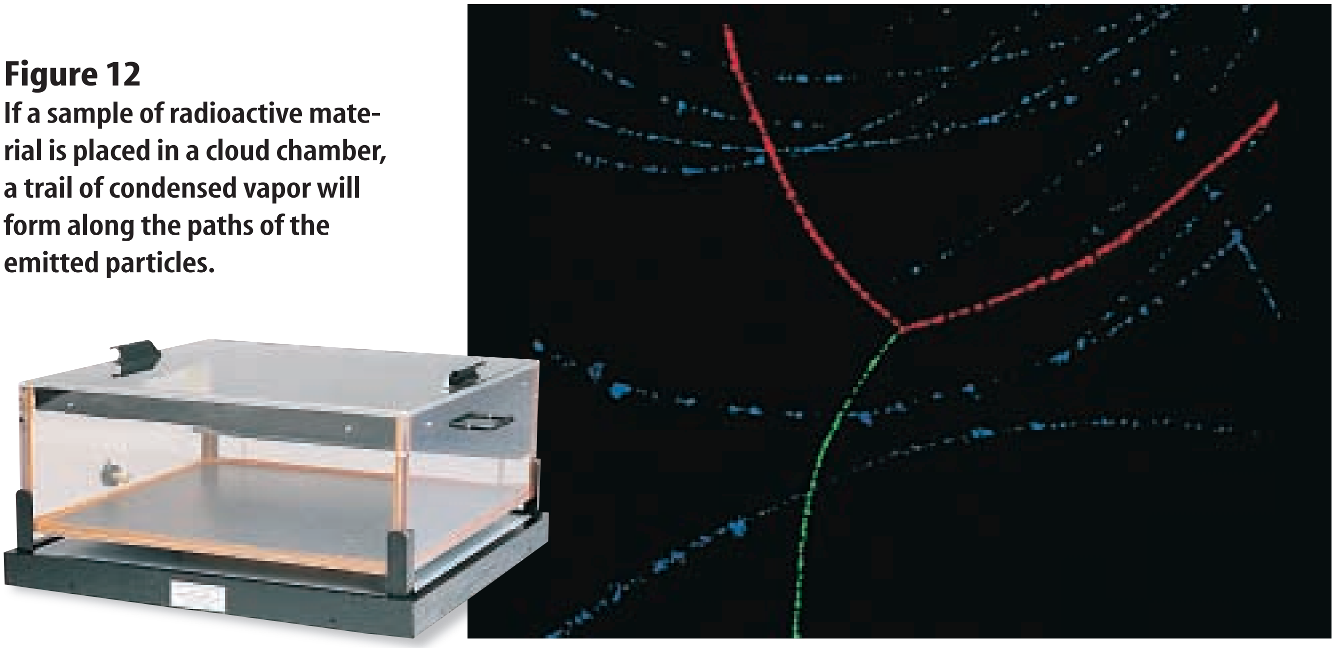

**Figure 12**
**If a sample of radioactive material is placed in a cloud chamber, a trail of condensed vapor will form along the paths of the emitted particles.**

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**Bubble Chambers** Another way to detect and monitor the paths of nuclear particles is by using a bubble chamber. A **bubble chamber** holds a superheated liquid, which doesn't boil because the pressure in the chamber is high. When a moving particle leaves ions behind, the liquid boils along the trail. The path shows up as tracks of bubbles, like the ones in **Figure 13.**

**Electroscopes** Do you remember how an electroscope can be used to detect electric charges? When an electroscope is given a negative charge, its leaves repel each other and spread apart, as in **Figure 14A.** They will remain apart until their extra electrons have somewhere to go and discharge the electroscope. The excess charge can be neutralized if it combines with positive charges. Nuclear radiation moving through the air can remove electrons from some molecules in air, as shown in **Figure 14B,** and cause other molecules in air to gain electrons. When this occurs near the leaves of the electroscope, some positively charged molecules in the air can come in contact with the electroscope and attract the electrons from the leaves, as **Figure 14C** shows. As these negatively charged leaves lose their charges, they move together. **Figure 14D** shows this last step in the process. The same process also will occur if the electroscope leaves are positively charged. Then the electrons move from negative ions in the air to the electroscope leaves.

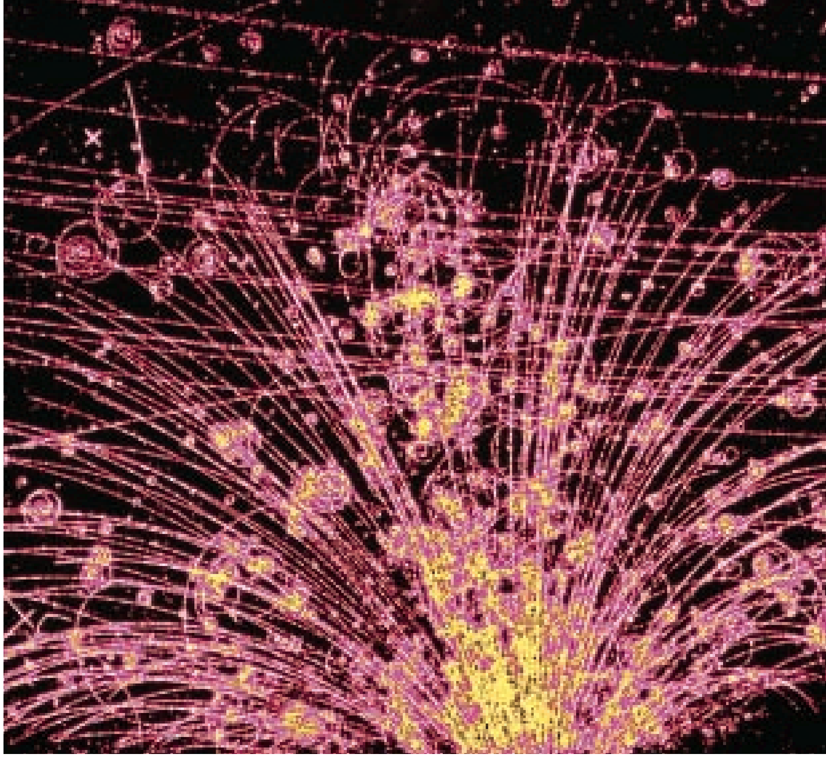
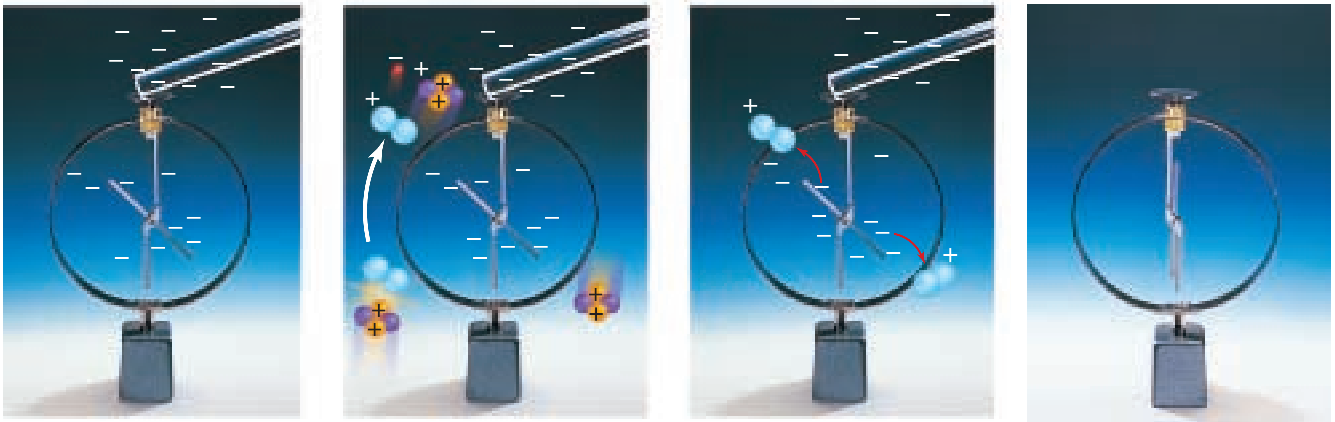


