ALPHA DECAY

Since the attractive forces between nucleons are of short range, the total binding energy in a nucleus is approximately proportional to its mass number A, the number of nucleons it contains. The repulsive electric forces between protons, however are of unlimited range and total disruptive energy in a nucleus is approximately proportional to Z^2 (Coulomb energy part $E_c \propto Z(Z-1)$, $E_c \propto Z^2$).

Nuclei which contain 210 or more nucleons (i.e $A \geqslant 210$) are so large that the short-range nuclear forces that hold them together are barely able to counterbalance the mutual repulsion of their protons. Alpha decay occurs in such nuclei to increase their stability by reducing their size.

■ But the question may arise, why are alpha particles emitted rather than, say individual protons or ${}_2He^3$ nuclei ??

⇒ The answer remains in the high binding energy of the alpha particle. To escape from a nucleus, a particle must have kinetic energy, and only the alpha particle mass is sufficiently smaller than that of its constituent nucleons for such energy to be available.

■ Range of α-particles :- The most important property of α-particles is their ability to ionise the material through which they pass and finally when its energy falls below the ionisation potential of the material converted into neutral helium atom by capturing two electrons.

● **Range** :- Distance through which an α-particle travels in a specified material before stopping to ionise it is called its range in that material.

The range of the α-particle depends on —

i) Initial energy of the α-particle.

ii) Ionisation potential of the gas.

iii) Nature and temperature and pressure of the gas.

Range of α-particle, R ~~deped~~ and velocity of the α-particles v are related by the relation

$$\boxed{R \propto v^3}$$

This is known as the Geiger law.

since $E = \frac{1}{2}mv^2$,

Therefore $\boxed{R \propto E^{3/2}}$

● **Specific ionisation** :- Due to ionisation, there will be a large number of ion-pairs generated along the path of the α-particle in the material. The number of ion-pairs formed per unit length at any point in the path of the α-particles is called specific ionisation and is symbolised by I.

since $E \propto R^{2/3}$

$$\therefore \frac{dE}{dR} \propto R^{-1/3} \propto \frac{1}{v} \quad [\because R \propto v^3]$$

Thus the ionisation produced by an α-particle at any point in its track is inversely proportional to its velocity at that point.

Proof of Greiger law :- α - particles lose more energy per unit path length near the end of their range because they move slowly and ~~interact~~ interact for a longer time with atoms near which they pass.

$$\therefore -\frac{dE}{dx} = \frac{K}{v} \qquad K = \text{Constant}$$

Again,
$$E = \frac{1}{2}mv^2$$

$$\therefore \frac{dE}{dx} = mv\frac{dv}{dx}$$

$$\therefore -mv\frac{dv}{dx} = \frac{K}{v}$$

$$\therefore -\int_v^0 v^2 dv = \frac{K}{m}\int_0^R dx$$

$$\therefore R = \frac{m}{3K}v^3 = av^3$$

$$\therefore \boxed{R \propto v^3} \quad \text{Greiger law}$$

Straggling of range :- The α - particles of the same initial energy have more or less the same range in matter. However a small spread in the values of ranges about a mean value is observed. This phenomenon is known as the straggling of range.

- Straggling of range occures mainly due to two reasons

i) There is statistical fluctuation in the number of collisions suffered by different particles about a mean value in travelling over a given distance.

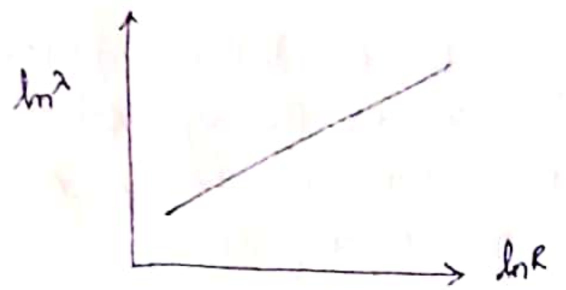
ii) There is also a statistical fluctuation about a mean value in the energy loss per collision.

• **Stopping power** :- The energy of α - particles progressively decreases as they pass through increasing thicknesses of matter. The amount of energy loss of an α. particle per unit path length in the absorber is called the stopping power of the absorber.

• **Geiger - Nuttall law** :- An important quantitative relation between the range R of the α- particle and decay constant λ of the emitting nuclei was experimentally discovered by Geiger and Nuttall and is called Geiger Nuttall law. According to this law, α- particles emitted by substances having larger λ (or shorter half lives) have larger ranges and vice versa. The relation runs as,

$$\ln\lambda = A + B \ln R$$

where, A and B are constant



Again, $R \propto E^{3/2}$

$$\therefore \ln\lambda = C + D \ln E$$

$$\therefore \ln T_{1/2} = C' + -D' \ln E$$

• **Significance** :- It states that short-lived isotopes emit more energetic alpha particles than long lived ones. The relationship also shows that half-lives are exponentially dependent on decay energy, so that very large changes in half life make comparatively small differences in decay energy.

α- disintegration energy :-

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

The kinetic energy ~~the decay process~~ of the emitted α- particle in the decay process is of the order of few MeV. This shows that the process is a nuclear transformation.

Q value of the decay process, known as the α-disintegration energy is the total energy released in the disintegration process and is given by

$$Q_\alpha = (M_X - M_\alpha - M_Y)c^2$$

where M's are the masses of the particles.

For heavy nuclei, $Q_\alpha > 0$. So the decay can occur spontaneously.

- Kinetic energy of the emitted α- particle can be derived from the Q- value by the application of laws of conservation of momentum and energy. Assuming the nucleus to be at rest during decay,

$$0 = M_\alpha v_\alpha - M_Y v_Y$$

and $$Q_\alpha = \frac{1}{2} M_\alpha v_\alpha^2 + \frac{1}{2} M_Y v_Y^2$$

$$\therefore \quad Q_\alpha = \frac{1}{2} M_\alpha v_\alpha^2 \left(1 + \frac{M_\alpha}{M_Y}\right) = T_\alpha \left(1 + \frac{M_\alpha}{M_Y}\right)$$

$$\therefore \quad Q_\alpha = T_\alpha \left(1 + \frac{4}{A-4}\right)$$

$$\boxed{Q_\alpha = T_\alpha \cdot \left(\frac{A}{A-4}\right)}$$

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Questions

i) Why is kinetic energy of the emitted α-particle never equal to the disintegration energy Q?

ii) The radionuclide U^{232} decays into Th^{228} by emitting α-particle. Find the energy released in the decay. Is it possible for U^{232} to decay into U^{231} by emitting a neutron??
Atomic masses of U^{232}, U^{231} and neutron respectively 232.03715 U, 231.03629 U, 1.008665 U and Th^{228} (228.02874 U)

iii) The polonium isotope $_{84}Po^{210}$ is unstable and emits a 5.30 MeV α-particle. The atomic mass of $_{84}Po^{210}$ is 209.9829 u and that of $_{2}He^{4}$ is 4.0026 u. Identify the ~~daughter~~ daughter nuclide and find its atomic mass.