Chapter 3.

Radioactive decay :

(A) Alpha-decay (α-decay):-

In a radioactive decay when an elements radiates Helium particles as it's radiation, it's known as α-decay.

Transformation

$${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He + Q,$$ Q is disintegration energy.

(a) Disintegration Energy:- It's the energy is the sum of K.E. of the alpha particle & K.E. of the product nucleus.

i.e. $Q = \frac{1}{2} m_\alpha v_\alpha^2 + \frac{1}{2} m_d v_d^2$ —— (1)

d = daughter nucleus.

α = α-particle

Using conservation of linear momentum

$$m_\alpha v_\alpha + m_d v_d = 0$$

$$\Rightarrow v_d = \frac{m_\alpha v_\alpha}{m_d}$$

Therefore, $Q = \frac{1}{2} m_\alpha v_\alpha^2 + \frac{1}{2} \cancel{m_d} \cdot \frac{m_\alpha^2 v_\alpha^2}{m_d^{\cancel{2}}}$

$$\Rightarrow Q = \frac{1}{2} m_\alpha v_\alpha^2 \left(1 + \frac{m_\alpha}{m_d}\right)$$

Since ${}_2^4He$, ${}_{Z-2}^{A-4}Y$

So, $Q = K.E_\alpha \left[1 + \frac{m_\alpha}{m_d}\right]$

$$\Rightarrow Q = K.E_\alpha \left[\frac{m_d + m_\alpha}{m_d}\right]$$

$$\Rightarrow Q = K.E_\alpha \left[\frac{A}{A-4}\right]$$

Disintegration energy can also be express as

$$Q = [m_x - m_y - m_{He}] \times c^2$$

where masses are atomic masses.

Note:- $Q > 0$, must be, for α-emmession.

Range of alpha particles :-

When α-particles passes through a matter it ionizes the particles of the matter & there by loses energy gradually. The range of an alpha particle in any medium is define as the distanced travalled by it before stoping to ionised it. Range is measured in unit of length or in unit of mass.

Laws for Ranges:-

(1) Geiger's Empirical Relation :-

Experimentally it's found that monoenergetic α-parti--cles moving with velocity v, will have range R in Standard Temperature & Pressure (S.T.P) proportional to v^3. i.e $R \propto v^3$.

In terms of energy this relⁿ can be expressed as→

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

$$\boxed{E = \tfrac{1}{2}mv^2 \Rightarrow v^2 = \frac{2E}{m} \Rightarrow v \propto \sqrt{E}}$$

Derivation of Geiger's Law:-

The energy loss of the α-particle per unit length is inversely proportional to the velocity.

ie. $\Rightarrow \frac{-dE}{dx} \propto \frac{1}{v}$

$\Rightarrow \frac{-dE}{dx} = \frac{K}{v}$

$\Rightarrow \frac{-d}{dx}\left(\tfrac{1}{2}mv^2\right) = \frac{K}{v}$

$\Rightarrow -\frac{1}{\cancel{2}} mv.\cancel{2}\frac{dv}{dx} = \frac{K}{v}$

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

so, for total volume

$$\Rightarrow -m\int_{v}^{0} v^2\, dv = K\int_{0}^{R} dx$$

$$\Rightarrow -\frac{mv^3}{3} = KR$$

$$\Rightarrow R = \frac{-mv^3}{3K}$$

$$\Rightarrow R \propto v^3$$ [since $\frac{m}{3K}$ are constant.]

(A) Geiger - Nuttal Law :-

This is an empirical relationship between the range of the α-particle and disintegration constant. It is expressed as →

$$\log \lambda = A + B \log R.$$

Here A and B are constant having different values for different radioactive substances.

Since $R \propto E^{3/2}$, Geiger-Nuttal relationship can be written as

$$\log \lambda = C + D \log E$$

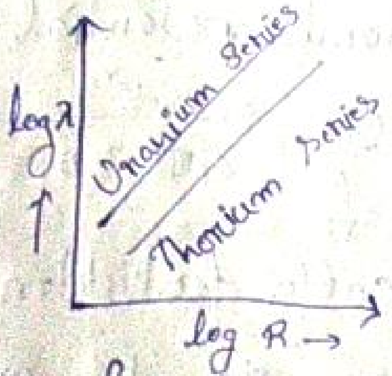


fig. (a)

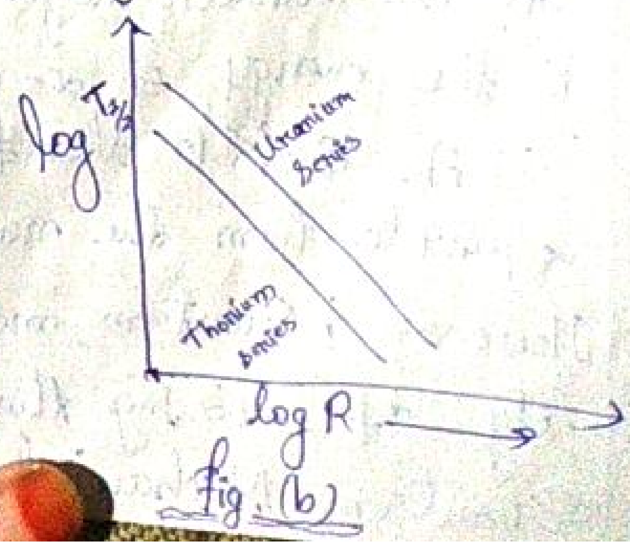


fig. (b)

Since $\lambda = \frac{0.693}{T_{1/2}}$,

The graph (b) between ~~Th~~ $\log T_{1/2}$ & $\log R$ will be '-ve' slope as in fig (b).

(4) Gamow's theory of α-decay:- [Tunnel effect]

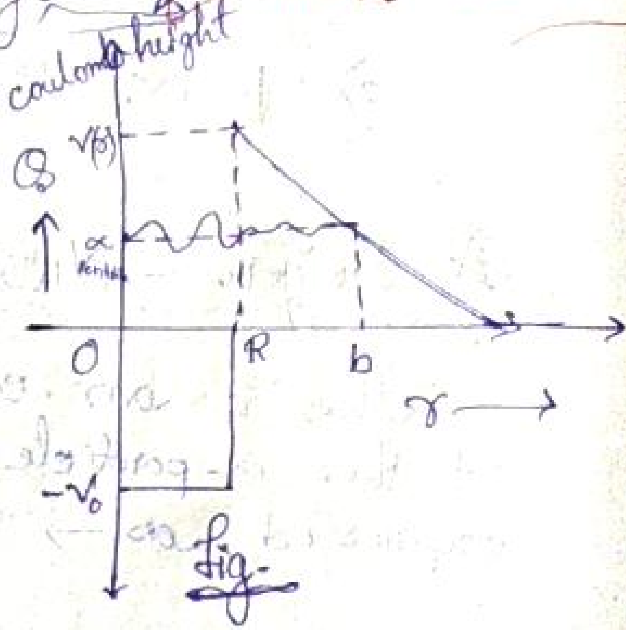


fig.

Befor the emmission of α-particles from the nucleus, the α-particle experiences the nuclear potential upto a distance R, which is the radius of the nucleus, and after that there, will be coulomb potential bet^n the α-particles and the daugher nucleus.

The coulomb potential at distance R is

$$B = \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0 R} \quad (1)$$

As the barrier height of the coulomb potential Q is the energy of α-particles. So, $Q = \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0 b}$ (2)

As $Q << B$ therefore emission of α-particle from the nucleus is classically forbidden. However, Quantum mechanically there will be probability of crossing this barrier which is known as Quantum Mechanical tunnel ~~or~~ effect.

Probability $= e^{-2\gamma d}$

$$\gamma = \sqrt{\frac{2m}{\hbar^2}(V_0 - E)}$$

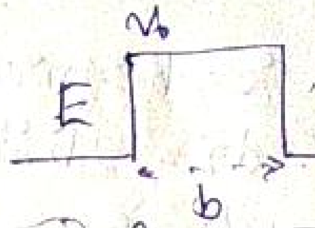


Fig.

