Lesson Objectives

- Describe the characteristics of radioactive emissions in regards to mass, charge, potential to ionize, and penetrate the material it strikes.
- Complete equations involving radioactive decay or particle bombardment when given pertinent information.

Lesson Vocabulary

- **radioactivity**: The spontaneous emission of matter and/or energy from the unstable nucleus of an atom.
- **alpha particle**: The nucleus of a helium-4 atom.
- **beta particle**: An electron.
- **gamma radiation**: Very high energy electromagnetic radiation.
- **neutron**: A neutron.
- **proton**: A proton.

Check Your Understanding

Recalling Prior Knowledge

- How are mass number and atomic number related to the amounts of different subatomic particles in a particular atom?
- What is different about multiple isotopes of a single element?

Types of Radioactive Decay

**Alpha Emission**

Alpha (\(\alpha\)) radiation was eventually found to be made up of particles that consisted of two protons bound to two neutrons. In other words, an **alpha particle** was simply the nucleus of a helium-4 atom. Because it does not have any electrons, the alpha particle carries a charge of +2. In nuclear equations, alpha particles can be represented by any of the following symbols:

\[ \alpha \quad ^4_2\alpha \quad ^4_2\text{He} \]
A typical alpha decay reaction is the conversion of uranium-238 to thorium-234:

\[ ^{238}_{92} \text{U} \rightarrow ^{234}_{90} \text{Th} + ^4_2 \alpha \]

Many of the largest elements in the periodic table are alpha-emitters. Notice that in this nuclear equation, the total mass number and the total atomic number are both conserved. The sum of the mass numbers and atomic numbers of the products are equal to the mass number and atomic number of the parent nucleus. This is a general feature of nuclear reactions. As a result, knowing that a specific nucleus decays by emitting alpha particles allows us to predict the product nucleus; we simply need to decrease the mass number by 4 and the atomic number by 2. The change in atomic number indicates a change in the element’s identity. The new element can be found by looking at the periodic table.

**Beta Emission**

Beta (\(\beta\)) emission is a slightly more complicated process. Unlike \(\alpha\)-emission, which simply expels some of the existing subatomic particles from the nucleus, \(\beta\)-emission also involves the transformation of a neutron into a proton and an electron. The proton remains bound to the nucleus, while the electron is ejected.

![FIGURE 1.2](image)

As it turns out, the beta radiation observed by early nuclear chemists was simply the result of ejected electrons. For historical reasons, the electron is sometimes referred to as a **beta particle** in this context. In nuclear equations, beta particles can be represented by any of the following symbols:

\[ \beta^- \quad \beta^0 \quad e^- \quad e^0 \]

Although an electron technically has a very small mass, considering an electron as though its mass is zero makes it easier to balance nuclear equations. During beta decay, the parent nucleus increases its atomic number by 1, but the mass number stays the same. This follows the idea that charge is also conserved in radioactive decay. A typical beta decay process involves carbon-14, which is used in radioactive dating techniques:

\[ ^{14}_6 \text{C} \rightarrow ^{14}_7 \text{N} + ^0_{-1} e \]

**Positron Emission**

A **positron** is the antimatter version of an electron. It has the same mass as an electron but the opposite charge. A positron can be designated by the following symbols:

\[ \beta^+ \quad \beta^0 \quad e^+ \quad e^0 \]

During a nuclear decay process that occurs by positron emission, a proton is converted into a neutron and a positron. The neutron remains in the nucleus, and the positron is expelled. Overall, the atomic number of the parent nucleus increases by one, and the mass number is unchanged. For example, carbon-11 emits a positron to become boron-11:

\[ ^{11}_6 \text{C} \rightarrow ^{11}_5 \text{B} + ^0_{+1} \beta \]

Positrons represent a special case, because they are a form of antimatter. When a positron encounters an electron, the two particles annihilate one another, and all of their mass is converted to pure energy. This energy is released in
the form of two gamma photons traveling in exactly opposite directions. Because of the abundance of electrons in any sample of matter, positrons will be consumed almost immediately in essentially all cases.

**Gamma Emission**

**Gamma (γ) radiation** was eventually found to be very high energy electromagnetic radiation, even more energetic than X-rays. Many nuclear processes are accompanied by a large release of energy. This energy is sometimes given off as a photon of gamma radiation. For example, both alpha and beta decay are often accompanied by the emission of gamma rays. Because photons have no mass or charge, they do not affect the mass number or atomic number balance in a nuclear equation. When included in the equations, the release of gamma radiation is generally given the symbol $^{0}\gamma$. You will not be required to predict whether a given nuclear reaction includes the release of gamma rays.

**Other radioactive particles**

Neutrons and protons are also involved in some nuclear reactions. The neutron is represented by the symbol $^{0}\text{n}$, while the proton is represented by the symbol $^{1}\text{p}$. Protons and neutrons are often involved in bombardment reactions in which the neutron or proton is shot at a large nucleus which then results in the decay of that nucleus.

**Penetrating Ability of Emissions**

The various types of emissions discussed above differ considerably in their ability to penetrate through matter. The alpha particle has the lowest penetrating power, primarily because it is the largest commonly expelled particle. Related to their larger mass, ejected alpha particles also move much slower than other types of nuclear decay products. A stream of alpha particles can be blocked by a sheet of paper or a human hand.

Beta particles (electrons) have a higher penetrating power than alpha particles, but they can still be stopped by a thin sheet of aluminum. However, the materials being bombarded with a high-energy stream of electrons can also become excited, potentially leading to additional reactivity.

Of the three basic types of emissions, gamma radiation has the highest penetrating power. Thick, high density materials (such as lead) are required to stop gamma emissions. The thickness of the shielding will determine the effectiveness of the protection offered by the lead.
Lesson Review Questions

Reviewing Concepts

1. Define radioactivity.
2. Define the terms below, noting their penetration abilities:
   a. alpha particle
   b. beta particle
   c. positron emission
   d. gamma emission
3. Explain how a Geiger counter detects radioactivity.

Problems

1. Americium-241 is a radioactive isotope found in many smoke detectors. If this nucleus decays by alpha emission, what is the decay product?
2. Write the nuclear decay products after the emission of a beta particle by phosphorus-32.
3. Write the nuclear decay products for the emission of a positron by potassium-40.
4. For each reaction below, indicate the product isotope:
   (a) $^{180}_{79}$Au $\rightarrow$ $\alpha$ + ?
   (b) $^{189}_{70}$Yb $\rightarrow$ $\beta^-$ + ?
   (c) $^{94}_{43}$Tc $\rightarrow$ $\beta^+$ + ?
5. For each reaction below, indicate the initial isotope:
   (a) ? $\rightarrow$ $\beta^-$ $^{98}_{41}$Nb
   (b) ? $\rightarrow$ $\alpha$ $^{146}_{64}$Gd
6. For each reaction below, determine the missing particle:
   (a) $^{49}_{24}$Cr $\rightarrow$ ? + $^{49}_{23}$V
   (b) $^{50}_{19}$K $\rightarrow$ ? + $^{40}_{20}$Ca

Further Reading / Supplementary Links

- Radioactive decay processes: http://www.chem.duke.edu/~jds/cruise_chem/nuclear/stability.html
- Table of isotopes and decay modes: http://ie.lbl.gov/decay/parent.pdf

Points to Consider

- How long does a sample of radioactive material remain hazardous?

References