

25.1 Nuclear Radiation

Connecting to Your World

Marie Curie was a Polish scientist whose research led to many discoveries about radiation and radioactive elements. In 1903 she and her husband Pierre, along with Antoine Henri Becquerel, won the Nobel Prize in physics for their work on radioactivity. She was also awarded the Nobel Prize in chemistry in 1911 for her research on radioactive elements. Marie Curie's research was essential to understanding and using newly discovered radioactive elements. In 1934 she died from leukemia caused by her long-term exposure to radiation. In this section, you will learn about the various types of radiation and their effects.



Radioactivity

In 1896, the French chemist Antoine Henri Becquerel (1852–1908) made an accidental discovery. He was studying the ability of uranium salts that had been exposed to sunlight to fog photographic film plates. During bad weather, Becquerel could not expose the sample to sunlight, but happened to leave it on top of the photographic plate. When he developed the plate, he discovered that the uranium salt still fogged the plate. At that time, two of Becquerel's associates were Marie Curie (1867–1934) and Pierre Curie (1859–1906). The Curies were able to show that rays emitted by the uranium atoms caused the fogging of the plates. Marie Curie named the process by which materials give off such rays **radioactivity**. The penetrating rays and particles emitted by a radioactive source are called **radiation**.

Nuclear reactions, which account for radioactivity, differ from chemical reactions in a number of important ways. In chemical reactions, atoms tend to attain stable electron configurations by losing electrons or sharing electrons. In nuclear reactions, the nuclei of unstable isotopes, called **radioisotopes**, gain stability by undergoing changes. These changes are always accompanied by the emission of large amounts of energy. Unlike chemical reactions, nuclear reactions are not affected by changes in temperature, pressure, or the presence of catalysts. They are also unaffected by the compounds in which the unstable isotopes are present. The nuclear reactions of a given radioisotope cannot be speeded up, slowed down, or turned off.

 **Checkpoint** What is radiation?

Guide for Reading

Key Concepts

- How does an unstable nucleus release energy?
- What are the three main types of nuclear radiation?

Vocabulary

radioactivity
radiation
radioisotopes
alpha particle
beta particle
gamma ray

Reading Strategy

Relating Text and Visuals As you read about types of radiation, look at Figure 25.1. List how the positive, negative, or neutral electric charge of each type of radiation, as described in the text, is related to how the radiation is deflected as it passes by the charged plates.

25.1

1 FOCUS

Objectives

25.1.1 Explain how an unstable nucleus releases energy.

25.1.2 Describe the three main types of nuclear radiation.

Guide for Reading

Build Vocabulary

L2

Word Parts Have students look up the meanings of the first three vocabulary terms. From these meanings, have them infer the meaning of the prefix used in all three terms. Students should infer that the prefix *radio-* means “to send out in all directions.”

Reading Strategy

L2

Using Context Clues Have students use context clues to infer the definition of *decay*, as it refers to radioactivity. Inferences should include that *decay* means “breaking down into smaller parts.”

2 INSTRUCT

Connecting to Your World

Have students examine the periodic table. Ask, **What element was named in honor of the Curies? (*curium*) Is this element radioactive? (yes)**

Radioactivity

Discuss

L2

Ask, **What particles in an atom are involved in chemical reactions? (*valence electrons*) What is the difference between a chemical reaction and a nuclear reaction? (*Chemical reactions involve the transfer or sharing of electrons; the nuclei remain unchanged. Nuclear reactions involve changes in the nuclei of atoms.*)**

Answers to...

 **Checkpoint** the penetrating rays and particles emitted by a radioactive source

Section 25.1 Nuclear Radiation 799



Section Resources

Print

- **Guided Reading and Study Workbook**, Section 25.1
- **Core Teaching Resources**, Section 25.1 Review
- **Transparencies**, T286–288

Technology

- **Interactive Textbook with ChemASAP**, Assessment 25.1

Types of Radiation

Discuss

L2

Explain that the nuclei of a radioactive element spontaneously decompose. Nuclear chemistry is the study of changes in matter that originate in atomic nuclei. Ask, **What types of radiation exist, and how harmful are they?** (*The three most common types of radiation emitted by unstable nuclei are alpha (α), beta (β), and gamma (γ) radiation. Although all forms of radiation are somewhat harmful, gamma rays are particularly dangerous because they penetrate body tissues.*) Explain that radioactivity reflects the tendency of atomic nuclei to achieve stability. Ask, **What makes a nucleus unstable?** (*It has too many or too few neutrons relative to the number of protons.*) Point out that the energy produced during nuclear decay can be released as electromagnetic radiation, such as gamma rays, or as kinetic energy, which is carried by particles, such as alpha particles, that are emitted from the nucleus.