**Figure 13**
**Particles of nuclear radiation can be detected as they leave trails of bubbles in a bubble chamber.**

**Figure 14**
**Nuclear radiation can cause an electroscope to lose its charge.**



**A** The electroscope leaves are charged with negative charge.

**B** Nuclear radiation, such as alpha particles, can create positive ions.

**C** Negative charges move from the leaves to positively charged ions.

**D** The electroscope leaves lose their negative charge and come together.

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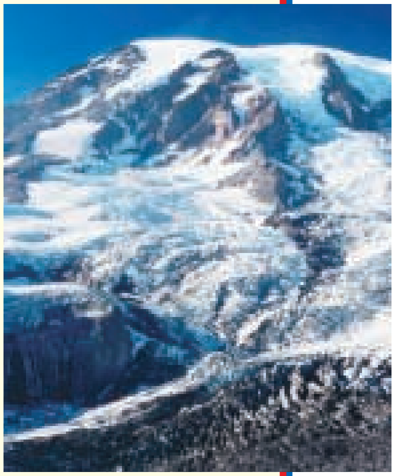
## Measuring Radiation

Large doses of radiation are harmful to living tissue. If you worked or lived in an environment that had potential for exposure to high levels of radiation—for example, a nuclear testing facility—you might want to know exactly how much radiation you were being exposed to. You could measure the radiation with a Geiger (GI gur) counter. A **Geiger counter** is a device that measures radioactivity by producing an electric current when radiation is present.

## Math Skills Activity

### How can radioactive half lives be used to measure geological time?



### Example Problem

The time it takes for half of the atoms of one element in a piece of rock to change into another element is called its half-life. Scientists use the half-lives of radioactive isotopes to measure geological time. Potassium-40 has a half-life of 1.28 billion years before it produces the stable daughter product argon-40. If three-fourths of the potassium-40 atoms in a rock had changed into atoms of argon-40, how old would you predict the rock to be?

### Solution

1. *This is what you know:*

   half-life of potassium-40 = 1.28 billion years
   75% of potassium-40 atoms have decayed

2. *This is what you want to find:*

   age of the rock

3. *Set up a pattern to help solve:*

   The age of the rock would be 2.56 billion years old.

**Rate of Decay**

| Time | % Potassium-40 | % Argon-40 |
|---|---|---|
| 1.28 billion years | 50% | 50% |
| 2.56 billion years | 25% | 75% |
| 3.84 billion years | 12.5% | 87.5% |

#### Practice Problem

Uranium-238 has a half-life of 4.5 billion years before half of the atoms change into lead-206. Determine the age of a rock in which approximately 94% of the atoms are lead-206.

**For more help, refer to the Math Skill Handbook.**

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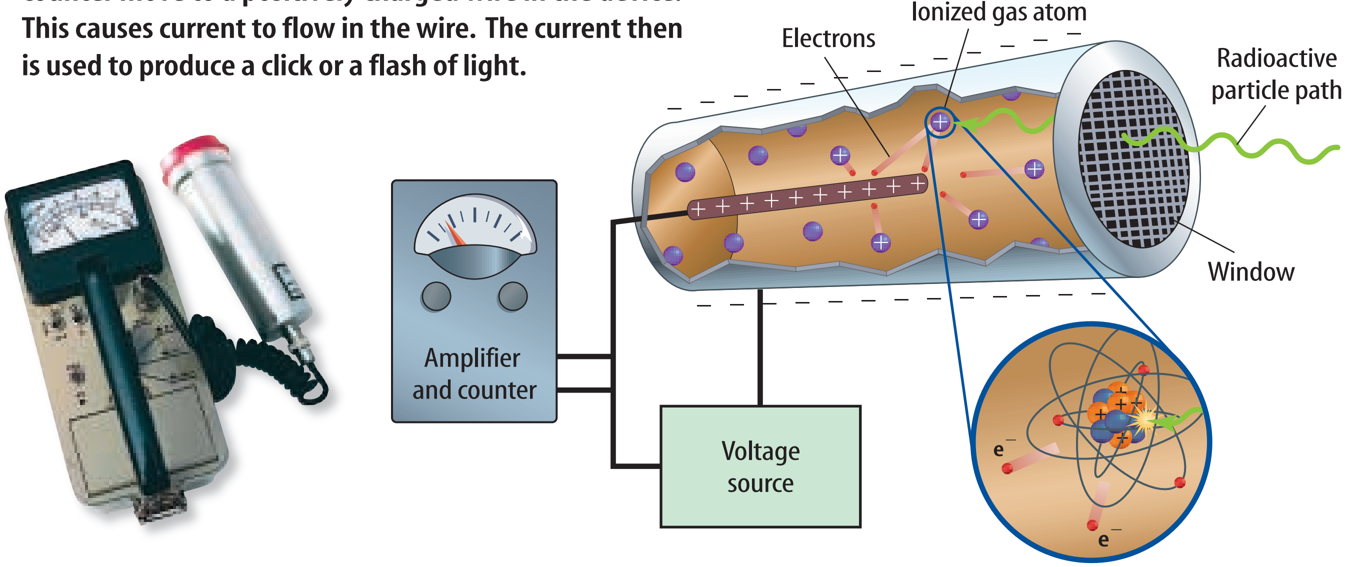
**Figure 15**
**Electrons that are stripped off gas molecules in a Geiger counter move to a positively charged wire in the device. This causes current to flow in the wire. The current then is used to produce a click or a flash of light.**



**Geiger Counters** **Figure 15** shows a Geiger counter. A Geiger counter has a tube with a positively charged wire running through the center of a negatively charged copper cylinder. This tube is filled with gas at a low pressure. When radiation enters the tube at one end, it knocks electrons from the atoms of the gas. These electrons then knock more electrons off other atoms in the gas, and an "electron avalanche" is produced. The free electrons are attracted to the positive wire in the tube. When a large number of electrons reaches the wire, a short, intense current is produced in the wire. This current is amplified to produce a clicking sound or flashing light. The intensity of radiation present is determined by the number of clicks or flashes of light each second.

✓ **Reading Check** *How does a Geiger counter indicate that radiation is present?*

## Background Radiation

It might surprise you to know that you are bathed in radiation that comes from your environment. This radiation, called background radiation, is not produced by humans. Instead it is low-level radiation emitted mainly by naturally occurring radioactive isotopes found in Earth's rocks, soils, and atmosphere. Building materials such as bricks, wood, and stones contain traces of these radioactive materials. Traces of naturally occurring radioactive isotopes are found in the food, water, and air consumed by all animals and plants. As a result, animals and plants also contain small amounts of these isotopes.

**Earth Science**
**INTEGRATION**

The formation of droplets in a cloud chamber is similar to the formation of rain drops in a cloud. Clouds contain droplets of very cold water. Rain forms when these droplets freeze around microscopic particles of dust and then melt as they fall through air warmer than freezing. Many attempts have been made to make rain fall from clouds. Research some attempts at artificial rainmaking and report your findings to your class.

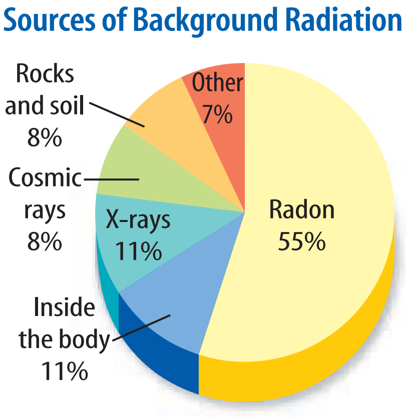


**Figure 16**
**This circle graph shows the sources of background radiation received on average by a person living in the United States.**

### Sources of Background Radiation

Background radiation comes from several sources, as shown in **Figure 16.** The largest source comes from the decay of radon gas. Radon is produced in Earth's crust by the decay of uranium-238 and emits an alpha particle when it decays. Radon gas can seep into houses and basements from the surrounding soil and rocks and can be inhaled.