The probability of crossing the barrier is

$$P = e^{-2\int \gamma(r)\,dr} \quad \text{———} \quad (3)$$

$$\gamma(r) = \sqrt{\frac{2m}{\hbar^2}\left\{V(r) - E\right\}}$$

$$= \sqrt{\frac{2m}{\hbar^2}\left\{\frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0 r} - \frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0 b}\right\}}$$

$$\gamma(r) = \sqrt{\frac{2m}{\hbar^2}\,\frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0}\left\{\frac{1}{r} - \frac{1}{b}\right\}}$$

$\therefore$ Probability $P = e^{-2\int \gamma(r)\,dr}$

$$P = e^{-2G}$$

where $G = \int \gamma(r)\,dr$

$$= \int \sqrt{\frac{2m}{\hbar^2}\,\frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0}\left\{\frac{1}{r} - \frac{1}{b}\right\}}\,dr$$

$$= \sqrt{\frac{2m}{\hbar^2}\,\frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0}} \int \left(\frac{1}{r} - \frac{1}{b}\right) dr \quad \text{———} \quad (4)$$

Now let $r = b\sin^2\theta$

$$\Rightarrow \frac{1}{r} = \frac{1}{b}\,\mathrm{cosec}^2\theta$$

so, putting the value in eq^n (4) integral part

$$\int \sqrt{\frac{1}{b}\left(\mathrm{cosec}^2\theta - 1\right)}\,dr \Rightarrow \int \sqrt{\frac{1}{b}\cot^2\theta}\,dr$$

$r = b\sin^2\theta$

$dr = 2b\sin\theta\cos\theta\, d\theta$

Therefore

$$= \int \sqrt{\frac{1}{b}\cot^2\theta}\; 2b\sin\theta\cos\theta\, d\theta$$

$$= 2\sqrt{b}\int \frac{\cos\theta}{\sin\theta}\sin\theta\cos\theta\, d\theta$$

$$= 2\sqrt{b}\int \cos^2\theta\, d\theta$$

$$= \sqrt{b}\int 2\cos^2\theta\, d\theta$$

$$= \sqrt{b}\int (1+\cos 2\theta)\, d\theta$$

The region here is $r = R$, $r = b$,

since $r = b\sin^2\theta$

$$\Rightarrow R = b\sin^2\theta$$

$$\Rightarrow \sin^2\theta = \frac{R}{b}$$

$$\Rightarrow \sin^2\theta = \sqrt{\frac{b}{b}} \qquad \text{if } \theta = \pi/2,\ R = b,$$

$$\Rightarrow \sin^2\theta = 1$$

Therefore, $= \sqrt{b}\int \left[\theta + \frac{\sin 2\theta}{2}\right]$

$$= \sqrt{b}\left[\frac{\pi}{2} - \sin^{-1}\sqrt{\frac{R}{b}} + \sqrt{\frac{R}{b}}\cdot\left(1-\frac{R}{b}\right)\right]$$

So, $G = \sqrt{\frac{2m}{\hbar^2}\frac{Z_1Z_2e^2}{4\pi\varepsilon_0}}\sqrt{b}\left[\frac{\pi}{2} - \sin^{-1}\sqrt{\frac{R}{b}} + \sqrt{\frac{R}{b}}\cdot\left(1-\frac{R}{b}\right)\right]$.

from eqn ① & ② $\frac{Q}{B} = \frac{R}{b}$

Putting this value

$$\Rightarrow G = \sqrt{\frac{2m}{\hbar^2}\frac{z_1 z_2 e^2}{4\pi\epsilon_0}\frac{z_1 z_2 e^2}{4\pi\epsilon_0 Q}}\left[\frac{\pi}{2} - \sin^{-1}\sqrt{\frac{Q}{B}} - \sqrt{\frac{Q}{B}\left(1-\frac{Q}{B}\right)}\right]$$

$$\Rightarrow G = \frac{z_1 z_2 e^2}{4\pi\epsilon_0}\sqrt{\frac{2m}{\hbar^2 Q}}\left[\cos^{-1}\sqrt{\frac{Q}{B}} - \sqrt{\frac{Q}{B}\left(1-\frac{Q}{B}\right)}\right]$$

[Since, formula $\frac{\pi}{2} - \sin^{-1}\theta = \cos^{-1}\theta$]

As $\frac{Q}{B}$ is very very $\frac{Q}{B} \ll 1$, so $\frac{Q^2}{B^2}$ term can be neglected. Here also $\cos^{-1}\sqrt{Q/B}$ can be written as $\frac{\pi}{2} - x$. ie $\frac{\pi}{2} - \sqrt{\frac{Q}{B}}$.

Therefore,

$$\Rightarrow G = \frac{z_1 z_2 e^2}{4\pi\epsilon_0}\sqrt{\frac{2m}{\hbar^2 Q}}\left[\left(\frac{\pi}{2} - \sqrt{\frac{Q}{B}}\right) - \sqrt{\frac{Q}{B}\left(1-\frac{Q}{B}\right)}\right]$$

$$\Rightarrow G = \frac{z_1 z_2 e^2}{4\pi\epsilon_0}\sqrt{\frac{2m}{\hbar^2 Q}}\left[\frac{\pi}{2} - 2\sqrt{\frac{Q}{B}}\right]$$

neglecting.

further can be approximated.

$$G = \frac{z_1 z_2 e^2}{4\pi\epsilon_0}\sqrt{\frac{2m}{\hbar^2 Q}} \cdot \frac{\pi}{2}.$$

As a-particles takes the most of the energy - So, Q can be written as $Q = \frac{1}{2} m_\alpha v_\alpha^2$.

P.T.O.

So, $G = \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0}\sqrt{\frac{2m}{\hbar^2}\cdot\frac{2}{mv^2}}\;\pi/2$

$\Rightarrow G = \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0} \frac{2}{\hbar v} \times \pi/2$

$\Rightarrow G = \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0 \hbar v}$

Beta - decay :-

Process

(i) ${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e + \bar{\nu} + Q$

(ii) ${}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + {}^{0}_{1}e + \nu + Q.$

Q. How electrons are emmited during β - decay although it can't existes inside the nucleus?

Ans :- Electron donot exist inside the nucleus. The emitted electrons have energy 2 - 3 MeV and if we calculate the energy by considering heisenberg uncertainity principle the energy comes out 20 MeV. Therefore e^- can't exist inside the nucleus. Electrons and positrons are created during the time of β^- decay in the process of conversion of nutron to proton and vice-versa. i.e $\;{}^{1}_{0}n \longrightarrow {}^{1}_{1}P + {}^{0}_{-1}e + \bar{\nu} + Q$

$\quad {}^{1}_{1}P \longrightarrow {}^{1}_{0}n + {}^{0}_{1}e + \nu + Q$

Q value :-

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

① β^--decay.

$$\Rightarrow Q = \left[M_{nuc}\left({}^{A}_{Z}X\right) - M_{nuc}\left({}^{A}_{Z+1}Y\right) - m_e\right]c^2$$

$$= \left[M_{atm}\left({}^{A}_{Z}X\right) - Zm_e - M_{atm}\left({}^{A}_{Z+1}Y\right)\right]$$

$$\Rightarrow Q = \left[M_a\left({}^{A}_{Z}X\right) - M_a\left({}^{A}_{Z+1}Y\right)\right]c^2.$$

② β^+-decay :-

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

$$Q = \left[M_{nuc}\left({}^{A}_{Z}X\right) - M_{nu}\left({}^{A}_{Z-1}Y\right) - m_e\right]c^2$$

$$\Rightarrow Q = \left[M_{atm}\left({}^{A}_{Z}X\right) - Zm_e - M\left({}^{A}_{Z-1}Y\right) + (Z-1)m_e - m_e\right]c^2$$

$$\Rightarrow Q = \left[M\left({}^{A}_{Z}X\right) - (Z+1)m_e + (Z-1)m_e - M\left({}^{A}_{Z-1}Y\right)\right] \times c^2$$

$$\Rightarrow Q = \left[M\left({}^{A}_{Z}X\right) - 2m_e - M\left({}^{A}_{Z-1}Y\right)\right]c^2$$

β^+-decay is possible if mass of the parent atom is greater than the mass of the daughter atom by at least amount 1.02 MeV.

③ Electron Capture :-

$${}^{A}_{Z}X + {}^{0}_{-1}e \rightarrow {}^{A}_{Z-1}Y$$

$$\Rightarrow Q = \left[M_{nu}\left({}^{A}_{Z}X\right) + m_e - M_{nu}\left({}^{A}_{Z-1}Y\right)\right]c^2 - B.E_e$$

$$\Rightarrow Q = \left[M_a\left({}^{A}_{Z}X\right) + Zm_e - M_a\left({}^{A}_{Z-1}Y\right) + (Z-1)m_e\right]c^2 - B_e$$

Here B_e is the $B.E_e$ of the e^- to the orbit

$$\Rightarrow Q = \left[M\left({}^{A}_{Z}X\right) - M\left({}^{A}_{Z-1}Y\right)\right]c^2 - B_e .$$

★ Neutrino hypothesis :-

① From the fig it's clear that electron's emitted in the process doesnot carry all the energy.

i.e. The 'Q' value of the process.

