Session – 35th - Modern Physics – III
(Radiactive Decay)

Mass Defect

$${}^{A}_{Z}X$$

$p \rightarrow Z$
$n \rightarrow (A-Z)$

$$m_x^{expected} = Z \times m_p + (A-Z) m_n$$

$$m_x^{observed} = m_x - Z m_e$$

$$\Delta m = m_x^{expected} - m_x^{observed}$$

$$= \left[Z m_p + (A-Z) m_n\right] - \left[m_x - Z m_e\right]$$

$$\boxed{\Delta m = Z m_p + (A-Z) m_n + Z m_e - m_x}$$

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The spontaneous emission of (α- β- γ) rays by certain unstable nuclei in order to gain stability.

α- decay → ${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He + Q$ (Conservation of charge/nuc. is applied)

($A > 210$)
(Usually)

3 conservation Laws

1. Conservation of charge/nucleons
2. Conservation of mass-energy
3. Conservation of linear momentum.

Q-value of nuclear reaction (energy released +ve)

- $\left[\sum (m_{Reactants}) - \sum (m_{products})\right]c^2 = \Delta m c^2$
- $\left[\sum (B.E.)_{products} - \sum (B.E.)_{Reactants}\right]$
- $\left[\sum (K.E.)_{products} - \sum (K.E.)_{Reactants}\right]$

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Cons. of linear momentum

$$p_y = p_\alpha$$

$$\sqrt{2m_y k_y} = \sqrt{2m_\alpha k_\alpha}$$

$$\Rightarrow \boxed{m_y k_y = m_\alpha k_\alpha} \quad -①$$

$$\boxed{K_y + K_\alpha = Q} \quad -②.$$

$$K_y = \left(\frac{m_\alpha}{m_\alpha + m_y}\right) Q$$

$$K_\alpha = \left(\frac{m_y}{m_\alpha + m_y}\right) Q$$

α- decay → ${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He + Q$ (Cons. of charge/nuc. is applied)

$(A > 210)$ (usually) (excess protons) (n/p) increases

${}^{A}_{Z}X$: $p \to Z$, $n \to (A-Z)$

${}^{A-4}_{Z-2}Y$: $p \to (Z-2)$, $n \to [(A-Z)-2]$

${}^{4}_{2}He$: $p \to 2$, $n \to 2$

$$Q = \Delta m c^2 = \left[\underbrace{(m_x - Z m_e)}_{\text{Reactants' mass}} - \underbrace{\{(m_y - (Z-2)m_e) + (m_{He} - 2m_e)\}}_{\text{Products' mass}}\right] c^2$$

$$= (m_x - Z\cancel{m_e} - m_y + Z\cancel{m_e} - 2\cancel{m_e} - m_{He} + 2\cancel{m_e})c^2$$

$$Q = (m_x - m_y - m_{He})c^2$$

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α-decay- $${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He + Q$$

$$Q\text{-value} = (m_X - m_Y - m_{He})c^2$$

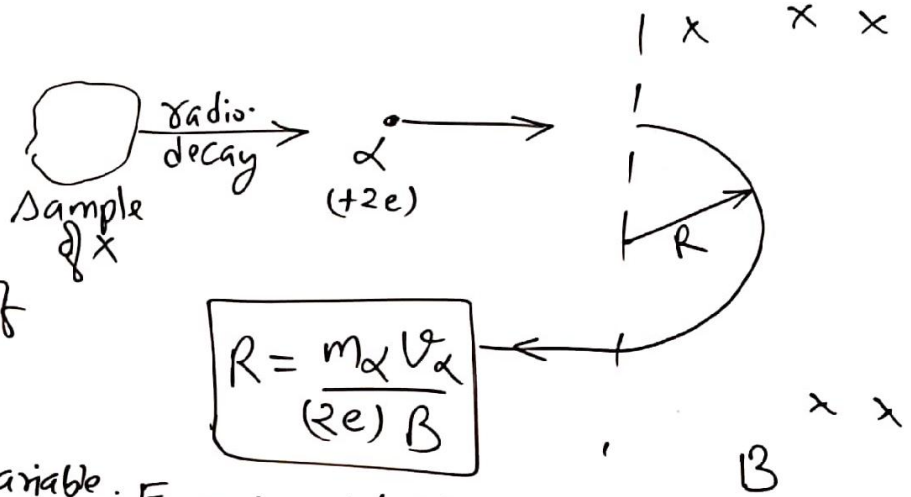
$$K_\alpha = \frac{m_Y}{m_\alpha + m_Y} Q$$

$$K_Y = \frac{m_\alpha}{m_\alpha + m_Y} Q$$

→ Kinetic energy of α-particle.

→ Q. will K_α be constant or variable.

Q. will speed (v_α) of α-particles be constant?



$$R = \frac{m_\alpha v_\alpha}{(2e)B}$$

Experimental Observation

→ Discrete spectrum of α-particles.

