25.1 Nuclear Radiation

Connecting to Your World

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.

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.

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Checkpunt

What is radiation?
Types of Radiation

**Discuss**

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

**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  or 4 2α. 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](image)

**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.
Radiation is emitted during the radioactive decay process.

**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.

\[
\text{Neutron} \quad \longrightarrow \quad \text{Proton} \quad + \quad \text{Electron (beta particle)}
\]

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.

\[
\text{C}^{14} \quad \longrightarrow \quad \text{N}^{14} \quad + \quad \beta^- \text{(beta emission)}
\]

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.

**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** Tell students that beta decay can result in either the emission of an electron (a \(\beta^-\) particle) or a positron (a \(\beta^+\) 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.
Section 25.1 (continued)

Relate
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.)

Evaluate Understanding
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
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.

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

Connecting Concepts
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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 yield sign so the atoms cannot be balanced. What two items must be balanced to achieve a balanced equation for radioactive decay?

25.1 Section Assessment

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

25.1 Section Assessment

1. An unstable nucleus releases energy by emitting radiation during radioactive decay.
2. alpha radiation, beta radiation, and gamma radiation
3. The nucleus undergoes change.
4. 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.
5. 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.
6. Gamma radiation is most penetrating.