Some background radiation comes from high-speed nuclei, called cosmic rays, that hit the top of Earth's atmosphere. They produce showers of particles, including alpha, beta, and gamma radiation. Most of this radiation is absorbed by the atmosphere. As you go higher, less atmosphere is above you to absorb this radiation. Therefore, the background radiation from cosmic rays increases with elevation.

### Radiation in Your Body

Naturally occurring radiation also is found inside your body. Some of the elements in your body that are essential for life have naturally occurring radioactive isotopes. For example, about one out of every trillion carbon atoms is carbon-14, which emits a beta particle when it decays. With each breath, you inhale about 3 million carbon-14 atoms.

The amount of background radiation a person receives can vary greatly. The amount depends on the type of rocks underground, the type of materials used to construct the person's home, and the elevation at which the person lives, among other things. However, because it comes from naturally occurring processes, background radiation never can be eliminated.

## Section 3 Assessment

1. What are four ways that radioactivity can be detected?
2. How are cloud and bubble chambers similar? How are they different?
3. How can an electroscope be used to detect nuclear radiation?
4. Briefly explain how a Geiger counter operates.
5. **Think Critically** Which device would be used to check the amount of radiation present in your home? What are the possible sources of the radiation?

### Skill Builder Activities

6. **Drawing Conclusions** You are observing the presence of nuclear radiation with a bubble chamber and see two kinds of trails. Some trails are short and thick, and others are long and thin. What type of nuclear radiation might have caused each trail? **For more help, refer to the Science Skill Handbook.**
7. **Drawing Conclusions** Explain why homes can contain radon gas even though radon-22 has a half-life of only four days. **For more help, refer to the Science Skill Handbook.**

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SECTION 4

# Nuclear Reactions

## Nuclear Fission

Do you know what the first step in a game of pool is? One player shoots the cue ball into a triangle of densely packed billiard balls. If the cue ball hits the triangle right on, the balls spread apart, or break. In 1938, two physicists named Otto Hahn and Fritz Strassmann found that a similar result occurs when a neutron is shot into the large nucleus of a uranium-235 atom. The nucleus is split.

Lise Meitner was the first to offer a theory to explain the splitting of a nucleus. She concluded that the neutron fired into the nucleus disturbs and distorts the uranium-235 nucleus. The nuclear strong force is no longer enough to overcome the electrical repulsion within the nucleus, causing it to split into two nuclei, as in **Figure 17.** The process of splitting a nucleus into two nuclei with smaller masses is called **nuclear fission.** The word *fission* means "to divide."

**✓ Reading Check** ***What initiates nuclear fission of a uranium-235 nucleus?***

Only large nuclei, such as the nuclei of uranium and plutonium atoms, can undergo nuclear fission. The products of a fission reaction usually include several individual neutrons in addition to the smaller nuclei. The total mass of the products is slightly less than the mass of the original nucleus and the neutron. This small amount of missing mass is converted to a tremendous amount of energy during the fission reaction.

### As You Read

### What You'll Learn

- **Explain** nuclear fission and how it can begin a chain reaction.
- **Discuss** how nuclear fusion occurs in the Sun.
- **Describe** how radioactive tracers can be used to diagnose medical problems.
- **Discuss** how nuclear reactions can help treat cancer.

### Vocabulary

nuclear fission
chain reaction
critical mass
nuclear fusion
tracer

### Why It's Important

Radiation from nuclear reactions can be used to generate power and diagnose and treat medical problems.

**Figure 17**
**When a neutron hits a uranium-235 nucleus, the uranium nucleus splits into two smaller nuclei and two or three free neutrons. Energy also is released.**

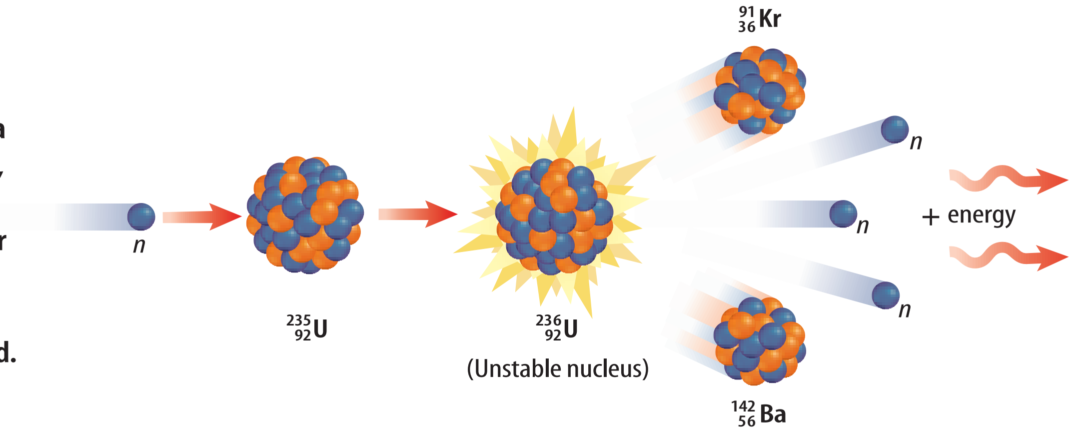

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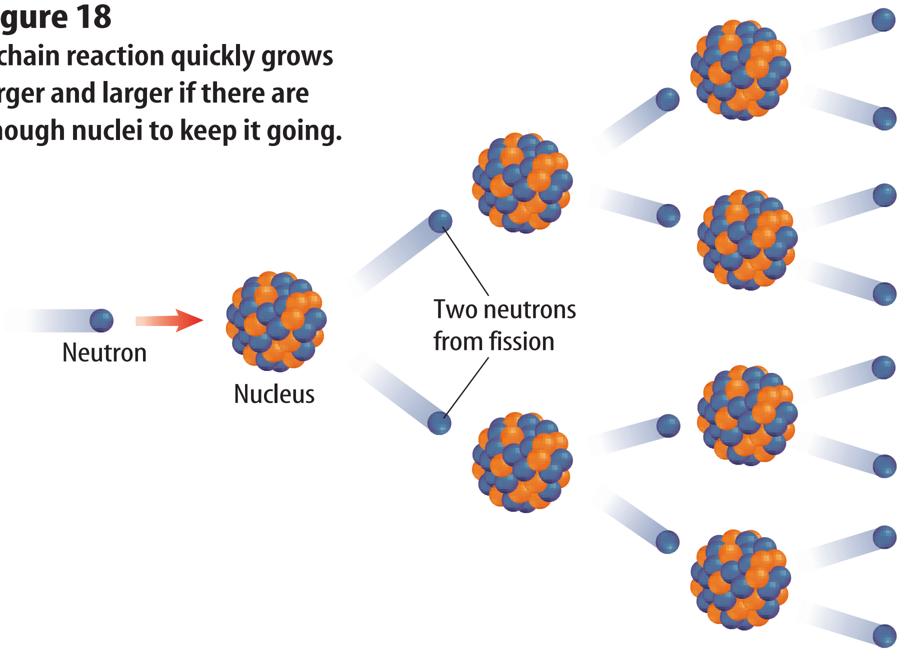
**Figure 18**
A chain reaction quickly grows larger and larger if there are enough nuclei to keep it going.



## Mini LAB

### Modeling a Nuclear Reaction

**Procedure**

1. Put **32 marbles,** each with an attached lump of **clay,** into a large **beaker.** These marbles with clay represent unstable atoms.
2. During a 1-min period, remove half of the marbles and pull off the clay. Place the removed marbles into another beaker and place the lumps of clay into a pile. Marbles without clay represent stable atoms. The clay represents waste from the reaction—smaller atoms that still might decay and give off energy.
3. Repeat this procedure four more times.

**Analysis**

1. How does this model show one of the main problems that is associated with using nuclear power to make electricity?
2. Why is it difficult to find a place for waste products from nuclear reactions?

**Chain Reactions** The energy released in a nuclear fission reaction is much greater than the energy released by the natural, spontaneous decay of a radioactive isotope. The neutrons produced in the fission reaction can then bombard and split other nuclei in the sample. These reactions each release more neutrons. If some other material is not present to absorb some of these neutrons as they are released, an uncontrolled chain reaction can result. A **chain reaction,** represented in **Figure 18,** is an ongoing series of fission reactions. Billions of reactions can occur each second during a chain reaction, resulting in the release of tremendous amounts of energy.

