Physics of atom

Lecture Three / Theoretical

Radioactive Decay Concepts

First stage

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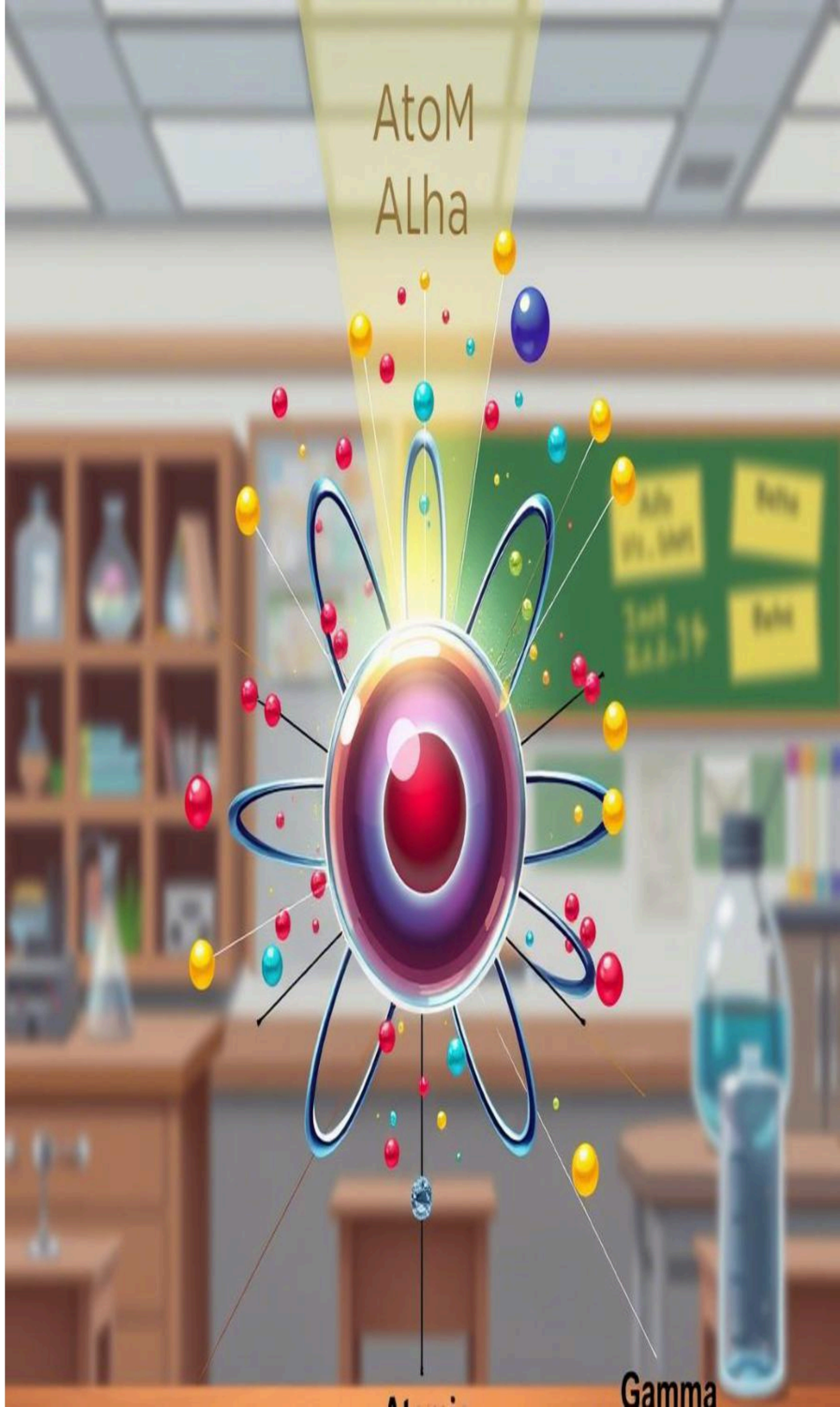
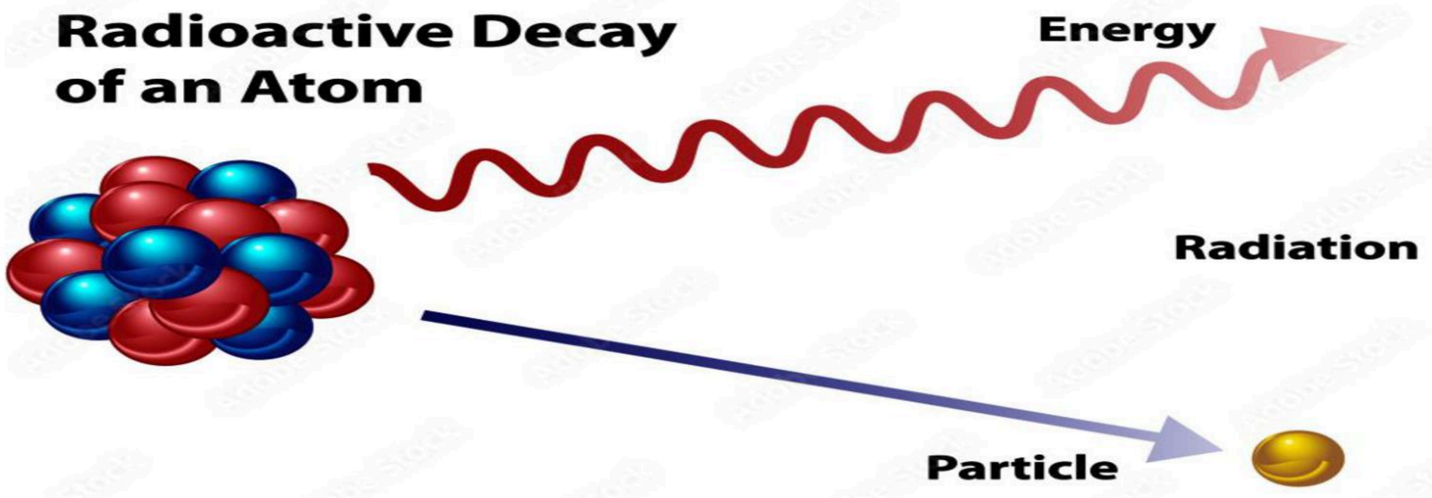