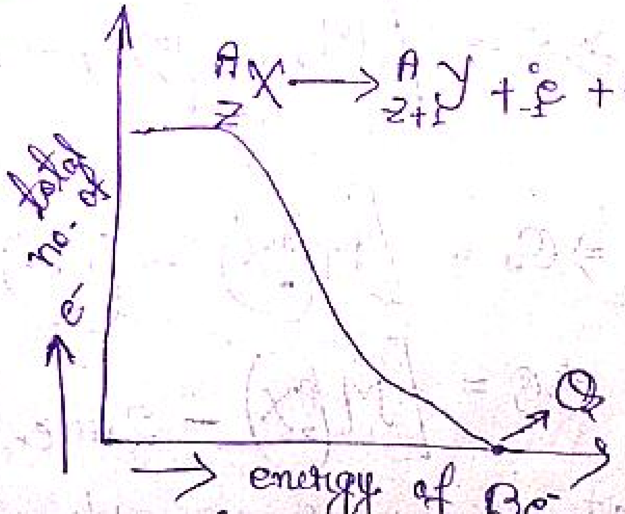


fig :

This is a violation of conservation of energy.

② β particles are emitted in the conservation of Proton ~~&~~ to Neutron and vice-versa.

$${}^{1}_{0}n \longrightarrow {}^{1}_{1}p + {}^{0}_{-1}\beta + \bar{\nu} + Q$$

$${}^{1}_{1}p \longrightarrow {}^{1}_{0}n + {}^{0}_{1}\beta + \nu + Q$$

Protons, neutrons & electrons are spin 1/2 particle.

$$\underset{\frac{1}{2}\hbar}{p} \longrightarrow \underset{\frac{1}{2}\hbar}{n} + \underset{\frac{1}{2}\hbar}{\beta^-}$$

So, it's clear that the law of conservation of angular momentum is also violated during the process.

In 1930 Pauli prostulated the existance of new particle, called nutrino, which is also emitted in the β- decay process in order to save the two conservation laws.

Properties :-

① Neutrino must be electrically natral in order to agree with the charge conservation.

② Mass of the neutrino is zero or almost zero. This is because the maximum energy of the emmited electron is equal to the mass-energy difference between parent & the product.

Maximum energy of the emitted e^- is equal to the Q value of decay process.

③ The spin of the neutrino is $\frac{1}{2}\hbar$ in order to satisfy the law of conservation of angular momentum.

④ The neutrino carries the energy equal to the difference betn 'Q' value of the decay process & the energy of the emitted electron.

⑤ $^{1}_{0}n \longrightarrow {}^{1}_{1}p + {}^{0}_{-1}\beta + \bar{\nu} + Q$

$^{1}_{1}p \longrightarrow {}^{1}_{0}n + {}^{0}_{+1}\beta + \nu + Q$

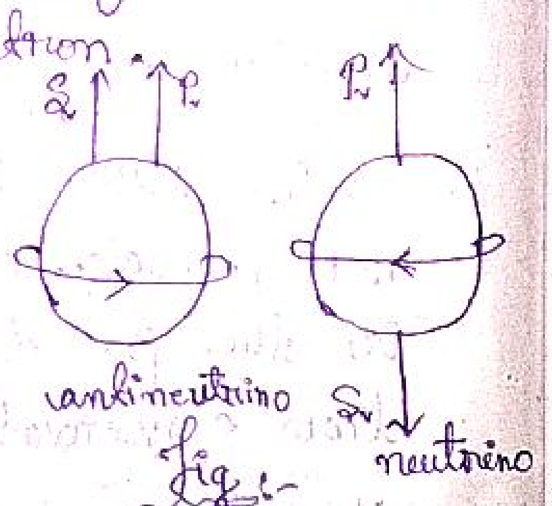


fig:-

Neutrino & antineutrino are two different particle. Neutrino spin vector is antiparallel to momentum vector.

But antineutrino spin vector is parallel ~~particle~~ to momentum vector.

(A) Helicity :- (H) :- Helicity is define as

$$H = \frac{\vec{P} \cdot \vec{S}}{|\vec{P}|\,|\vec{S}|}$$

where p is the momentum & S is the spin. The Helicity for neutrino is '-1' & for antineutrino is "+1".

(B) γ - decay :-

When a nucleus decays by the emission of 'α' or 'β', it is left in the excited stat, then the product decays electromagnetically by emission of γ- photon in order to reach the ground state.

$${}^{A}_{Z}X \longrightarrow \overset{\text{Excited state}}{{}^{A-4}_{Z-2}Y^{*}} + {}^{4}_{2}He + Q.$$

$$\underset{\text{Excited state}}{{}^{A-4}_{Z-2}Y^{*}} \longrightarrow {}^{A-4}_{Z-2}Y + \gamma$$

If E^* and E are the energys of excited state & ground state respectively then energy of the γ photon is $E^* - E = h\nu$.

When the decaying nucleus is at rest then the conservation of linear momentum states that the momentum of the nucleus will be equal & opposite

to the momentum of γ photon. The mo-
-mentum of the nucleus will be therefore
$\frac{hc}{\nu}$.

Nuclear Reactions : unit - 4

Types of Nuclear Reactions:-

① **Elastic scattering :-** The incident particle strikes the target nucleus & leaves without loss of energy & in general with altered direction of motion. $X_1(x_1, x_2)X_2$

$${}^{4}_{2}He + {}^{197}_{79}Au \longrightarrow {}^{197}_{79}Au + {}^{4}_{2}He$$
$$(x_1) \quad (X_1) \quad (X_2) \quad (x_2)$$

② **Inelastic Scattering :-**

In this case K.E. is not conserved, some of the K.E. will be taken up by the target nucleus & hence excited to the higher energy state

$X_1(x_1, x_2)X_2^{*}$

eg

$${}^{7}_{3}Li + {}^{1}_{1}H \longrightarrow {}^{7}_{3}Li^{*} + {}^{1}_{1}H$$
$$(X) \quad (x_1)$$

$${}^{7}_{3}Li^{*} \longrightarrow {}^{7}_{3}Li + \gamma$$
$$(X_2) \quad (x_2)$$

③ Pick up reaction :-

When the projectile gains nucleons from the target then it's called pick up reaction.

eg $_{1}^{2}H + {}_{8}^{16}O \longrightarrow {}_{8}^{15}O + {}_{1}^{3}H$

i.e. $_{8}^{16}O\ ({}_{1}^{2}H, {}_{1}^{3}H)\ {}_{8}^{15}O$.

④ Stripping Reaction :- When nucleons from the projectile are captured by the target nucleus it's called stripping reaction.

eg :- $_{29}^{63}Cu + {}_{1}^{2}H \longrightarrow {}_{29}^{64}Cu + {}_{1}^{1}H$

$_{29}^{63}Cu\ ({}_{1}^{2}H, {}_{1}^{1}H)\ {}_{29}^{64}Cu$

In pick up or stripping reactions the involved nucleon is assume to leave or enter the target nucleus without disturbing the other nucleons. This reactions are known as direct reactions.

⑤ Radio active Capture :-

The incident particle is captured by the target nucleus & new nucleus is formed while the access energy will be emited in terms of γ photon.

$$^{12}_{6}C + ^{1}_{1}H \longrightarrow ^{13}_{7}N + \gamma$$

$$X(\alpha, \gamma)Y.$$

⑥ Disintegration Reaction:- It's the most general type of reaction in which incident particle is absorped & different particle is ejected.

ⓐ Proton induced nuclear reaction:-

$$^{9}_{4}Be + ^{1}_{1}H \longrightarrow ^{6}_{3}Li + ^{4}_{2}He \qquad x(P, \alpha)y$$

$$^{9}_{4}Be(^{1}_{1}H, ^{4}_{2}He)^{6}_{3}Li.$$

$$^{9}_{4}Be + ^{1}_{1}H \longrightarrow ^{9}_{4}Be + ^{2}_{1}H$$

$$^{9}_{4}Be(P, D)^{9}_{4}Be$$

$$\left.\begin{array}{l} ^{9}_{4}Be + ^{1}_{1}H \longrightarrow ^{9}_{5}B + ^{1}_{0}n \\ ^{7}_{3}Li + ^{1}_{1}H \longrightarrow ^{7}_{4}Be + ^{1}_{0}n \end{array}\right\} x(P, n)y.$$

ⓑ Doiterium induced :-

$$^{6}_{3}Li + ^{2}_{1}H \longrightarrow ^{4}_{2}He + ^{4}_{2}He \quad X(d, \alpha)Y$$

$^{12}_{6}C + ^{2}_{1}H \longrightarrow ^{13}_{6}C + ^{1}_{1}H$ $\Big\rangle$ $X(d,p)Y$.