When controlled, the large amounts of energy released in nuclear fission reactions can be used to generate electricity. Nuclear fission reactions also are used in nuclear weapons.

**Critical Mass** To be useful, chain reactions cannot grow out of control or die out. Especially when chain reactions are used to produce electricity, they should occur at a relatively constant rate. How can the rate of chain reactions be controlled when they involve so much energy? Chain reactions can be controlled if the number of neutrons that are available to start additional fission reactions is controlled carefully. This can be done by adding materials that absorb neutrons. If enough neutrons are absorbed, the chain reaction will continue at a constant rate. The **critical mass** is the amount of fissionable material required so that each fission reaction produces approximately one more fission reaction. If less than the critical mass of reaction material is present, a chain reaction will not occur.

## Nuclear Fusion

Tremendous amounts of energy can be released in nuclear fission. In fact, splitting one uranium-235 nucleus produces about 30 million times more energy than chemically reacting one molecule of dynamite. Even more energy can be released in another type of nuclear reaction, called nuclear fusion. In **nuclear fusion,** two nuclei with low masses are combined to form one nucleus of larger mass. Fusion fuses atomic nuclei together, and fission splits nuclei apart.

**SCIENCE Online**

**Research** Visit the Glencoe Science Web site at **science.glencoe.com** for more information about scientists' research involving nuclear fusion. Communicate to your class what you learn.

CLICK HERE

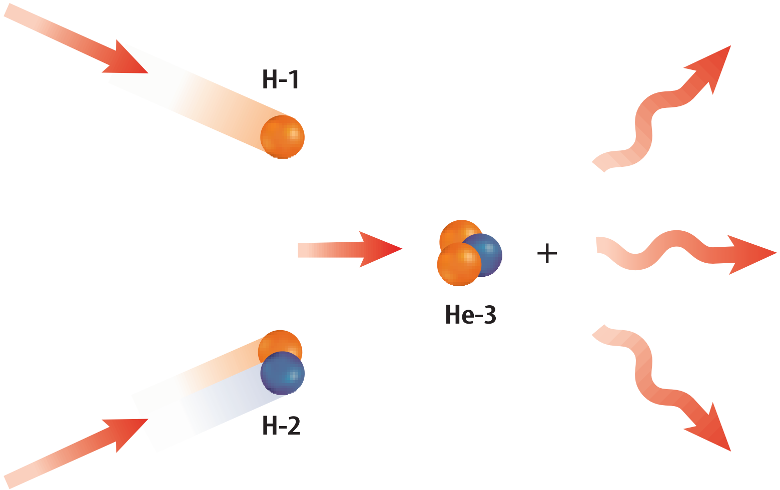
**Temperature and Fusion** For nuclear fusion to occur, positively charged nuclei must get close to each other. However, all nuclei repel each other because they have the same positive electric charge. If nuclei are moving fast, they can have enough kinetic energy to overcome the repulsive electrical force between them and get close to each other.

Remember that the kinetic energy of atoms or molecules increases as their temperature increases. Only at temperatures of millions of degrees Celsius are nuclei moving so fast that they can get close enough for fusion to occur. These extremely high temperatures are found in the center of stars, including the Sun.

**Nuclear Fusion and the Sun** The Sun is composed mainly of hydrogen. Most of the energy given off by the Sun is produced by a process involving the fusion of hydrogen nuclei. This process occurs in several stages, and one of the stages is shown in **Figure 19.** The net result of this process is that four hydrogen nuclei are converted into one helium nucleus. As this occurs, a small amount of mass is changed into an enormous amount of energy. Earth receives a small amount of this energy as heat and light.

As the Sun ages, the hydrogen nuclei are used up as they are converted into helium. So far, only about one percent of the Sun's mass has been converted into energy. Eventually, no hydrogen nuclei will be left, and the fusion reaction that changes hydrogen into helium will stop. However, it is estimated that the Sun has enough hydrogen to keep this reaction going for another 5 billion years.

**Figure 19**
**The fusion of hydrogen to form helium takes place in several stages in the Sun. One of these stages is shown here. An isotope of helium is produced when a proton and the hydrogen isotope H-2 undergo fusion.**



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**Chemistry INTEGRATION**

One way a uranium-235 atom can fission, or break apart, is into barium and krypton. Use a periodic table to find the atomic numbers of barium and krypton. What do they add up to? A uranium-235 atom can fission in several other ways such as producing neodymium and another element. What is the other element?

## Using Nuclear Reactions in Medicine

If you were going to meet a friend in a crowded area, it would be easier to find her if your friend told you that she would be wearing a red hat. In a similar way, scientists can find one molecule in a large group of molecules if they know that it is "wearing" something unique. Although a molecule can't wear a red hat, if it has a radioactive atom in it, it can be found easily in a large group of molecules, or even a living organism. Radioactive isotopes can be located by detecting the radiation they emit.

When a radioisotope is used to find or keep track of molecules in an organism, it is called a **tracer.** Scientists can use tracers to follow where a particular molecule goes in your body or to study how a particular organ functions. Tracers also are used in agriculture to monitor the uptake of nutrients and fertilizers. Examples of tracers include carbon-11, iodine-131, and sodium-24. These three radioisotopes are useful tracers because they are important in certain body processes. As a result, they accumulate inside the organism being studied.

✓ **Reading Check** *What use do tracers have in agriculture?*

**Iodine Tracers in the Thyroid** The thyroid gland is located in your neck and produces chemical compounds called hormones. These hormones help regulate several body processes, including growth. Because the element iodine accumulates in the thyroid, the radioisotope iodine-131 can be used to diagnose thyroid problems. As iodine-131 atoms are absorbed by the thyroid, their nuclei decay, emitting beta particles and gamma rays. The beta particles are absorbed by the surrounding tissues, but the gamma rays penetrate the skin. The emitted gamma rays can be detected and used to determine whether the thyroid is healthy, as shown in **Figure 20.** If the detected radiation is not intense, then the thyroid has not properly absorbed the iodine-131 and is not functioning properly. This could be due to the presence of a tumor. **Figure 21** shows how radioactive tracers are used to study the brain.

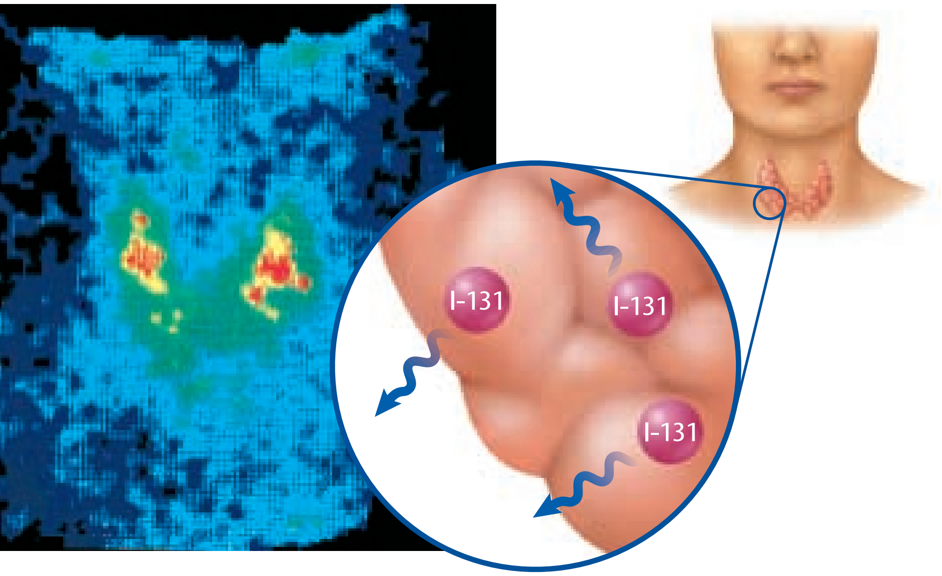

**Figure 20**
**Radioactive iodine-131 accumulates in the thyroid gland and emits gamma rays, which can be detected to form an image of a patient's thyroid.** *What are some advantages of being able to use iodine-131 to form an image of a thyroid?*