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α – decay – $\quad {}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He + Q$

$$Q\text{-value} = (m_X - m_Y - m_{He})c^2$$

$$K_\alpha = \frac{m_Y Q^*}{m_\alpha + m_Y}$$

$$K_Y = \frac{m_\alpha}{m_\alpha + m_Y} Q^*$$

Explanation of discrete spectrum of α-particles →

$${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y^* + {}^{4}_{2}He + Q$$

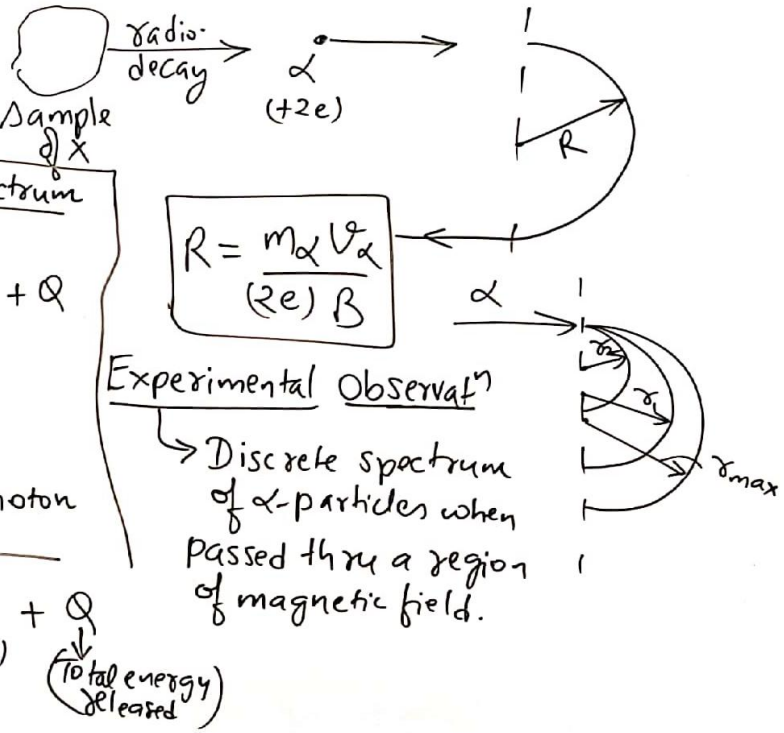
$${}^{A-4}_{Z-2}Y^* \rightarrow {}^{A-4}_{Z-2}Y + \gamma\text{-photon}\ (E)$$

(excited nucleus)

Add → $\quad {}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He + \gamma\ (E) + Q$

$(Q^* = Q - E)$

(Total energy released)



Experimental Observatn

→ Discrete spectrum of α-particles when passed thru a region of magnetic field.

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(Radiactive Decay)

β^+ decay → (excess protons) (rare)

$${}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}\beta^+ + Q$$

$p \to Z$, $n \to (A-Z)$

$p \to Z-1$, $n \to ((A-Z)+1)$

Cons. of Charge & no. of nucleons → applied.

$${}^{1}_{1}p \to {}^{1}_{0}n + {}^{0}_{+1}\beta$$

Cons. of mass & energy

$$Q = \underbrace{\left[(m_x - Zm_e) - \left\{(m_y - (Z-1)m_e) + m_e\right\}\right]}_{\Delta m} c^2$$

$m_{reactants}$ $m_{product}$

Cons. of lin. momentum

$$K_{\beta^+} = \left(\frac{m_y}{m_y + m_\beta}\right) Q$$

$$K_y = \left(\frac{m_\beta}{m_y + m_\beta}\right) Q$$

$K_{\beta^+} >> K_y$

$$Q = (m_x - Z\cancel{m_e} - m_y + Z\cancel{m_e} - m_e - m_e)c^2$$

$$\boxed{Q = (m_x - m_y - 2m_e)c^2}$$

Q. Will K_β be const. or variable for different ${}^{A}_{Z}X$ atoms?

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(Radiactive Decay)

β^+ decay → (excess protons) (rare)

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

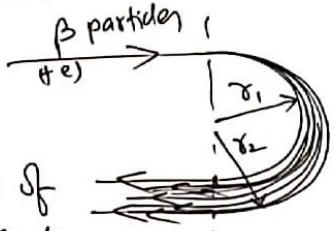
$${}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}\beta^+ + \nu + Q$$

positron

(E)

$$Q^* = (Q - E)$$

Experimental Observation →



The spectrum of β particles is continuous

Cons. of lin. momentum

$$K_{\beta^+} = \left(\frac{m_y}{m_y + m_\beta}\right) Q^*$$

$$K_y = \left(\frac{m_\beta}{m_y + m_\beta}\right) Q^*$$

$K_{\beta^+} >> K_y$

Pauli explained → by introducing particles → neutrino (ν) & antineutrino ($\bar{\nu}$).

- (ν) → (when neutron is produced) → β^+ decay.
- ($\bar{\nu}$) → (when neutron converts into a proton) → in β^- decay.
- rest mass → zero
- charge less
- travel with c (speed of light)
- $m_s = \pm 1/2$

→ β-particle spectrum isn't characteristic of nucleus y.