TEACHER Demo

An Effect of Radiation

L1

Purpose Students observe the effects of radiation on photographic film.

Materials photographic film, radiation source, key

Safety Use only safely packaged radiation sources. Do not directly touch any radioactive material.

Procedure Explain that radiation reduces silver in photographic film. This property led to the discovery of radioactivity by Becquerel. Place a metal key on top of unexposed photographic film that has been wrapped in black paper. Place a radiation source on top of the key. After one week, develop the film.

Expected Outcome The area of the film that was beneath the key is unexposed, unlike the rest of the film.

Point out that the film badges worn by persons working with radioactivity operate by the same mechanism. They serve as important radiation detectors, safeguarding against overexposure to ionizing radiation.

The discovery of radioactivity disproved Dalton's assumption that atoms are indivisible. A radioactive atom, or radioisotope, undergoes drastic changes as it emits radiation. These radioisotopes have unstable nuclei. The stability of a nucleus depends on the ratio of neutrons to protons in the nucleus, and on the overall size of the nucleus. Too many or too few neutrons relative to the number of protons makes a nucleus unstable. **An unstable nucleus releases energy by emitting radiation during the process of radioactive decay.** Unstable radioisotopes of one element are transformed into stable (nonradioactive) isotopes of a different element. Radioactive decay is spontaneous and does not require any input of energy.

Types of Radiation

Radiation is emitted during radioactive decay. **The three main types of nuclear radiation are alpha radiation, beta radiation, and gamma radiation.** Table 25.1 summarizes the characteristics of these three types of radiation. The different types of radiation can be separated by an electric field as shown in Figure 25.1.

Alpha Radiation The type of radiation called alpha radiation consists of helium nuclei that have been emitted from a radioactive source. Each of these emitted particles, called an **alpha particle**, contains two protons and two neutrons and has a double positive charge. In nuclear equations, an alpha particle is written ${}^4_2\text{He}$ or α . The electric charge symbol is generally omitted.

The radioisotope uranium-238 releases alpha radiation and is transformed into another radioisotope, thorium-234. Figure 25.2a illustrates this process.

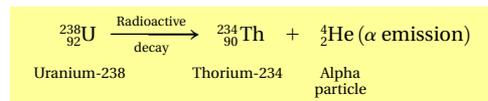
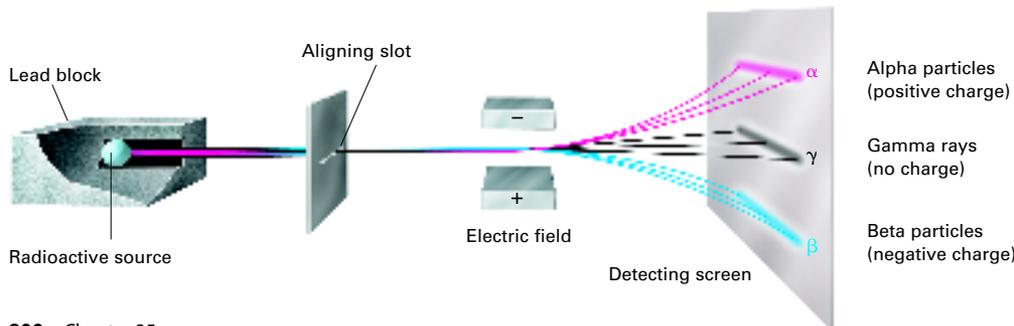


Figure 25.1 These three types of radiation deflect differently as they pass between a pair of electrically charged plates. Alpha particles (α) and beta particles (β) are deflected in opposite directions—alpha particles toward the negative plate and beta particles toward the positive plate. Gamma rays are undeflected. **Applying Concepts** Why are gamma rays not deflected?

Note that this nuclear equation is balanced. The sum of the mass numbers (superscripts) on the right equals the sum on the left. The same is true for the atomic numbers (subscripts).

When an atom loses an alpha particle, the atomic number of the product atom is lower by two and its mass number is lower by four. Because of their large mass and charge, alpha particles do not tend to travel very far and are not very penetrating. A sheet of paper or the surface of your skin easily stops them. However, radioisotopes that emit alpha particles are dangerous when ingested. The particles do not have to travel far to penetrate soft tissue and cause damage.