$^{23}_{11}Na + ^{2}_{1}H \longrightarrow ^{24}_{12}Mg + ^{1}_{0}n$ $\Big\rangle$ $X(d,n)Y$.

(c) α-particle induced reactions:-

$^{7}_{3}Li + ^{4}_{2}He \longrightarrow ^{11}_{5}B + \gamma$ $\Big\rangle$ $X(\alpha,\gamma)Y$.

$^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$ $\Big\rangle$ $X(\alpha,p)Y$.

$^{10}_{5}B + ^{4}_{2}He \longrightarrow ^{13}_{7}N + ^{1}_{0}n$ $\Big\rangle$ $X(\alpha,n)Y$.

(d) Neutron induced reactions:-

$^{27}_{13}Al + ^{1}_{0}n \longrightarrow ^{28}_{13}Al + \gamma$ $\Big\rangle$ $X(n,\gamma)Y$.

$^{10}_{5}B + ^{1}_{0}n \longrightarrow ^{7}_{3}Li + ^{4}_{2}He$ $\Big\rangle$ $X(n,\alpha)Y$.

$^{24}_{12}Mg + ^{1}_{0}n \longrightarrow ^{24}_{11}Na + ^{1}_{1}H$ $\Big\rangle$ $X(n,p)Y$.

$^{107}_{47}Ag + ^{1}_{0}n \longrightarrow ^{107}_{47}Ag + ^{1}_{0}n$ $\Big\rangle$ $X(n,n)Y$.

(7) Compound Reactions:- In this case the projectile 'a' is captured by the target nucleus 'A' to form a compound nucleus C^* in an excited state. The deexcitation of C^* occurs into a product nucleus 'B' and emmession of a particle b

$$a + A \rightarrow C^* \rightarrow B + b.$$

i.e. $a + A \longrightarrow B + b$

eg:- $^{63}_{29}Cu + ^1_1H \rightarrow ^{64}_{30}Zn$

either $\longrightarrow ^{62}_{30}Zn + 2^1_0n$

or $\longrightarrow ^{63}_{30}Zn + ^1_0n$

or $\longrightarrow ^{62}_{29}Cu + ^1_0n + ^1_1H$

(8) Photo disintegration :- In this case high energy photon is captured by a target nucleus & hence the nucleus is excited to a high energy state & then it will disintegrate

$$^2_1H + \gamma \longrightarrow ^1_1H + ^1_0n$$

$$X(\gamma, n)Y.$$

(9) Fission Reactions :- The process of breaking up of the nucleus of a heavy atom into two, more or less equal fragments with releasing a large no. of energy is called fission Reaction.

$$^{235}_{92}U + ^1_0n \longrightarrow ^{236}_{92}U^* \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^1_0n + Q.$$

(10) Fusion Reaction :-

The process through which two or more light nuclei combine together to form a single heavy atom is know as nuclear fusion reaction.

eg $${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{4}_{2}He .$$

Conservation laws in nuclear reaction?

(1) Conservation of charge :-

The sum of the changes on the reactant side in a nuclear reaction is equal to the sum of the changes of product side.

(2) Conservation of mass no:-

The total mass no. before and after reaction remain same.

(3) Conservation of mass energy:-

Total mass energy in a nuclear reaction remain unchanged. Let us consider a reaction →

$$a + X \rightarrow Y + b \quad X(a,b)Y.$$

according to mass energy conservation →

$$(m_a c^2 + E_a) + m_x c^2 \rightarrow (m_y c^2 + E_Y) + (m_b c^2 + E_b)$$

Here E_a is the K.E. of the projectile a, E_Y & E_b are

K.E. of the product Y & b respectively.

$m_a c^2$, $m_X c^2$, $m_Y c^2$ and $m_b c^2$ are the rest mass energies of a, X, Y & b respectively.

④ Conservation of linear momentum:- The sum of the linear momentum vectors of the nuclide taking part in the reaction is equal to the sum of the linear momentum vector of the products.

⑤ Conservation of total angular momentum:-

The total angular momentum of a nuclear reaction is remain same before and after reaction.

⑥ Conservation of Parity:-

The total parity of the system is the product of particles of the target nucleus & the projectile. The net parity before & after nuclear reaction remain same.

⑦ Conservation spin & statistics:-

The spin & statistical character must be same before & after reaction. Hence the statistics followed by the product must be same as that followed by the reactants.

⑦ Energies of Nuclear Reactions:— Q value

Let us consider the nuclear reaction

$$a + X \longrightarrow Y + b$$

here X is the target which is at rest. Y & b are the products. From mass-energy conservation

$$(m_a c^2 + E_a) + m_X c^2 \longrightarrow (m_Y c^2 + E_Y) + (m_b c^2 + E_b)$$

$$\Rightarrow m_a c^2 + m_X c^2 - m_Y c^2 - m_b c^2 = E_Y + E_b - E_a = Q.$$

This quantity $E_Y + E_b - E_a$ is the Q value of the reaction.

① Exoergetic Reaction:— If $m_X + m_a > m_Y + m_b$ then $Q > 0$, In such reaction energy is released.

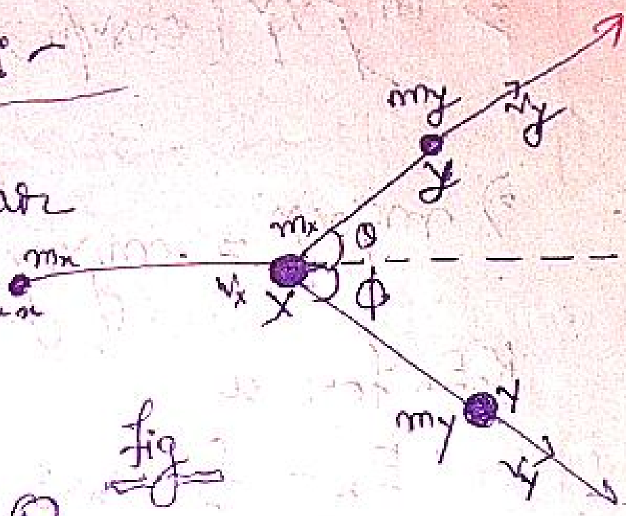
② Endoergic Reaction:—

If $m_X + m_a < m_Y + m_b$ then $Q < 0$, In that reaction energy need to be supplied so that the nuclear reaction will take place.

③ If $m_X + m_a = m_Y + m_b$ then $Q = 0$, then elastic scattering will occure.

Expression of Q value:-

Using conservation of linear momentum along the target direction



fig

$$m_x v_x = m_y v_y \cos\theta + m_y v_y \cos\phi \quad \text{--- (1)}$$

$$\Rightarrow m_y v_y \cos\phi = m_x v_x - m_y v_y \cos\theta \quad \text{--- (2)}$$

Along the perpendicular direction, before collision the momentum is zero along Y.

So,

$$\Rightarrow 0 = m_y v_y \sin\theta - m_y v_y \sin\phi.$$

$$\Rightarrow m_y v_y \sin\theta = m_y v_y \sin\phi \quad \text{--- (3)}$$

Squaring and adding (2) & (3) we get

$$\Rightarrow m_y^2 v_y^2 \cos^2\phi + m_y^2 v_y^2 \sin^2\theta = m_x^2 v_x^2 + m_y^2 v_y^2 \cos^2\theta - 2 m_x v_x m_y v_y \cos\theta + m_y^2 v_y^2 \sin^2\phi.$$

$$\Rightarrow m_y^2 v_y^2 \cos^2\phi + m_y^2 v_y^2 \sin^2\phi = m_y^2 v_y^2 \sin^2\theta + m_x^2 v_x^2 + m_y^2 v_y^2 \cos^2\theta - 2 m_x v_x m_y v_y \cos\theta.$$

$\Rightarrow m_y^2 v_y^2 (\cos^2\phi + \sin^2\phi) = m_y^2 v_y^2 (\sin^2\theta + \cos^2\theta)$
$+ m_x^2 v_x^2 - 2 m_x v_x m_y v_y \cos\theta$

$\Rightarrow m_y^2 v_y^2 = m_y^2 v_y^2 + m_x^2 v_x^2 - 2 m_x v_x m_y v_y \cos\theta$