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# NATIONAL GEOGRAPHIC VISUALIZING PET SCANS

**Figure 21**

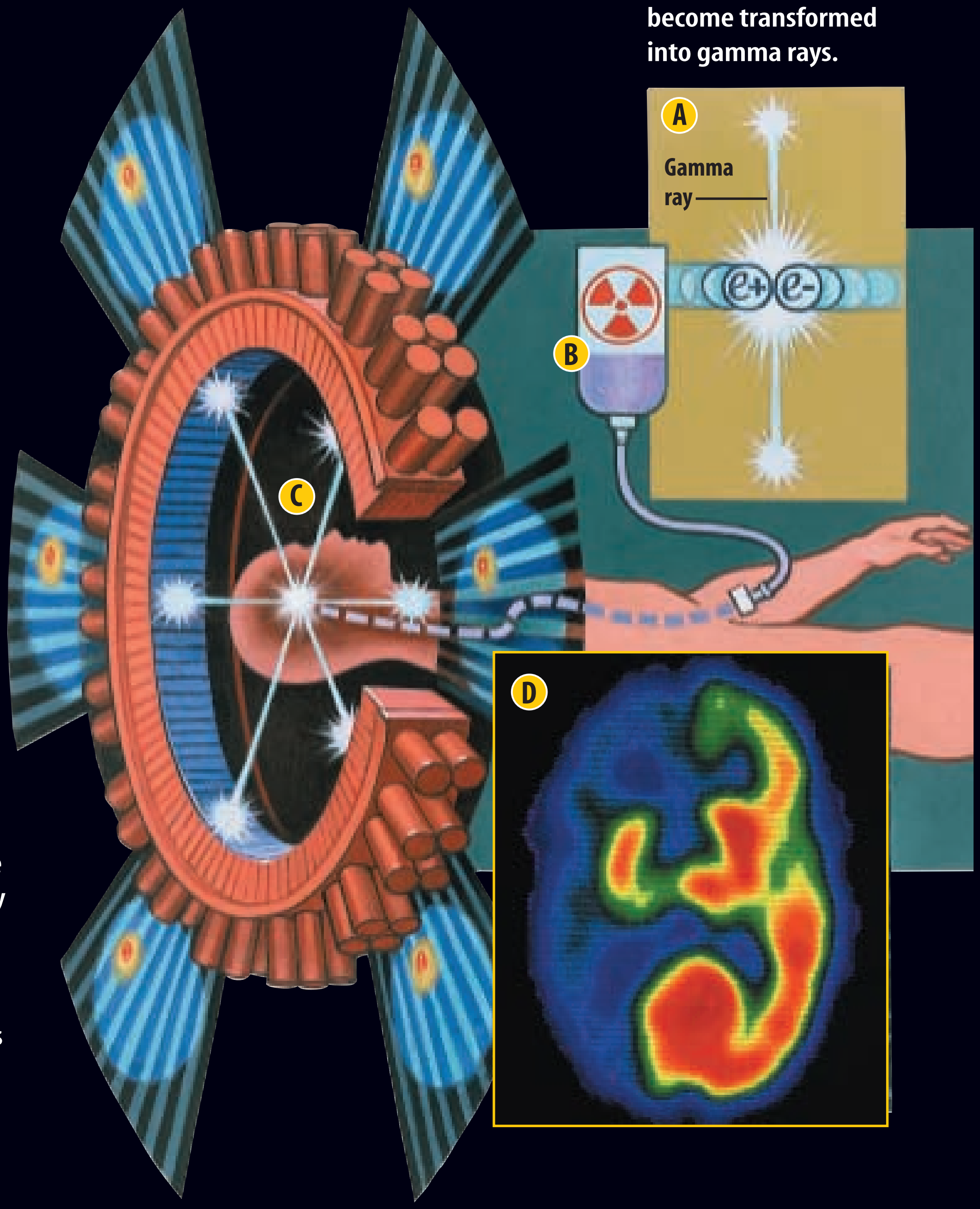
The diagram below shows an imaging technique known as Positron Emission Tomography, or PET. Positrons are emitted from the nuclei of certain radioactive isotopes when a proton changes to a neutron. PET can form images that show the level of activity in different areas of the brain. These images can reveal tumors and regions of abnormal brain activity.

**A** When positrons are emitted from the nucleus of an atom, they can hit electrons from other atoms and become transformed into gamma rays.

**B** The radioactive isotope fluorine-18 emits positrons when it decays. Fluorine-18 atoms are chemically attached to molecules that are absorbed by brain tissue. These compounds are injected into the patient and carried by blood to the brain.

**C** Inside the patient's brain, the decay of the radioactive fluorine-18 nuclei emits positrons that collide with electrons. The gamma rays that are released are sensed by the detectors.

**D** A computer uses the information collected by the detectors to generate an image of the activity level in the brain. This image shows normal activity in the right side of the brain (red, yellow, green) but below-normal activity in the left (purple).



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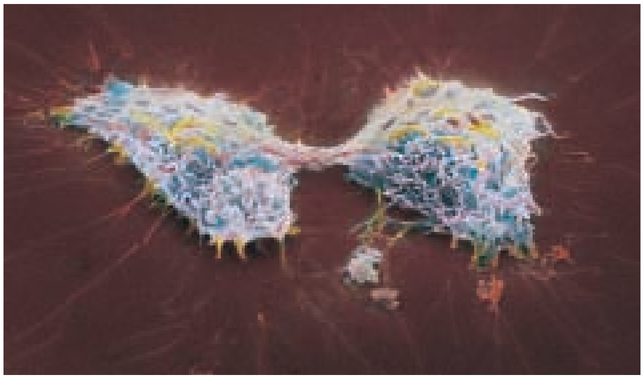

**Figure 22**
**Cancer cells, such as the ones shown here, can be killed with carefully-measured doses of radiation.**

## Treating Cancer with Radioactivity

When a person has cancer, a group of cells in that person's body grows out of control and can form a tumor. Radiation can be used to stop some types of cancerous cells from growing. Remember that the radiation that is given off during nuclear decay is strong enough to ionize nearby atoms. If a source of radiation is placed near cancer cells, atoms in the cells can be ionized. If the ionized atoms are in a critical molecule, such as the DNA or RNA of a cancer cell, then the molecule might no longer function properly. The cell then could die or stop growing, as shown in **Figure 22.**

When possible, a radioactive isotope such as gold-198 or iridium-192 is implanted within or near the tumor. Other times, tumors are treated from outside the body. Typically, an intense beam of gamma rays from the decay of cobalt-60 is focused on the tumor for a short period of time. The gamma rays pass through the body and into the tumor. How can physicians be sure that only the cancer cells will absorb radiation? Because cancer cells grow quickly, they are more susceptible to absorbing radiation and being damaged than healthy cells are. However, other cells in the body that grow quickly also are damaged, which is why cancer patients who have radiation therapy sometimes experience severe side effects.

## Section 4 Assessment

1. Why is critical mass important in some applications of nuclear fission?
2. Explain why it would be difficult to start a fusion reaction on Earth.
3. How might a tracer be used to diagnose a digestive problem?
4. Why does nuclear radiation cause damage to living cells?
5. **Think Critically** During nuclear fission, large nuclei with high masses are split into two nuclei with smaller masses. During nuclear fusion, two nuclei with low masses are combined to form one nucleus of larger mass. How are the two processes similar?

### Skill Builder Activities

6. **Concept Mapping** Make a concept map to show how a chain reaction occurs when U-235 is bombarded with a neutron. Show how each of the three neutrons given as products begins another fission reaction. **For more help, refer to the Science Skill Handbook.**
7. **Identifying a Question** Suppose you had a medical problem and the doctor suggested a diagnostic test that involved a radioactive tracer. Using what you have learned about medical applications of radioactivity, write a set of questions you might ask your doctor. **For more help, refer to the Science Skill Handbook.**

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# Activity

## Chain Reactions

In an uncontrolled nuclear chain reaction, the number of reactions increases as additional neutrons split more nuclei. In a controlled nuclear reaction, neutrons are absorbed, so the reaction continues at a constant rate. How could you model a controlled and an uncontrolled nuclear reaction in the classroom?