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Facts and Figures

Nuclear Decay

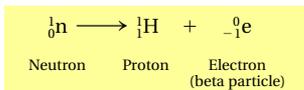
Nuclear decay, unlike chemical reactions, is unaffected by temperature, pressure, or the presence of catalysts. Spontaneous nuclear decay cannot be slowed down, speeded up, or stopped. Nuclear decay illustrates the

interconnected nature of matter and energy; matter is related to energy according to the equation $E = mc^2$, where c is a constant equal to the speed of light.

Table 25.1

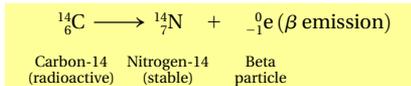
| Characteristics of Some Types of Radiation | | | |
|--|---------------------------------|-------------------------------|---------------------------------------|
| Property | Alpha radiation | Beta radiation | Gamma radiation |
| Composition | Alpha particle (helium nucleus) | Beta particle (electron) | High-energy electromagnetic radiation |
| Symbol | α , ${}^4_2\text{He}$ | β , ${}^0_{-1}\text{e}$ | γ |
| Charge | 2+ | 1- | 0 |
| Mass (amu) | 4 | 1/1837 | 0 |
| Common source | Radium-226 | Carbon-14 | Cobalt-60 |
| Penetrating power | Low (0.05 mm body tissue) | Moderate (4 mm body tissue) | Very high (penetrates body easily) |
| Shielding | Paper, clothing | Metal foil | Lead, concrete (incompletely shields) |

Beta Radiation An electron resulting from the breaking apart of a neutron in an atom is called a **beta particle**. The neutron breaks apart into a proton, which remains in the nucleus, and a fast-moving electron, which is released.



The symbol for the electron has a subscript of -1 where the atomic number would be written. This represents the electron's negative charge. The superscript 0 where a mass number would be written represents the extremely small mass of the electron compared to that of a proton.

Carbon-14 emits a beta particle as it undergoes radioactive decay to form nitrogen-14. Figure 25.2b shows this beta emission.



The nitrogen-14 atom has the same atomic mass number as carbon-14, but its atomic number has increased by 1. It contains an additional proton and one fewer neutron. The nuclear equation is balanced.

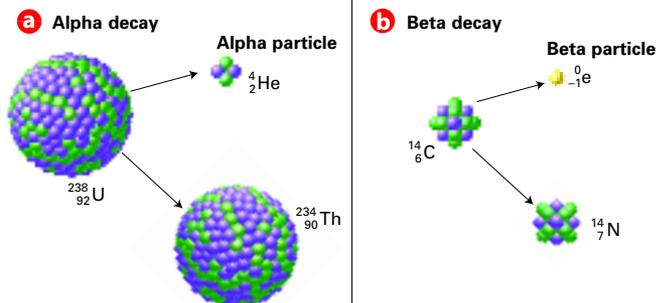


Figure 25.2 Radiation is emitted during radioactive decay.

a Uranium-238 undergoes alpha decay to form thorium-234.

b Carbon-14 undergoes beta decay to form nitrogen-14.

Interpreting Diagrams What particle is emitted in each decay process?

Use Visuals

L1

Table 25.1 Have students examine the table. Encourage them to memorize the names and symbols used to represent each type of radiation. Point out the differences in charge and mass. Students may wish to recreate Table 25.1 on an index card and use the information to help them write and balance nuclear equations. Point out the relative penetrating power of each type of radiation and the precautions necessary to effectively block different types of radiation.

Discuss

L2

Tell students that beta decay can result in either the emission of an electron (a β^- particle) or a positron (a β^+ particle). Present students with the partial equation for the decay of chlorine-32 into sulfur-32. Ask, **Which kind of particle would need to be emitted to balance the equation?** (a positron) Explain that during positron emission, a proton is converted into a neutron. Ask, **What kind of unstable nuclei would be likely to emit positrons?** (one with too many protons for the number of neutrons) Explain that emission of a positron also results in a neutrino, while emission of an electron is accompanied by emission of an anti-neutrino. Neutrinos and anti-neutrinos have no charge and virtually no mass. The emission of neutrinos and anti-neutrinos are not included in the student text because they are not chemically significant and do not react significantly with matter. However, the laws of energy-mass conservation and momentum conservation are satisfied by the presence of neutrinos and anti-neutrinos

Facts and Figures

Isotopes vs. Radioisotopes

Radioisotopes of an element are not chemically different from other isotopes of that element. Chemical reactivity depends on the electron structure of an atom, not its nuclear makeup.

Answers to...

Figure 25.1 They have no charge and so are unaffected by the electric field.