K.E. for x

$E_x = \frac{1}{2} m_x v_x^2$ similarily for y

$\Rightarrow v_x^2 = \frac{2E_x}{m_x}$ $\qquad v_y^2 = \frac{2E_y}{m_y}$

and for y

$\Rightarrow v_y^2 = \frac{2E_y}{m_y}$

putting the value of v_x^2, v_y^2 and v_y^2 in above eqn

$\Rightarrow m_y^2 \left(\frac{2E_y}{m_y}\right) = m_x^2 \left(\frac{2E_x}{m_x}\right) + m_y^2 \left(\frac{2E_y}{m_n}\right) - 2 m_x m_y \sqrt{\frac{2E_x}{m_n}} \cdot \sqrt{\frac{2E_y}{m_y}} \cos\theta$

$\Rightarrow 2 m_y E_y = 2 m_x E_x + 2 m_y E_y - 2\sqrt{4 m_x m_y E_x E_y} \cos\theta$

$\Rightarrow m_y E_y = m_x E_x + m_y E_y - 2\sqrt{m_x m_y E_x E_y} \cos\theta$

$\Rightarrow E_y = \frac{m_x}{m_y} E_x + \frac{m_y}{m_y} E_y - \frac{2\sqrt{m_x m_y E_x E_y}}{m_y} \cos\theta$

putting $Q = E_y + E_y - E_x$

$\Rightarrow E_y = Q - E_y + E_x$ in above equation we get

$Q - E_y + E_x = \frac{m_x}{m_y} E_x + \frac{m_y}{m_y} E_y - \frac{2\sqrt{m_x m_y E_x E_y}}{m_y} \cos\theta$

$$\Rightarrow Q = \frac{m_x}{m_y} E_x + \frac{m_y}{m_y} E_y - \frac{2\sqrt{m_x m_y E_x E_y}}{m_y} \cos\theta$$

$$- E_y + E_x$$

$$\Rightarrow Q = E_x\left(1 + \frac{m_x}{m_y}\right) - E_y\left(1 - \frac{m_y}{m_y}\right) - \frac{2\sqrt{m_x m_y E_x E_y}}{m_y} \cos\theta.$$

If the product particle y emarges at right angles to the incident direction then $\cos\theta = 0$

So, $Q = E_x\left(1 + \frac{m_x}{m_y}\right) - E_y\left(1 - \frac{m_y}{m_y}\right)$.

Nuclear Cross-Section :-

Nuclear cross-section is a quantitative measers of the probability.

the no. of target nuclei in the foil.

Intensity of the incident beam $I = \frac{N}{A}$.

The total no. of nuclei in the target is $nA\Delta x$.

So, the no. of nuclei undergo reaction

$$\Delta n \propto \frac{N}{A} n A \Delta x$$

$$= \sigma N n \Delta x$$

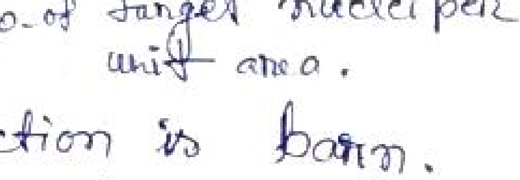
$$\Rightarrow \sigma = \frac{\Delta n}{N(n\Delta x)}$$

$$\Rightarrow \sigma = \frac{\Delta n}{N \times \text{no. of target nuclei per unit area}}$$

Unit of nuclear cross-section is barn.

$1 \text{ barn} = 10^{-28} m^2$.

Differential Cross Section:- In nuclear reactions the product particles are not emitted isotopically. If dN be the no. of product nuclei emmited per unit time in a solid angle $d\Omega$ at some angle θ then $\frac{dN}{N} = n\, dx\, d\sigma$



where $d\sigma$ is the small cross-section corresponding to the small solid angle $d\Omega$.

fig

$$\Rightarrow \frac{1}{N}\frac{dN}{d\Omega} = n\, dx \frac{d\sigma}{d\Omega}$$

$$\Rightarrow \frac{d\sigma}{d\Omega} = \frac{\frac{1}{N}\frac{dN}{d\Omega}}{n\,dx}$$

$\frac{d\sigma}{d\Omega}$ is called differential cross-section of nuclear reactions. So, the total cross-section :

$$\sigma = \int \frac{d\sigma}{d\Omega}\, d\Omega$$

=

06/06/2022.

Rutherford Scattering formula :-

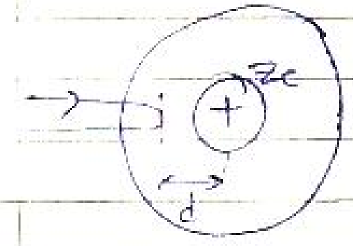


fig 1

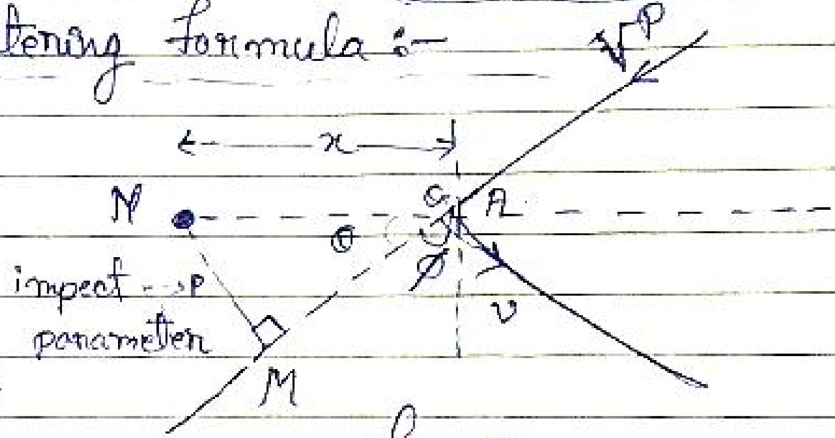


fig. 2.

Potential at distance of closest approach

$$= \frac{1}{4\pi\epsilon_0}\frac{Ze}{d}.$$

Potential energy of the alpha particle at distance of closest approach is

$$= \frac{Ze}{4\pi\epsilon_0 d} \times 2e$$

$$= \frac{2Ze^2}{4\pi\epsilon_0 d}$$

At distance of closest approach K.E. of α-particle is equal to the P.E. of α-particle, ie K.E = P.E.

Therefore $E = \dfrac{2Ze^2}{4\pi\epsilon_0 d}$ $\quad = \boxed{K.E = E}$

$$\Rightarrow d = \frac{2Ze^2}{4\pi\epsilon_0 E} \quad \text{——— (1)}$$

K.E. of α-particle at point P will be $= \frac{1}{2}mV^2$.

K.E. of α-particle at point A is $= \frac{1}{2}mv^2$

P.E. of α-particle at point A is $= \dfrac{1}{4\pi\epsilon_0}\dfrac{2Ze^2}{x}$

By principle of conservation of energy

$$\frac{1}{2}mV^2 = \frac{1}{2}mv^2 + \frac{2Ze^2}{4\pi\epsilon_0 x}$$

$$\Rightarrow v^2 = \left(\frac{1}{2}mV^2 - \frac{2Ze^2}{4\pi\epsilon_0 x}\right)\frac{2}{m}$$

$$\Rightarrow v^2 = V^2\left[1 - \frac{4Ze^2}{4\pi\epsilon_0 mV^2}\right]$$

$$\Rightarrow v^2 = V^2\left[1 - \frac{b}{x}\right] \quad , \quad \left(b = \frac{2Ze^2 \times 2}{4\pi\epsilon_0 mV^2}\right) \quad (2)$$

Angular momentum of the α-particle at point A about the nucleus N is $= mVp$

angular momentum of the α-particle at A about N is mvx.