Introduction to Radioactive Decay



- **Radioactive decay** also known as **nuclear decay** or **radioactivity** is a **spontaneous process** by which an **unstable atomic nucleus loses energy** by **emitting radiation**.
- This process transforms the unstable atom nucleus into a **more stable configuration**, often resulting in the formation of a different **element or isotope**.

- The **emitted radiation** can take several **forms or (types)**, including:

- **Alpha (α) particles (α-decay)**: Helium nuclei ${}^{4}_{2}He$ consisting of 2 protons and 2 neutrons.

- **Beta (β) particles (β-decay)**: High-energy electrons (β^-) or positrons (β^+).

- **Gamma (γ) rays (γ-decay)**: Electromagnetic radiation with very high energy.

Why Does Radioactive Decay Occur?

- **Binding energy per nucleon:** Nuclei with lower binding energy per nucleon are less stable and more likely to decay.

- **Neutron-to-proton ratio:** Certain isotopes have too many or too few neutrons relative to protons, making them energetically unstable and more likely to decay.

- **Quantum tunneling:** Even if the nucleus is theoretically stable, quantum mechanics allows for small probabilities of decay.

Alpha emission (α-decay) :

- **Occurs** because the **strong nuclear force** is unable hold **very large nuclei together (heavy nucleus)**.
- The **electrical repulsion** between the protons of the nucleus pushes apart and can act over a much larger distance than the strong nuclear force.
- Since the strong nuclear force can only act on particles directly beside each other, the electrical repulsion **overpowers** the string nuclear force and pushes the nucleons apart .
- **α- particles** is identical to that of **helium nucleus**, it contains **two protons** and **two neutrons.**
- **The general nuclear reaction for α-decay can be written as:**

$$ {}^{A}_{Z}X\,(parent) \longrightarrow {}^{A-4}_{Z-2}Y\,(daughter) + {}^{4}_{2}He $$

Unstable atom | More Stable atom | α- particles

Problems

1)Identify the daughter nucleus formed when Plutonium-239 ($^{239}_{94}$pu) undergoes alpha decay.

Sol/

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

$$^{239}_{94}\text{pu} \longrightarrow \, ^{235}_{92}Y + \, ^{4}_{2}He$$

2) Write the balanced nuclear equation for the alpha decay of Thorium-232 ($^{232}_{90}Th$) .

3) Write the balanced nuclear equation for the alpha decay of Plutonium-244($^{244}_{94}$pu) .

4) Write the balanced nuclear equation for the alpha decay of Radon-222 ($^{222}_{86}$Rn) .

5) Identify the daughter nucleus formed when Americium-241 ($^{241}_{95}$Am) undergoes alpha decay.

6) Write the balanced nuclear equation for the alpha decay of Californium-252 ($^{252}_{98}$Cf) .

Beta (β) emission (β-decay)

Beta decay is one process that unstable atoms can use to become more stable. There are **two** types of beta decay, **beta-minus** and **beta-plus**.

1) Beta-minus decay (β^- decay) : This process occurs when a nucleus has an **excess** of **neutrons** relative to **protons**, making it unstable and this type of radioactive decay in which a **neutron** within an atomic nucleus is transformed into a **proton**, emitting an **electron (the beta –minus particle,e^-)** and an **antineutrino ($\overline{\nu}_e$)**.

$$n \longrightarrow p + e^- + \overline{\nu}_e$$

$${}^{14}_{6}C \longrightarrow {}^{14}_{7}N + e^- + \overline{\nu}_e$$

Before decay:
neutron (0 charge).
After decay:
proton (+1 charge) +
electron (-1 charge) +
antineutrino (0 charge).