### What You'll Investigate

How can you use dominoes to model chain reactions?

### Materials

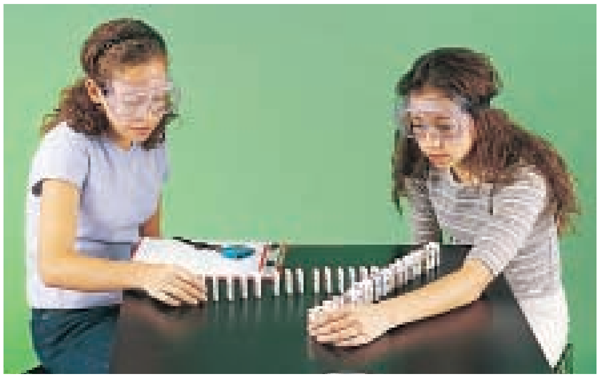
dominoes
stopwatch

### Goals

- **Model** a controlled and uncontrolled chain reaction
- **Compare** the two types of chain reactions

### Procedure

1. Set up a single line of dominoes standing on end so that when the first domino is pushed over, it will knock over the second and each domino will knock over the one following it.
2. Using the stopwatch, time how long it takes from the moment the first domino is pushed over until the last domino falls over. Record the time.
3. Using the same number of dominoes as in step 1, set up a series of dominoes in which at least one of the dominoes will knock down two others, so that two lines of dominoes will continue falling. In other words, the series should have at least one point that looks like the letter Y.
4. Repeat step 2.



### Conclude and Apply

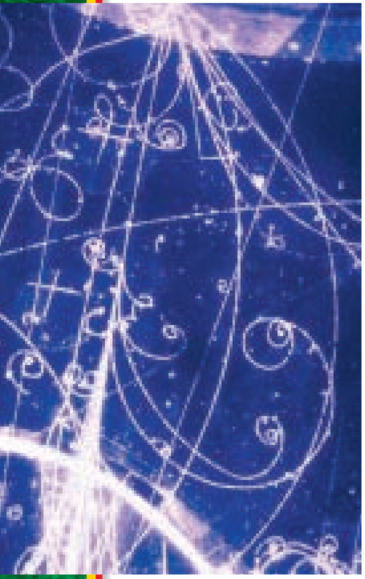
1. **Compare** the amount of time it took for all of the dominoes to fall in each of your two arrangements.
2. Were the same number of dominoes falling at a particular time in both domino arrangements? Explain.
3. Which of your domino arrangements represented a controlled chain reaction? Which represented an uncontrolled chain reaction?
4. **Describe** how the concept of critical mass was represented in your model of a controlled chain reaction.
5. Assuming that they had equal amounts of material, which would finish faster—a controlled or an uncontrolled nuclear chain reaction? Explain.

### Communicating Your Data

**Explain** to friends or members of your family how a controlled nuclear chain reaction can be used in nuclear power plants to generate electricity.

# Activity
## Model and Invent

# Modeling Transmutation



Imagine what would happen if the oxygen atoms around you began changing into nitrogen atoms. Without oxygen, most living organisms, including people, could not live. Fortunately, more than 99.9 percent of all oxygen atoms are stable and do not decay. Usually, when an unstable nucleus decays, an alpha or beta particle is thrown out of its nucleus, and the atom becomes a new element. A uranium-238 atom, for example, will undergo eight alpha decays and six beta decays to become lead. This process of one element changing into another element is called transmutation. You will model this decay process during this activity.

## Recognize the Problem

How could you create a model of a uranium-238 atom and the decay process it undergoes during transmutation?

## Thinking Critically

What types of materials could you use to represent the protons and neutrons in a U-238 nucleus? How could you use these materials to model transmutation?

### Possible Materials

brown rice
white rice
colored candies
dried beans
dried seeds
glue
poster board

### Safety Precautions

Never eat foods used in the lab.

### Data Source

Refer to your textbook for general information about transmutation.

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## Planning the Model

1. **Choose** two materials of different colors or shapes for the protons and neutrons of your nucleus model. Choose a material for the negatively charged beta particle.
2. **Decide** how to model the transmutation process. Will you create a new nucleus model for each new element? How will you model an alpha or beta particle leaving the nucleus?
3. **Create** a transmutation chart to show the results of each transmutation step of a uranium-238 atom with the identity, atomic number, and mass number of each new element formed and the type of radiation particle emitted at each step. A uranium-238 atom will undergo the following decay steps before transmuting into a lead-206 atom: alpha decay, beta decay, beta decay, alpha decay, alpha decay, alpha decay, alpha decay, alpha decay, beta decay, beta decay, alpha decay, beta decay, beta decay, alpha decay.

### Check the Model Plans

1. **Describe** your model plan and transmutation chart to your teacher and ask how they can be improved.
2. **Present** your plan and chart to your class. Ask classmates to suggest improvements in both.

## Making the Model

1. Construct your model of a uranium-238 nucleus showing the correct number of protons and neutrons.
2. Using your nucleus model, demonstrate the transmutation of a uranium-238 nucleus into a lead-206 nucleus by following the decay sequence outlined in the previous section.
3. Show the emission of an alpha particle or beta particle between each transmutation step.

## Analyzing and Applying Results

1. **Compare** how alpha and beta decay change an atom's atomic number.
2. **Compare** how alpha and beta decay change the mass number of an atom.
3. **Calculate** the ratio of neutrons to protons in lead-206 and uranium-238. In which nucleus is the ratio closer to 1.5?
4. Alchemists living during the Middle Ages spent much time trying to turn lead into gold. Identify the decay processes needed to accomplish this task.

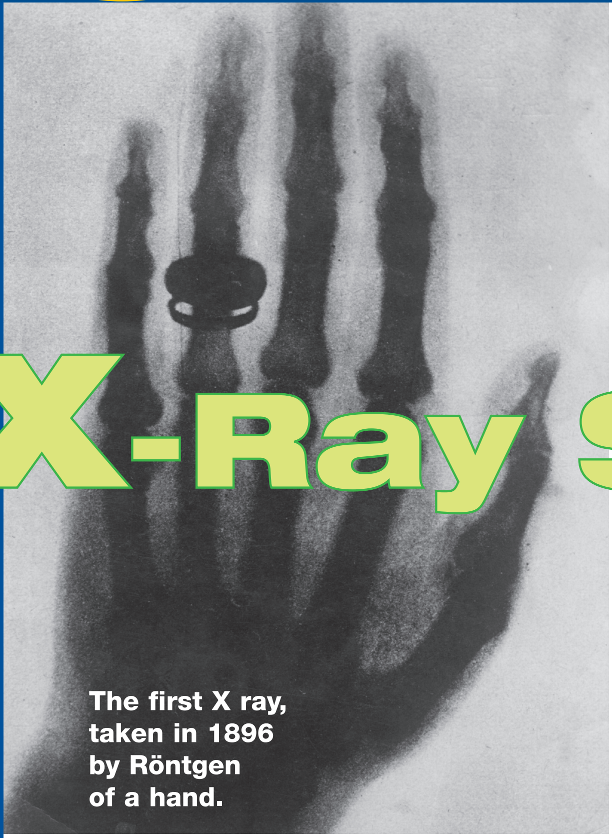
### Communicating Your Data

Show your model to the class and explain how your model represents the transmutation of U-238 into Pb-206.

# Oops! Accidents in SCIENCE

SOMETIMES GREAT DISCOVERIES HAPPEN BY ACCIDENT!