Now, using conservation of angular momentum

$$mVp = mvx$$

$$\Rightarrow v = \frac{Vp}{x} \quad \text{——— (3)}$$

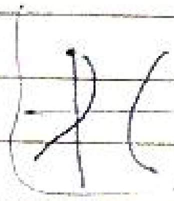
from eqn (2) & (3)

$$\Rightarrow \left(\frac{Vp}{x}\right)^2 = V^2\left[1 - \frac{b}{x}\right]$$

$$\Rightarrow \frac{V^2p^2}{x^2} = V^2\left[1 - \frac{b}{x}\right]$$

$$\Rightarrow p^2 = x^2 - bx$$

$$\Rightarrow p^2 = x(x-b) \quad \text{——— (4)}$$



From the coordinat geometry of hyperbola $x = p\cot\theta/2$

putting the value of x from (4).

$$p^2 = p\cot\theta/2\,(p\cot\theta/2 - b)$$

$$\Rightarrow p = p\cot^2\theta/2 \,\{ - b\cos\theta/2$$

$$\Rightarrow b\cot\theta/2 = p\cot^2\theta/2 - p$$

$$\Rightarrow b\cot\theta/2 = p\left(\cot^2\theta/2 - 1\right)$$

$$\Rightarrow b = p\left(\frac{\cot^2\theta/2 - 1}{\cot\theta/2}\right)$$

$$\Rightarrow b = p\left[\cot\theta/2 - \tan\theta/2\right]$$

$$\Rightarrow b = p\left[\frac{\cos\theta/2}{\sin\theta/2} - \frac{\sin\theta/2}{\cos\theta/2}\right]$$

$$\Rightarrow b = p\left[\frac{\cos^2\theta/2 - \sin^2\theta/2}{\sin\theta/2\cos\theta/2}\right]$$

$$\Rightarrow b = 2p\left[\frac{\cos 2\theta}{2\sin\theta/2\cos\theta/2}\right]$$

$$\Rightarrow b = 2p\left[\frac{\cos 2\theta}{\sin 2\theta}\right]$$

$$\Rightarrow b = 2p\tan\theta/2$$

$$\Rightarrow \tan\theta = \cancel{\frac{b}{2p}}\ \frac{2P}{b} \quad \text{------} \quad (5)$$

$$2\theta + \phi = \pi$$

$$\Rightarrow \phi = \pi - 2\theta$$

$$\Rightarrow \frac{\phi}{2} = \pi/2 - \theta$$

$$\Rightarrow \cot(\phi/2) = \cot(\pi/2 - \theta) = \tan\theta$$

$$\Rightarrow \cot(\phi/2) = \frac{2p}{b}$$

$$\Rightarrow p = \frac{b}{2}\cot(\phi/2) \quad \text{------} \quad (6)$$

putting value of b we get from (2)

$$= p = \frac{1}{2} \cdot \frac{2Ze^2 \, 2}{4\pi\varepsilon_0 mv^2} \cot(\phi/2)$$

$$\Rightarrow p = \frac{d}{2} \cot(\phi/2) \text{ ——— } (7)$$

The cross section at scattering angle ϕ is

$$\sigma = \pi p^2$$

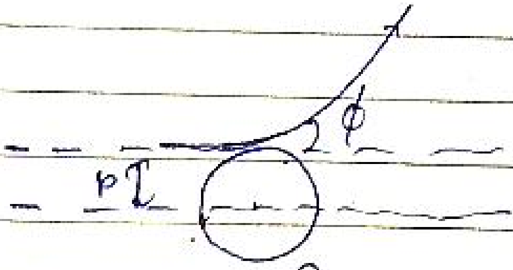


fig 3.

Let us consider the thickness of the gold foil is 't' & area is A and no. of nuclei per unit volm of the foil is n.
Total no. of nuclei in the foil is = nAt.
The target area for scattering by at least an angle ϕ = $\sigma \times nAt$
$= \sigma n A t$
Let us consider no. of incident α-particle is N_i no. of interacting α-particle at scattering angle ϕ is N_s.

so, $$\frac{N_s}{N_i} = \frac{\sigma n A t}{A}$$

$$\Rightarrow \frac{N_s}{N_i} = \pi p^2 n t$$

$$\Rightarrow \frac{N_s}{N_i} = \pi n \frac{d^2}{4} \cot^2(\phi/2)\, t$$

$$\Rightarrow f = \pi n \frac{4Z^2 \, 4e^4}{4 \cdot 16 \pi^2 \varepsilon_0^2 m^2 v^4} \cot^2(\phi/2)\, t.$$

f is probability of scattering at ϕ angle

(A) Interaction of γ-ray with Matter :-

γ-rays are EM radiation of very short wavelength and therefore they have no electric charge & can't be deflected by electric & magnetic fields.

The precise measurement of γ-energies is therefore not possible by usual magnetic spectrographs. The absorption of γ-rays is also diff. from that of the charged particle like α & β. Again γ-radiations are highly penetrating. The charge particles lose their energies by elastic collisions, so that they slow down & come to rest & absorbed at the end of their definite well define range. On the other hand γ-rays have no definite range but their intensity decreases exponentially, as they pass through the matter according to the law

$$I = I_0 e^{-\mu x}$$

, where I_0 is the intensity of the incident beam, μ is the absorption coefficient of the substance & I is the intensity of the γ-ray beam after traversing a thickness 'x'. γ-ray interact with matter by three diff. - processes $\longrightarrow$

(1) Photoelectric Absorption :- In this process a γ-ray photon interacts with an atom in such a way that all of it's energy is absorped by an orbital e^- of the atom. As a result the e^- is

ejected & γ- photon loses its identity.
According to einstein eqn the K.E. of the ejected photoelectrons are.

for K shell $T_K = h\nu - W_K$,

$$T_L = h\nu - W_L$$

$$T_M = h\nu - W_m.$$

Where T_K, T_L, T_m represence the K.E. energies of the photoe: ejected from, K, L, M shells respectively & W_K, W_L, W_m are the B.E of the e: in K, L & M shells respectively.

The photoectric absorption of γ- rays varies directly as
$$\rightarrow Z^5 \left(\frac{m_0c^2}{h\nu}\right)^{7/2}.$$

If the energy of the γ- ray photon is very very high then the probability of photoelectric ab- is very less.

② Compton Scattering:-

In this process a γ- ray photon interacts with an atoms of low atomic no, in such a way that the γ-ray is scattered by one of the free electrons and as a result the e: is separated from the atom & the photon moves with reduced energy in a different direction from the original direction

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& remove from the incident beam. Energy of the scattered & the recoil e^- are given by

$$h\nu' = \frac{h\nu}{1 + \frac{h\nu}{m_0c^2}(1-\cos\phi)}$$

$$T = \frac{h\nu/m_0c^2\,(1-\cos\phi)}{\left[1 + \frac{h\nu}{m_0c^2}(1-\cos\phi)\right]} h\nu.$$

(5) Electron pair production :- In this process the γ-ray photon of high energy passing close to an atomic nucleus ~~and~~ gets annihilated and forms a pair of e^- & e^+.

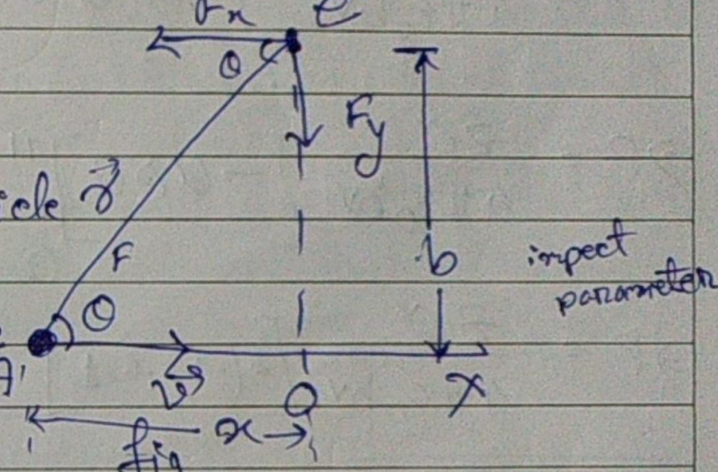
$$\gamma \longrightarrow {}_{-1}^{0}e + {}_{+1}^{0}e$$

In this process energy is converted into mass using mass-energy relⁿ. As the rest mass energy of e^- & e^+ are 0.51 MeV. Therefore the energy ~~of~~ γ-ray photon for pair production must be at least 1.02 MeV.

If the energy of the photon is greater than

(2) Energy lost in the interaction of charge particle with matter :-

(1) Bohr's formula :-



fig

Force betn the charge particle and the electron is

$$F = \frac{1}{4\pi\varepsilon_0} \frac{ze \times e}{r^2}$$

Only y component of the force will be remaining as x components will cancells each other. So

$$F_y = \frac{1}{4\pi\varepsilon_0} \frac{ze^2}{r^2} \sin\theta$$

Net momentum transfer to the electron will be

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$$P = \int_{-\alpha}^{\alpha} F_y \times dt$$

$$\Rightarrow P = \int_{-\alpha}^{\alpha} \frac{1}{4\pi\varepsilon_0} \frac{ze^2}{r^2} \sin\theta \quad dt \text{ --- } (1)$$