The general nuclear reaction for β^- decay can be written as:

$${}^{A}_{Z}X_{(parent)} \longrightarrow {}^{A}_{Z+1}Y\ (daughter) + e^- + \overline{\nu}_e$$

Beta (β) emission (β-decay)

2) Beta-plus decay (β^+ decay) : This process occurs when a nucleus has too many **protons** relative to **neutrons** and this type of radioactive decay in which a **proton** inside an atomic nucleus is converted into a **neutron** , and in the process, a **positron (the antiparticle of an electron, the beta -plus particle, e^+)** and a **neutrino(v_e)** are emitted.

$$p^+ \longrightarrow n + e^+ + v$$

$$^{22}_{11}Na \longrightarrow {}^{22}_{10}Ne + e^+ + v$$

Before decay:
proton (+1 charge).
After decay:
neutron (0 charge) + positron (+1 charge) + neutrino (0 charge).

The general nuclear reaction for β^+ decay can be written as:

$$^{A}_{Z}X_{(parent)} \longrightarrow {}^{A}_{Z-1}Y\ (daughter) + e^+ + v$$

Key Differences Between Beta-Plus and Beta-Minus Decay

	Aspect	Beta-Minus Decay (β^-)	Beta-Plus Decay (β^+)
1	Converts	Converts neutron → proton	Converts proton → neutron
2	Mass number (A)	Remains unchanged	Remains unchanged
3	Atomic number (Z)	Increases by 1	Decreases by 1
4	Particle emitted	Electron ($e-$)	Positron ($e+$)
5	Neutrino emitted	Antineutrino ($\bar{v}$)	Neutrino (v)

Problems

1) Write the complete nuclear reaction for the <u>beta-minus</u> decay of $^{32}_{15}P$?

Sol/

$$^{A}_{Z}X_{(parent)} \longrightarrow {}_{Z+1}^{A}Y \ (daughter) + e^{-} + \overline{\nu}_e$$

$$^{32}_{15}\mathrm{P} \longrightarrow {}^{32}_{16}S + e^{-} + \overline{\nu}_e$$

2) Write the complete nuclear reaction for the <u>beta-minus</u> decay of $^{234}_{90}Th$?

3) Write the complete nuclear reaction for the <u>beta-minus</u> decay of $^{60}_{27}Co$?

4) Write the complete nuclear reaction for the <u>beta-minus</u> decay of $^{131}_{53}I$?

5) Write the complete nuclear reaction for the <u>beta-minus</u> decay of $^{210}_{83}Bi$?

Problems

1) The isotope Fluorine-18 ($^{18}_{9}F$) undergoes <u>beta-plus</u> decay , determine the resulting daughter nucleus?

Sol/

$$^{A}_{Z}X_{(parent)} \longrightarrow {}_{Z-1}^{\;\;A}Y\;(daughter) + e^{+} + v$$

$$^{18}_{9}F \longrightarrow {}^{18}_{8}O + e^{+} + v$$

2) The isotope Nitrogen-13 ($^{13}_{7}$N) undergoes <u>beta-plus</u> decay , determine the resulting daughter nucleus.

3) The isotope Magnesium-23 ($^{23}_{12}$Mg) undergoes <u>beta-plus</u> decay , determine the resulting daughter nucleus.

4) The isotope Phosphorus-30 ($^{30}_{15}P$) undergoes <u>beta-plus</u> decay , determine the resulting daughter nucleus.

Gamma Decay (γ-decay)

After processes like **alpha decay, beta decay**, or **nuclear fission (It is rare)**, the resulting **nucleus may remain in an excited (metastable) state with excess energy**. This **nucleus** transitions to a **lower energy state** by **emitting a gamma photon (γ-ray) (Electromagnetic Radiation).** The element remains the same; only the **energy state of the nucleus changes**.

$$\textbf{Thorium} - \textbf{234}^{*} \rightarrow \textbf{Thorium} - \textbf{234} + \gamma \text{ - } \textbf{ray}$$

the asterisk (*) denotes an excited nucleus.

Summary Table: Gamma, Beta, and Alpha Decay

Aspect	Gamma decay	Bate decay	Alpha decay
Definition	Emission of gamma rays (high-energy photons)	Emission of beta particles (electrons/positrons)	Emission of alpha particles (helium nuclei)
Emitted Particle	Gamma ray (γ) – photon (no mass/charge).	Beta particle (β^-: electron; β^+: positron).	Alpha particle (α) – ${}^{4}_{2}He$ nucleus (2p + 2n).
Change in Z	No change	Increases by 1 (β^-) or decreases by 1 (β^+)	Decreases by 2
Change in A	No change	No change	Decreases by 4
Penetration Power	Highest (stopped by thick lead/concrete)	Moderate (stopped by aluminum/plastic)	Lowest (stopped by paper/skin)
Common Sources	Excited nuclei (e.g., after α/β decay).	Radioactive isotopes (e.g., Carbon-14, Iodine-131).	Heavy nuclei (e.g., Uranium-238, Radium-226).
Applications	Medical imaging, sterilization, cancer therapy	Radiocarbon dating, PET scans.	Smoke detectors, static eliminators, research.