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Phys 145 (General Physics)

Chapter 9: Nuclear Physics (part 2)

Week n° 13

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Chapter 9: Nuclear Physics

- **We will learn in this chapter 9:**

- Radioactivity
- Half-Life
- Radioactive Decays

Chapter 9: Nuclear Physics (Second part)

- **We will learn in this second part of chapter 9:**

- Radioactive Decays

Radioactive decays

In all nuclear processes, the following quantities must be conserved:

1. **Energy**
2. **Momentum**
3. **Electric charge**
4. **Number of nucleons**

α decay

Alpha (α) decay is the spontaneous emission of an alpha particle (helium nucleus) from the nucleus.

The alpha particle is then a group of two protons and two neutrons.

A helium nucleus is very stable.

Typically occurs with heavy nuclides (A > 150) and Z above 83 are unstable, often followed by gamma and characteristic x-ray emission.

$$^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He^{+2} + \text{transition energy}$$

$$^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{234}_{90}Th + 2{}^{0}_{0}\gamma$$

Examples of α decay

$$^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

$$^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

$$^{222}_{86}Rn \longrightarrow {}^{218}_{84}Po + {}^{4}_{2}He$$

β decay: converting protons and neutrons

- There are certain combinations of protons and neutrons that are more stable than others.
- Note: proton ($^{1}_{1}p$), neutron ($^{1}_{0}n$)

$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$ (β⁻ emission)

$^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{1}e$ (β⁺ emission)

$^{1}_{1}p + {}^{0}_{-1}e \rightarrow {}^{1}_{0}n$ (EC – electron capture)

β decay

A beta particle is a fast moving electron which is emitted from the nucleus of an atom undergoing radioactive decay.

Beta decay occurs when a neutron changes into a proton and an electron.

Electrons or **positrons** having small mass and variable energy.

β⁻ decay

A nuclear neutron changes into a nuclear proton.

$$ {}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}\mathrm{e} $$

$$ {}^{A}_{Z}X \xrightarrow{\beta^-} {}^{A}_{Z+1}Y + {}^{0}_{-1}e + \bar{\nu} $$

$$ {}^{3}_{1}H \xrightarrow{\beta^-} {}^{3}_{2}He + {}^{0}_{-1}e + \bar{\nu} $$

$$ {}^{22}_{11}Na \xrightarrow{\beta^-} {}^{22}_{10}Ne + {}^{0}_{-1}e + \bar{\nu} $$

$\bar{\nu}$ is the anti-neutrino (no mass, no charge)

β⁻ decay

$$ {}^{218}_{84}Po \xrightarrow{\beta^-} {}^{218}_{85}Rn + {}^{0}_{-1}e + \bar{\nu} $$

$$ {}^{234}_{90}Th \xrightarrow{\beta^-} {}^{234}_{91}Pa + {}^{0}_{-1}e + \bar{\nu} $$

$$ {}^{210}_{81}Tl \xrightarrow{\beta^-} {}^{210}_{82}Pb + {}^{0}_{-1}e + \bar{\nu} $$

β⁺ decay

a nuclear proton changes into a nuclear neutron.

$$ {}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{1}\mathrm{e} $$

$$ {}^{A}_{Z}X \xrightarrow{\beta^+} {}^{A}_{Z-1}Y + {}^{0}_{1}e + \nu $$

$$ {}^{11}_{6}C \xrightarrow{\beta^+} {}^{11}_{5}B + {}^{0}_{1}e + \nu $$

ν is the neutrino (no mass, no charge)

Electron capture (EC)

In an Electron capture a parent nucleus may capture one of its orbital electrons and emit a neutrino. This is a process which competes with positron emission and has the same effect on the atomic number. Most commonly, it is a K-shell electron which is captured, and this is referred to as K-capture.

$$ {}^{A}_{Z}X + {}^{0}_{1}e \xrightarrow{EC} {}^{A}_{Z-1}Y + \nu $$

$$ {}^{7}_{4}Be + {}^{0}_{1}e \xrightarrow{EC} {}^{7}_{3}Y + \nu $$

γ decay

Gamma rays are not charged particles like alpha and beta particles.

Gamma rays are electromagnetic radiation with high frequency.

When a nucleus undergoes a transition from higher to lower energy level, they are equivalent to light quanta and X rays, their energies much greater and the half live for γ decay are very short, the emitting alpha or beta particles to form a new atom, the nuclei of the new atom formed may still have too much energy to be completely stable. The γ decay is internal conversion .

This excess energy is emitted as gamma rays (gamma ray photons have energies of ~ 1 x 10^{-12} J).

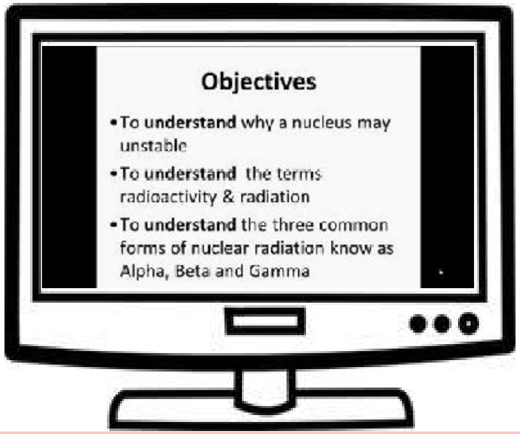
γ decay

Gamma radioactivity is composed of electromagnetic rays. It is distinguished from x-rays only by the fact that it comes from the nucleus. Most gamma rays are higher in energy than x-rays and therefore are very penetrating.

$$ {}^{A}_{Z}X^{*} \xrightarrow{\gamma} {}^{A}_{Z}X + {}^{0}_{0}\gamma $$

$$ {}^{3}_{2}He^{*} \xrightarrow{\gamma} {}^{3}_{2}He + {}^{0}_{0}\gamma $$

Video 01 of week 13: Radioactivity



Summary of week 13

- **Alpha decay** $\quad {}^{A}_{Z}X \xrightarrow{\alpha} {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$
- **Beta decays** $\quad \begin{cases} {}^{A}_{Z}X \xrightarrow{\beta^-} {}^{A}_{Z+1}Y + {}^{0}_{-1}e + \overline{\nu} \\ {}^{A}_{Z}X \xrightarrow{\beta^+} {}^{A}_{Z-1}Y + {}^{0}_{1}e + \nu \end{cases}$
- **Gamma decay** $\quad {}^{A}_{Z}X^{*} \xrightarrow{\gamma} {}^{A}_{Z}X + {}^{0}_{0}\gamma$
- **Electron capture** $\quad {}^{A}_{Z}X + {}^{0}_{1}e \xrightarrow{EC} {}^{A}_{Z-1}Y + \nu$

$\quad {}^{0}_{-1}e = e$: electron; ${}^{0}_{1}e = e^{+}$: positron;

$\quad {}^{0}_{0}\gamma = \gamma$: photon;

$\quad \nu$: neutrino; $\overline{\nu}$: anti-neutrino

Quiz for week 13