$\Rightarrow$ Putting the values in eqn (1) we get

$$\Rightarrow P = \int \frac{1}{4\pi\varepsilon_0} \frac{ze^2}{} \int \frac{\sin^2\theta}{b^2} \sin\theta \cdot \frac{b}{v} \operatorname{cosec}^2\theta \, d\theta$$

$$\Rightarrow P = \frac{ze^2}{4\pi\varepsilon_0 bv} \int_0^{\pi} \cancel{\sin^2\theta} \sin\theta \left(\frac{1}{\cancel{\sin^2\theta}}\right) d\theta$$

$$\Rightarrow P = \frac{ze^2}{4\pi\varepsilon_0 bv} \int_0^{\pi} \sin\theta \, d\theta$$

$$\Rightarrow P = \frac{ze^2}{4\pi\varepsilon_0 bv} \left[-\cos\theta\right]_0^{\pi}$$

$$\Rightarrow P = \frac{ze^2}{4\pi\varepsilon_0 bv} \left[-(-1) + 1\right]$$

$$\boxed{\Rightarrow P = \frac{ze^2}{4\pi\varepsilon_0 bv} \times 2} \text{ --- } (2)$$

$$\Rightarrow P = \frac{ze^2}{2\pi\varepsilon_0 bv}$$

This is the momentum transfered to the e^-.

distance $= -x$

$-x = t \times v$

$\Rightarrow t = \frac{-x}{v}$

$$\cot\theta = \frac{x}{b}$$

$\Rightarrow x = b\cot\theta$

so $\Rightarrow t = \frac{-b\cot\theta}{v}$

$\Rightarrow \frac{dt}{d\theta} = \frac{-b}{v}(-\operatorname{cosec}^2\theta)$

$\Rightarrow dt = \frac{+b}{v} \operatorname{cosec}^2\theta \, d\theta$

and $\sin\theta = \frac{b}{r}$

$\Rightarrow r = \frac{b}{\sin\theta}$

since $\cot\theta = \frac{\cos\theta}{\sin\theta}$

if $x = -\alpha$, $\theta = 0$

$x = \alpha$, $\theta = \pi$

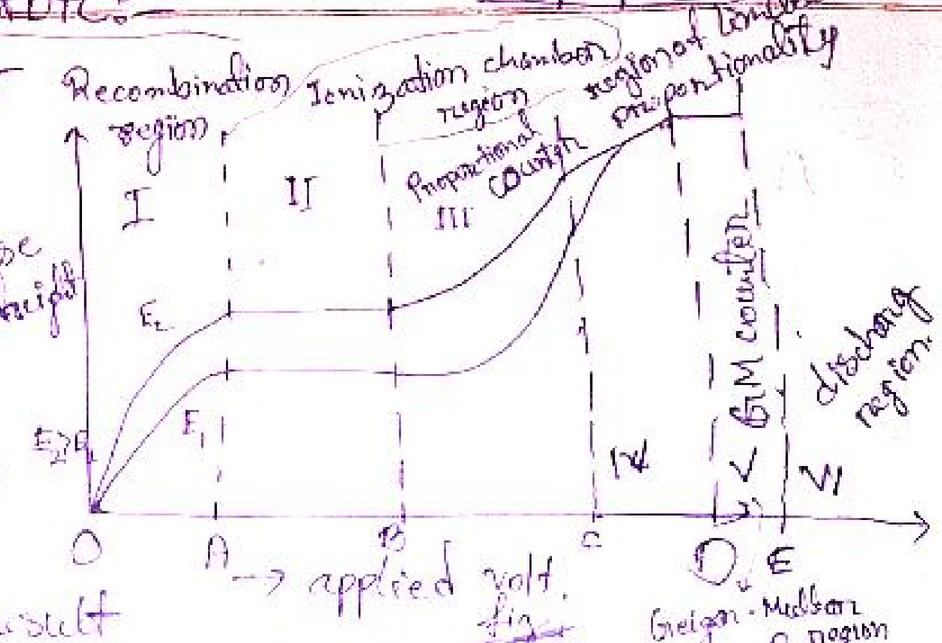
Unit 6.

Nuclear detector:

10/06/2023

(1) Recombination Region:-

Initialy when the applied volt. is low, the electric field is so low that the recombination of +ve & -ve ions takes place. As a result all the ion pairs are not detected. As the E field increases the ion moves faster so that there will be less recombination and thus large number of ions reach the electrod.



fig

The region I (O-A) is called recombination region.

(2) Ionization chamber:-

In region II voltage is large enough so, that a little amount of ions undergo recombination and the pulse height attains a saturated value. This region is called ionisation chamber region.

(3) Proportional Counter Region:-

In this region the voltage applied is so high that electrons liberated in the primary ionization get sufficient energy to cause secondary ionization. In this region secondary ionization produced is proportional to the primary ionization. This region is called proportional ionization reg.

and the instrument operates in this region called proportional counter region.

(4) Beyond proportional counter region the gas multiplication effect continues to increase very rapidly. The pulse height is no longer proportional to the initial energy of the incident particle and this region is known as region of limited proportionaty.

(5) GM region :- In GM region the pulse height is completely independent of the initial no. ions & their energy. In this region all the radiations give the same pulse height.

(6) — Beyond geiger Mullar region there will be an onset of continous electrical discharge.

11/06/2022

(1). Ionization Chambers— An ionization chamber is a closed vessel filled with gas having two electrodes with a potential difference of the order of few hundred to few thousand volts betn them. ~~Here~~ the electric field 'X' within the ionization chamber is relatively low.

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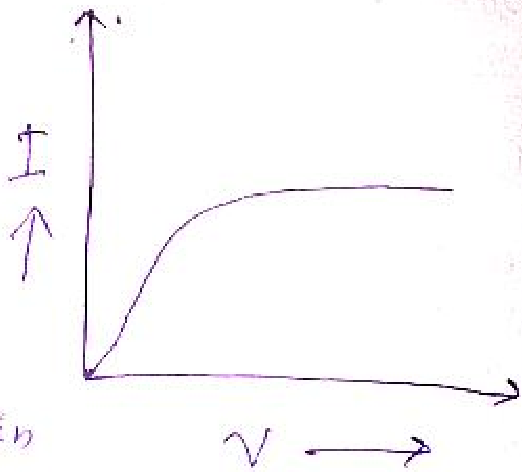
The primary ions produced in the chamber donot get sufficient energy to produce secondary ions.

From the graph we can see that the ionization current increases with increase-ing applied Volt. & finaly reaches at a saturated value.



fig

i.e. for a given source the rate of ion pair production within the gas is constant.

At low voltage the velocity gain by the ions dues to the applied e-field is small. Thus the ions required longer times to reach the e & hence they have greater chance of recombination while travel through the gas. Therefore the ionization current is less.

When applied voltage increases the process of recon-mbination becomes less & finally when potential is sufficiently high all the ions are collected by the respective electrons & ionization current becom satur-ated.

when the field 'X' is applied the acceleration of the ions will be towards the respective e.

$$f = \frac{e \times X}{m} = \frac{eX}{m}$$

However this increase in velocity because of this acceleration doesnot continue indefinitly because the ions suffers collisions. If 'λ' is the mean free path betn two successive collisions & '$\bar{c}$' is the thermal velocity, then the mean time betn two successive collision will be $\tau = \frac{\lambda}{c}$.

The gain in velocity of an ion betn two successive collisions $v = \frac{s}{\tau}$

$$\Rightarrow v = \frac{\frac{1}{2} f \tau^2}{\tau}$$

$$\Rightarrow v = \frac{1}{2} f \tau$$

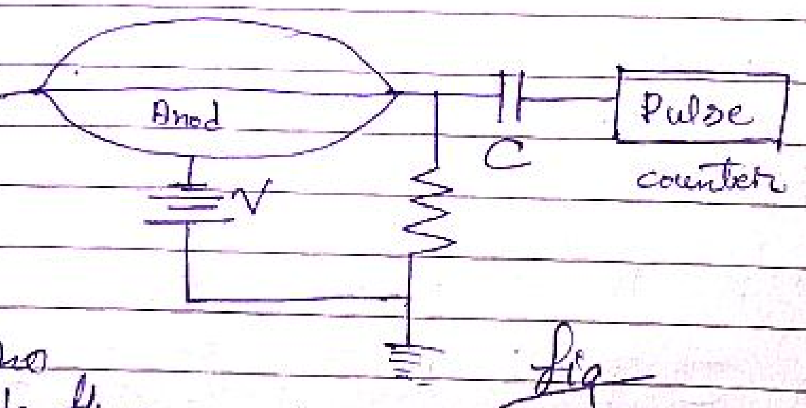
$$\Rightarrow v = \frac{1}{2} \frac{eX}{m} \tau \qquad \left(\text{Since } f = \frac{eX}{m} \right.$$

$$\Rightarrow v = \frac{Xe\lambda}{2mc}$$

$$\Rightarrow v = KX \quad \text{where } K = \frac{e\lambda}{2mc}$$

This term $K = \frac{e\lambda}{2mc}$ is called ionic mobility.