Figure 25.2 alpha particle (helium nucleus); beta particle (electron)

Section 25.1 (continued)

Relate L2

Point out that radio waves, microwaves, visible light, ultraviolet light, and X-rays are all forms of electromagnetic radiation. Ask, **How does a gamma ray differ from other types of electromagnetic radiation?** (These other types are not directly produced by the radioactive decay of a nucleus.)

ASSESS

Evaluate Understanding L2

Write several partial equations for nuclear decay involving alpha and beta particles. Include parent and daughter nuclei only in the equations. For each equation, have students compare the parent and daughter nuclei to identify the type of particle emitted. Ask students to justify their conclusions. Ask, **What other type of emission is possible during nuclear decay?** (gamma emission)

Reteach L1

Remind students that when writing a nuclear equation, the sums of the mass numbers and atomic numbers of the reactants must equal the sums of the mass and atomic numbers of the products. Students should check their equations by comparing the sums of the superscripts and subscripts on each side of the equation.

Connecting Concepts

Atomic numbers (charge) and mass numbers must be balanced.



If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 25.1.

with ChemASAP

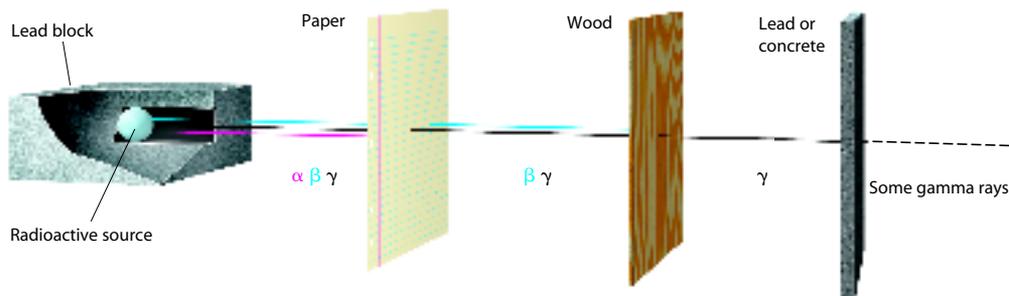
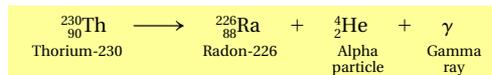


Figure 25.3 Because of their large mass and charge, alpha particles (red) are the least penetrating of the three main types of radiation. Gamma rays (black) have no mass or charge and are the most penetrating.

A beta particle has less charge than an alpha particle and much less mass than an alpha particle. Consequently, beta particles are more penetrating. Beta particles can pass through paper but are stopped by aluminum foil or thin pieces of wood.

Gamma Radiation A high-energy photon emitted by a radioisotope is called a **gamma ray**. The high-energy photons are electromagnetic radiation. Nuclei often emit gamma rays along with alpha or beta particles during radioactive decay. The following example demonstrates this process.



Because gamma rays have no mass and no electrical charge, the emission of gamma radiation does not alter the atomic number or mass number of an atom. Gamma rays are extremely penetrating and can be very dangerous. Gamma rays pass easily through paper, wood, and the human body. They can be stopped, although not completely, by several meters of concrete or several centimeters of lead, as shown in Figure 25.3.

25.1 Section Assessment

- Key Concept** How does an unstable nucleus release energy?
- Key Concept** What are the three main types of nuclear radiation?
- What part of an atom undergoes change during radioactive decay?
- How is the atomic number of a nucleus changed by alpha decay? By beta decay? By gamma decay?
- How is the atomic mass number of a nucleus changed by alpha decay? By beta decay? By gamma decay?
- Which of the three kinds of radiation described in this section is the most penetrating?

Connecting Concepts

Connecting Concepts Refer back to the rules for balancing chemical equations introduced in Section 11.1. An equation for radioactive decay has different nuclei appearing on each side of the yields sign so the atoms cannot be balanced. What two items must be balanced to achieve a balanced equation for radioactive decay?



Assessment 25.1 Test yourself on the concepts in Section 25.1.

with ChemASAP

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Section 25.1 Assessment

- An unstable nucleus releases energy by emitting radiation during radioactive decay.
- alpha radiation, beta radiation, and gamma radiation
- The nucleus undergoes change.
- In alpha decay, the atomic number decreases by two. In beta decay, the atomic number increases by one. The emission of gamma radiation does not change the atomic number.
- In alpha decay, the mass number decreases by four. In beta decay, the mass number does not change. The emission of gamma radiation does not change the mass number.
- Gamma radiation is most penetrating.