# X-Ray Surprise

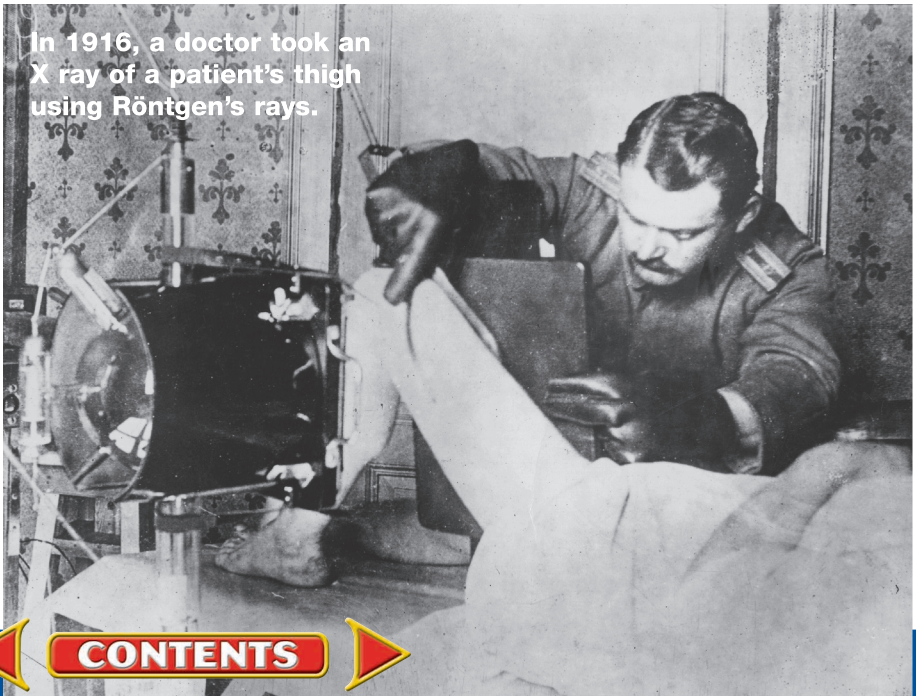


The first X ray, taken in 1896 by Röntgen of a hand.

The image on the X-ray screen looked like a metal box with wires attached to it. The airport security guard blinked, but her expression didn't change. "Excuse me, sir, could you step over here?" The passenger cooperated and the mysterious metal box turned out to be a tackle box tangled up with wires from a miniature radio headset. "Next time you fly, please bring a plastic tackle box," the guard advised. "It won't set off any alarms!"

Today, X rays of people and objects are fairly routine. But back in 1895, in Germany, an X ray was unknown and about to be discovered. Physics professor Wilhelm Röntgen was experimenting with a glass tube from which most of the air had been removed.

He sent a jolt of electricity from one end of the tube to the other and tried to observe the results. "What's wrong?" he asked himself. There was too much light in the room to see what was happening in the tube. So Röntgen darkened the room, put black paper around the tube, and restarted the electricity. The tube glowed. And in the dark room, a screen also glowed. Röntgen knew that something besides light must be coming from the tube, but what? He hadn't a clue. So he called these mysterious, unknown rays, X rays.



In 1916, a doctor took an X ray of a patient's thigh using Röntgen's rays.

An X ray of a suitcase, a briefcase, and a handbag reveals their contents. What objects can you identify?

## Medical Breakthrough

What Röntgen didn't know at the time is that X-ray radiation is a part of the electromagnetic spectrum with a shorter wavelength than light. X rays are created in an X-ray machine when a tungsten target is hit with electrons. The radiation produced passes easily through soft body tissues and materials, but is stopped by dense materials, such as metal and bone. X rays that pass through the soft material can be captured on film, leaving an outline of the dense material—an X ray.

Thanks to Röntgen's accidental discovery, doctors can look inside the human body. Fractured bones can be spotted, and certain diseases detected. However, too much exposure to X rays is dangerous to the body. But even this downside has been put to use, as radiation treatment to destroy cancerous cells.

An airport security check

## X-Ray Visions

New uses for X rays continue to emerge. For example, one powerful type of X ray can look through vehicles and buildings to identify terrorists. Another new use of X rays is in identifying land mines so they can be safely removed from war zones. Other scientists are trying to focus X-ray radiation in the same way that light is focused in a laser beam. These "xasers" will allow biologists to study the structure of proteins. The most far out use is far out in space. Astronomers are using satellites to study sources of X rays from black holes deep in outer space.

**CONNECTIONS** **Research** **Investigate the jobs of radiologists and radiology technicians. What training do they receive? How do they contribute to keeping people healthy?**

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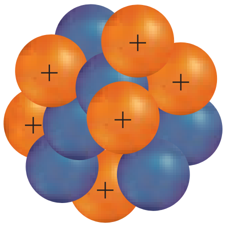
# Chapter 9 Study Guide

## Reviewing Main Ideas

### Section 1 Radioactivity


Nucleus

1. The protons and neutrons in an atomic nucleus are held together by the strong force. *What other force acts among particles in the nucleus?*
2. The ratio of protons to neutrons indicates whether a nucleus will be stable or unstable. Large nuclei tend to be unstable.
3. Radioactivity is the emission of energy or particles from an unstable nucleus.
4. Radioactivity was discovered accidentally by Henri Becquerel about 100 years ago.

### Section 2 Nuclear Decay

1. The three common types of radiation emitted from a decaying nucleus are alpha particles, beta particles, and gamma rays. In alpha and beta decay, particles are given off. In gamma decay, energy is released.
2. Alpha and beta decay cause transmutation where the nucleus of one element changes into the nucleus of another element.
3. Half-life is the amount of time that it takes for half of the atoms in a radioactive sample to decay.
4. The half-lives of radioactive carbon and uranium isotopes can be used to calculate the ages of objects that contain these substances. *Would you use carbon-14 or uranium dating to find the age of a bone?*

### Section 3 Detecting Radioactivity

1. Radioactivity can be detected with a cloud chamber, a bubble chamber, an electroscope, or a Geiger counter.
2. A Geiger counter indicates the intensity of radiation with a clicking sound or a flashing light that increases in frequency as more radiation is present.
3. Background radiation is low-level radiation emitted by naturally occurring isotopes found in Earth's rocks and soils, the atmosphere, and inside your body.

### Section 4 Nuclear Reactions

1. Nuclei are split during fission and combined during fusion. In each reaction, large amounts of energy are released. *What are two ways that this energy can be used?*

2. Neutrons released from a nucleus during fission can split other nuclei, leading to a chain reaction.
3. Radioactive tracers can go to targeted areas of the body and then be detected to diagnose some health problems.
4. Some radiation can kill cancer cells.