(4) G.M Counter (Geiger - Muller).



fig

If the voltage applied betn electrods of a proportional counter exceed a certain limit. The charge collected is no longer proportional to the charge created. In this region the total no. of ion produced become independent of the initial no of ions produced by the incoming radiation.

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This region is called Geiger-Muller region.

GM Counter Working principle :-

The gas chamber is filled with inered gas like 'Ar' mixed with the vapour of ethyle alchohole in the ration 10:1 & at a ~~t~~ pressure 10 cm of marcury. When an ionizating particle enters GM tube it ionized the 'Ar' gas atom. Because of the cylindrical shape of the electrod. the e- field is very strong near the anode. The e- realeased due to the ionization are accelerated rapidly towards the anode which will cause further ionization. This process is commutative & a lang avalanche of e- is produced. The 2nd avalanche is triggerd during the deexcitation of excited gas molecule within the first avalanche. The photon emited during this deexcitation process can trigger the emision of photoelectron from the cathod surface. These e- again gives rise to new avalanches while travel to the anode. The electrons being very light reach the anode in a very short period of time but the massive +ve ions move slowly & they form a sheath of charge around the anode. This reduces the e- field near the anode & no further pulse is detected. The period during which ionization stop & the instruments become inactive

Quenching process:-

When GM tube operates in a Greiger region the tube should not give any pulses due to the avalanches created by the photoelectron. The process of prohibiting undesirable pulses is called Quenching. Ethyle alchohole is mixed with the innerd gas for this purpose. The +ve ions while moving towards the cathod gets neutralized by trans-fering their charge to the alchohol ions. The alchohole ions capture e^- from the cathod & are neutralized. Hence there are no further pulses due to the photo-e^-s.

14/06/2022

Elementary particle :-

The interaction betn the elementary particle can be explained as follows →

① The gravitational in.

Gravity is ~~of~~ ofcou an important force in our daily lifes but it has no importants on the scall of fundamental interaction betn particle in subatomic region. force eg. gravitational force betn two proton just touching at their surfaces is about 10^{-38} of the strong force betn them.

The gravitational force is carried by a graviton which is expected to exists but yet has to be discovered.

② Weak interaction :-

The weak interaction is responsible for nuclear β- decay & other similar decay processes involving fundamental particles. But this interaction doesnot play major role in binding of a nuclei. The weak interaction betn two neighbouring proton

Teacher's Signature :

is about 10^{-7} that of the strong force betn them. The range of weak interaction is on the scall of 0.001 fm. (ie 10^{-18} m). The weak force is carried by the weak Bosons $W^{\pm}$ & Z^{0}, which are responsible for the process of sucha as β-decay. They are madiator.

③ Electromagnetic interaction :-

Electromagnetism is important in the structure & interaction of the fundumantal particls.
eg some particls interact or decay primarily through this mechanism. Electromagnetic forces are of infinite range. Within the atom EM force are dominant. The EM force betn neighbouring proton in nucleus is 10^{-2} of the strong force. The EM force is carried by photons.

④ Strong interaction :- The strong force, which is responsible for the Binding of nuclei, is the dominant one in the reactions & decays of the most of the fundumental particls. The range of strong interaction is of the ordero of 1 fm Proton - nutrons are made of quarks & the strong interaction betn the quark is carried by gluons.

④ Classification of particles :-

There are three familys of elementary material particles

① Leptons — The leptons interacts only through weak or EM interaction.

No experiment has yet been able to reveal any internal structure for the leptons, they appear to be truly fundamental particles that they cannot be split into further smaller particles. all the known leptons have spin 1/2.

Lepton family

Particle	Antiparticle	charge (e)	spin	Mass MeV/c²
e^-	e^+	-1	1/2	0.511
ν_e	$\bar{\nu}_e$	0	1/2	0
μ^-	μ^+	-1	1/2	105.7
ν_μ	$\bar{\nu}_\mu$	0	1/2	0
τ^-	τ^+	-1	1/2	1777
ν_τ	$\bar{\nu}_\tau$	0	1/2	0

fig :- Table

neutrino masses are very small but non-zero.

② Mesons :- Mesons are strongly interacting particles having integral spin. Mesons can produced in reactions through strong interaction, They decay to other mesons or leptons through strong, EM or weak interaction.

	Particle	anti particle	charge (e)	spin
1)	π^+	π^-	+1	0
	π^0	π^0	0	0
2)	K^+	K^-	+1	0
	K^0	K^0	0	0
3)	η	η	0	0
4)	ρ^+	ρ^-	+1	1
5	J/ψ	J/ψ	0	1

eg Pions can decay according to

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu \quad \text{(weak inter.)}$$

$$\pi^0 \rightarrow \gamma + \gamma \quad \text{(EM int.)}$$

③ **Baryons :-** The baryons are strongly interacting particle with half integral spin. Like the mesons the baryon can be produced in reactions with nucleons through strong interaction.

eg $$P + P \longrightarrow P + \Lambda^0 + K^+$$

$\Lambda^0 \longrightarrow p + \pi^-$

(lamda)

	Particle	antip	charge (e)	spin
	p	$\bar{p}$	+1	1/2
	n	$\bar{n}$	0	1/2
lamda	Λ^0	$\bar{\Lambda}^0$	0	1/2
sigma	Σ^0	$\bar{\Sigma}^0$	0	1/2
	Σ^-	$\bar{\Sigma}^-$	−1	1/2
	Σ^+	$\bar{\Sigma}^+$	+1	1/2
omega	Ω^-	$\bar{\Omega}^-$	−1	3/2

Baryons can decay through strong, weak, or EM interactions.

Mesons & Baryons are called as ~~hydrons~~ hadrons.

④ Conservation Laws:- ① Energy. ② Linear momentum. ③ Angular mo. ④ Parity ⑤ charge. ⑥

⑥ Lepton no. Conservation:- In β^--decay we always find an antineutrino emitted, never a neutrino conversely in β^+-decay it is the neutrino which is emitted.
In order to solve that case lepton no. (L) is assigned to each Lepton.

Teacher's Signature :

After

e^- & neutrino is assigned with $L = +1$, and.

e^+ & antineutrino are assigned with $L = -1$.

all Mesons & Baryons are assigned $L = 0$.

eg:- ① $n \rightarrow P + e^- + \overline{\nu_e}$

$L = 0 \rightarrow 0 \; +1 \; -1$.

In any process total Lepton no remain constant.

② $P \rightarrow n + e^+ + \nu_e$

$L = 0 \rightarrow 0 \; -1 \; +1$

③ Baryon no. Conservation :- (B) Baryons are subject to a similar conservation law. All Baryons are assigned with Baryon no. (B) '+1' & all antibaryon are " with $B = -1$.

All mesons & Lepton have $B = 0$. In any process the total baryon no. must remain const.

eg:- ① $P + P \rightarrow P + P + P + \overline{P}$

$B = +1 \; +1 \rightarrow +1 \; +1 \; +1 \; -1$. (Baryon no. conserved)

② $P + P \rightarrow P + P + \overline{n}$

$+1 \; +1 \qquad +1 \; +1 \; -1$ B is not conserved.

This reaction is forbidden. not possible.

Expt. No. ....

Strangness conservation :- (S) :-

The following reactions

① $P + P \rightarrow P + n + \pi^+$

② $P + P \rightarrow P + n + K^+$ ✗ not

③ $P + P \rightarrow P + n + \pi^+ + \pi^0$

can be used to produced pions but similarly reactions cannot be used to produced K mesons.

$P + P \rightarrow P + n + K^+$

$P + P \rightarrow P + n + K^0$ ~~+K~~

they are not happening

But however the following reactions can be observed ->

$P + P \rightarrow P + n + K^+ + \bar{K}^0$

& $P + P \rightarrow P + P + K^+ + K^-$

(1) Pi Mesons can be produced in ~~sig~~ odd or even numbers but K-mesons can be produced only in paires.

(2) The reaction $\pi^- + P \rightarrow \pi^+ + \Sigma^-$ conserves electric charge & Baryon no.

Teacher's Signature : ______________

However this reaction doesnot occur. Instead the following reaction is easily observed

① $\pi^- + P \longrightarrow K^+ + \Sigma^-$

② This unusual behaviors are explained by introducing a new conserved quantity which is called Strangness (S). The strangeness is defind as

$S = Y - B$ here Y is the hypercharge

B is " Baryon no.

For K^+, K^0 ~~strangness is~~ $\Sigma^+, \Sigma^0, \Sigma^-$ $S = 1$

& $K^-, \overline{K^0}$ $\Lambda^0, \Sigma^+, \Sigma^0, \Sigma^-$, $S = -1$

(Zeta) Ξ^0, Ξ^+ $S = 2$.

Other hadrons have $S = 0$.