**After You Read**

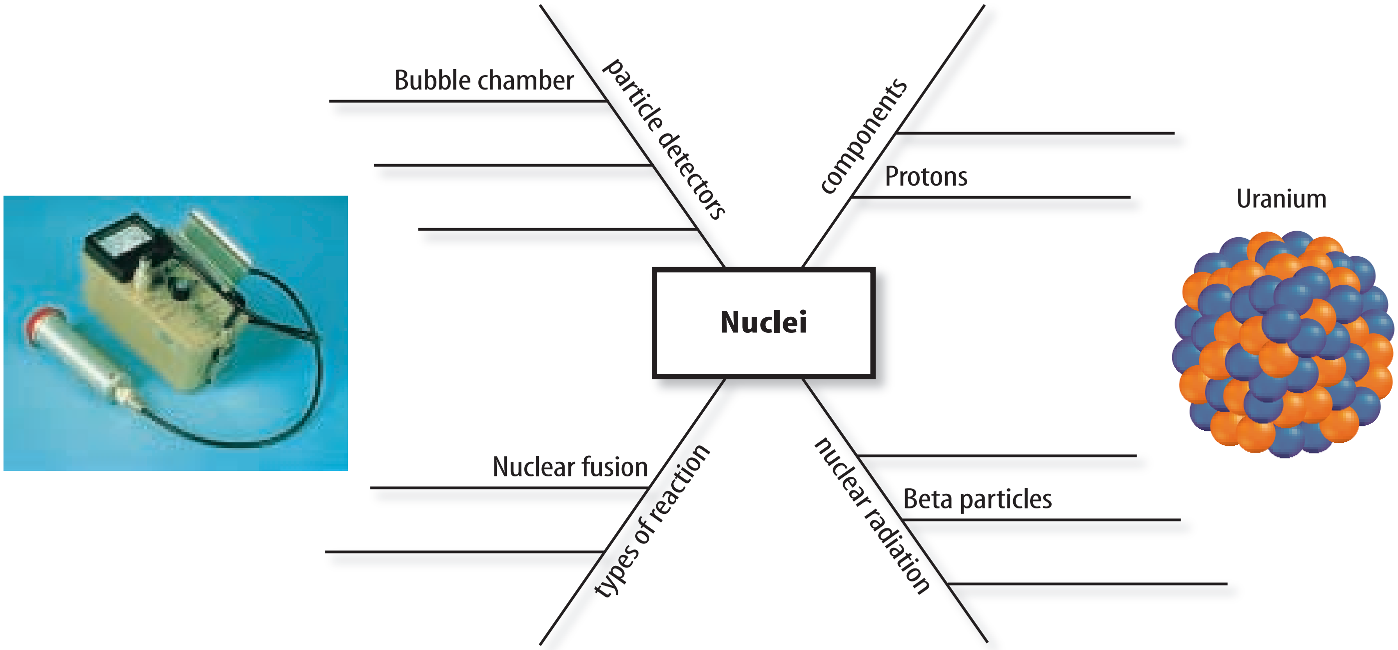
**FOLDABLES Reading & Study Skills**

On the inside center section of your Main Ideas Study Fold, list positive and negative uses of radioactive materials and nuclear reactions.

# Chapter 9 Study Guide

## Visualizing Main Ideas

*Complete the following concept map on radioactivity.*



## Vocabulary Review

### Vocabulary Words

- **a.** alpha particle
- **b.** beta particle
- **c.** bubble chamber
- **d.** chain reaction
- **e.** cloud chamber
- **f.** critical mass
- **g.** gamma ray
- **h.** Geiger counter
- **i.** half-life
- **j.** nuclear fission
- **k.** nuclear fusion
- **l.** radioactivity
- **m.** strong force
- **n.** tracer
- **o.** transmutation

### Study Tip

Make a study schedule for yourself. If you have a planner, write down exactly which hours you plan to spend studying and stick to it.

### Using Vocabulary

*Use what you know about the vocabulary words to explain the differences in the following sets of words. Then explain how the words are related.*

**1.** cloud chamber, bubble chamber

**2.** chain reaction, critical mass

**3.** nuclear fission, nuclear fusion

**4.** radioactivity, half-life

**5.** alpha particle, beta particle, gamma ray

**6.** Geiger counter, tracer

**7.** nuclear fission, transmutation

**8.** electroscope, Geiger counter

**9.** strong force, radioactivity

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# Chapter 9 Assessment

## Checking Concepts

*Choose the word or phrase that best answers the question.*

**1.** What keeps particles in a nucleus together?
**A)** strong force
**B)** repulsion
**C)** electrical force
**D)** atomic glue

**2.** Which of the following describes all nuclei with more than 83 protons?
**A)** radioactive
**B)** repulsive
**C)** synthetic
**D)** stable

**3.** What is an electron that is produced when a neutron decays called?
**A)** an alpha particle
**B)** a beta particle
**C)** gamma radiation
**D)** a negatron

**4.** Which of the following describes an isotope's half-life?
**A)** a constant time interval
**B)** a varied time interval
**C)** an increasing time interval
**D)** a decreasing time interval

**5.** For which of the following could carbon-14 dating be used?
**A)** a Roman scroll
**B)** a marble column
**C)** dinosaur fossils
**D)** rocks

**6.** Which device would be most useful for measuring the amount of radiation in a nuclear laboratory?
**A)** a cloud chamber
**B)** a Geiger counter
**C)** an electroscope
**D)** a bubble chamber

**7.** Which term describes an ongoing series of fission reactions?
**A)** chain reaction
**B)** decay reaction
**C)** positron emission
**D)** fusion reaction

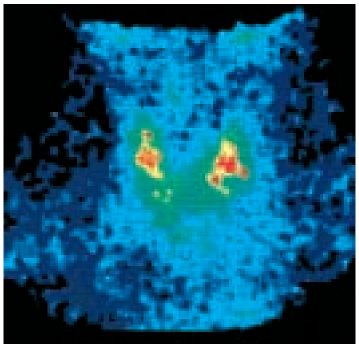
**8.** Which process is responsible for the tremendous energy released by the Sun?
**A)** nuclear decay
**B)** nuclear fission
**C)** nuclear fusion
**D)** combustion

**9.** Which radioisotope acts as an external source of ionizing radiation in the treatment of cancer?
**A)** cobalt-60
**B)** carbon-14
**C)** gold-198
**D)** technetium-99

**10.** Which of the following is a common medical application of radiation?
**A)** assist breathing
**B)** treat infections
**C)** heal broken bones
**D)** treat cancers

## Thinking Critically

**11.** When a nucleus emits gamma radiation, what happens to the atomic number?



**12.** How do the properties of alpha particles make them harmful? Explain.

**13.** Why does the amount of background radiation a person receives vary greatly?

**14.** Explain how radioisotopes could be used to study how plants take up nutrients from the soil.

**15.** How can doctors tell if a patient's thyroid is not working correctly by using iodine tracers?

## Developing Skills

**16. Communicating** Prepare a presentation to explain how a Geiger counter works.

**17. Making and Using Tables** Construct a table summarizing the characteristics of each of the three common types of radiation. Include the symbol for the radiation, what type of particle or energy it produces, and what it can penetrate.

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**18. Predicting** Predict what type of radiation will be emitted during each of the following nuclear reactions:

**a.** uranium-238 decays into thorium-234

**b.** boron-12 decays into carbon-12

**19. Interpreting Data** Using the data below, construct a graph plotting the mass numbers versus. the half-lives of radioisotopes. Is it possible to use your graph to predict the half-life of a radioisotope given its mass number?

**Isotope Half-Lives**

| Radioisotope | Mass Number | Half-Life |
|---|---|---|
| Radon | 222 | 4 days |
| Thorium | 234 | 24 days |
| Iodine | 131 | 8 days |
| Bismuth | 210 | 5 days |
| Polonium | 210 | 138 days |

**20. Recognizing Cause and Effect** Describe nuclear fission chain reactions. How are these chain reactions controlled? What might happen if they were not controlled?

## Performance Assessment

**21. Oral Presentation** Research the causes and effects of radon pollution in homes. Report your findings to the class.

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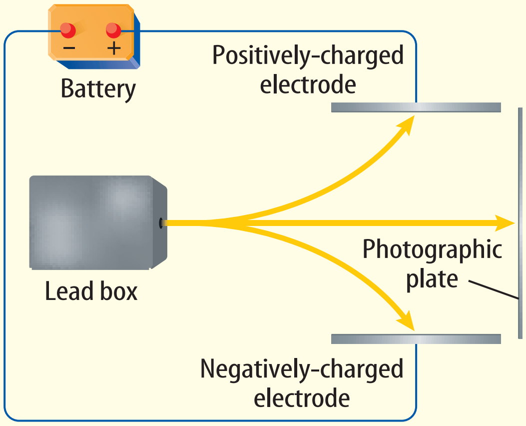
## THE PRINCETON REVIEW Test Practice

In 1903, Ernest Rutherford placed radioactive uranium ore in a lead box with a small pinhole. He aimed it so that radiation escaping from the hole passed through an electric field to reach a photographic plate.



*Study the diagram and answer the following questions.*

**1.** In this experiment, beta particles were deflected toward the positive electrode while alpha particles were deflected toward the negative electrode because:

**A)** Beta particles are negatively charged and alpha particles are positively charged.

**B)** Beta particles have a negative charge and a larger mass than alpha particles.

**C)** Beta particles have a positive charge and alpha particles are negative.

**D)** Beta particles have a positive charge and a larger mass than alpha particles.

**2.** Why were gamma rays not deflected by the charged plates in this experiment?

**F)** Gamma rays have negative charge.

**G)** Gamma rays have positive charge.

**H)** Gamma rays have no charge.

**J)** Gamma rays travel too fast.

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