Nuclear Physics.

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Nuclear Physics

Nuclear Physics is a field of physics that studies the building blocks and interreaction of Atomic nuclei.

What is Nucleon ?

The proton and the neutron are considered to be two differential charge states of the same particle which is called a nucleon.

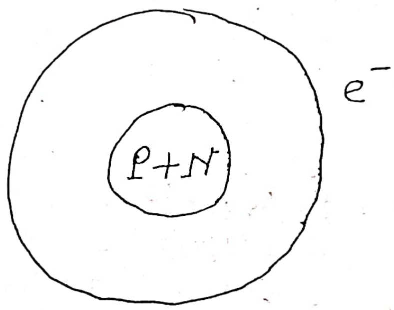


Fig: Nucleon.

Nuclide:

A species of nucleas, known as nuclide, is represted by schematically $_{Z}X^{A}$

Where, Z = atomic nub. inditescates no. of proton
A = mass no. indicates total mass no.
X = chemical symbol of species.

N = Number neutrons = (A−Z)

P → Proton — (+ve)
1·007274 amu
$= 1·6724 \times 10^{-27}$ kg.

N → Neutron — Neutral charge.
1·008665 amu
$= 1·6747 \times 10^{-27}$ kg.

Nomenclature:

Purural form of nucleon → Nuclide
Singular " " → Nuclei.

Classification of Nuclei :

1. **Isotopes :** Nuclei with the same atomic number but different mass number A are called Isotopes.
Examples: $_{28}Ni^{58}$, $_{28}Ni^{60}$ are isotopes of nickel.

2. **Isobars :** Nuclei having same mass number A but different atomic number Z are called isobares.
Examples: $_{22}Ti^{50}$ and $_{20}Cr^{50}$ are Isobars.

3. Isotone

3. **Isotone** : Neuclei having/ with the same neutrons number N are called Isotones. Examples: $_6C^{14}$, $_7N^{15}$, $_8O^{16}$ are isotones since no. of netutrons 8.

4. **Isomers**: There are atoms, which have the same atomic number Z and same mass number A but differ from one another in their nucleare energy states and exibibit differences in their internel structure.

5. **Mirror nuclei**: Nuclei having the same mass number A, but with the proton and neutron num. interchanged (that is the num. of protons are equal to the num. of neutrons in the other) are called mirror nuclei. Ex: $_4Be^7$ (Z=4, N=3), and $_3Li^7$ (Z=3, n=4)

Nuclear Charge:

The charge of nucleas is due to the protons Contained in it. Each proton has 1.6×10^{-19}c and is the same of charge of electron. Therefore, the nuclear charge is Ze. where Z is the atomic num. of nucleus and determined from x-ray scattering experiment.

☐ Define mass defect and binding energy. Establish the relationship between them.

Relation

Mass defect:

The mass defect of an atom defines as the difference between of its atomic mass and its mass number.

or, Mass defect defines as the difference between the mass of an isotope and its mass number.

Mass defect. $\boxed{\Delta M = M - A}$

Binding energy:

Nuclear binding energy is the energy required to separate an atomic nucleas completely into its constituent protons and neutrons. It is denoted by B.E.

$\boxed{B.E. = \Delta m c^2}$

Mass defect Rule:

The actual mass of a nucleas, containing Z protons and N neutrons, is less than $Zm_p + Nm_n$.

Relation between them :-

The mass of nucleus containing Z protons = Zm_p

" " " N neutrons = Nm_n

Actual mass of nucleas = M

∴ The difference in masses,

$$\Delta m = Zm_p + Nm_n - M$$

∴ Mass defect $\Delta m = Zm_p + Nm_n - M$.

We know,

$$E = mc^2$$

∴ Binding energy $B.E = \Delta m c^2$

$$\Rightarrow B.E = [(Zm_p + Nm_n) - M]c^2$$

∴ Binding energy

$$B.E = [(Zm_p + Nm_n) - M]c^2$$

∴ It is the relation between mass defect and bingding energy.

∴ Average Binding energy $= \frac{B.E}{A}$ [A = mass no.]

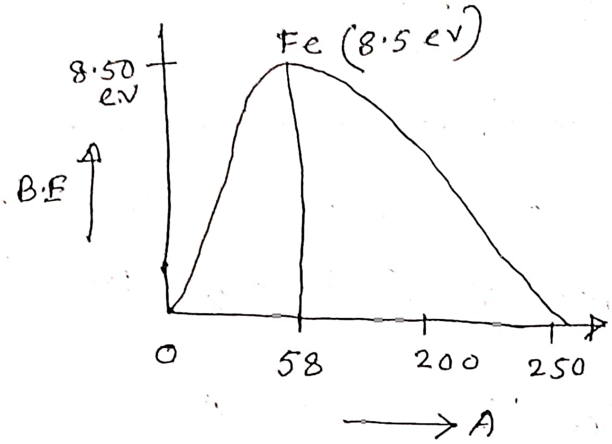


Fig: Binding energy of Fe.

Nuclear Reaction :

The reaction in which it is possible to brain about a change in the identity or characteristics of an atomic nucleas that results when it is bombarded with an energetic particle, as in fission, fusion or redio active decay.

First particle = Light particle = (α, β, γ, neutron etc)

Nuclear Reaction can be described as,

Projectile P + target T $\longrightarrow$ emitted particle x + residual nuclas R.

Shortly, $\boxed{T\,(P, x)\,R}$

Now, here we can described it,

Projectile a + target x → emitted Particle b + residual nucleas Y.

Now,

$$P + T \Rightarrow X + R$$

$\Rightarrow P + T$

$\Rightarrow X + R$

$\Rightarrow X$ + Energy.

* Reaction are two kinds:

1. Elastic Reaction
2. Inelastic ".
   - Exothermic Reaction
   - Endothemic Reaction.

Q value :- In nuclear physics, the Q value for a reaction is the amount of energy released by that reaction.

Now,

$$P + T \Rightarrow X + R$$

Q value of Nuclear Reaction:

$$(E_P + M_P c^2) + (0 + M_T c^2) = (E_R + M_R c^2) + (E_X + M_X c^2)$$

$$\Rightarrow E_P + M_P c^2 + M_T c^2 = E_R + M_R c^2 + E_X + M_X c^2$$

$$\Rightarrow (E_R + E_X) - E_P = [(M_P + M_T) - (M_X + M_R)]c^2$$

$$\therefore \boxed{Q = \Delta M c^2}$$

Significance of Q value :

1. $Q>0$ [+ve → Exothermic]
2. $Q<0$ [-ve → Endothermic].
3. $Q=0$ [→ Elastic] .

Q-value (using mass Conservative):

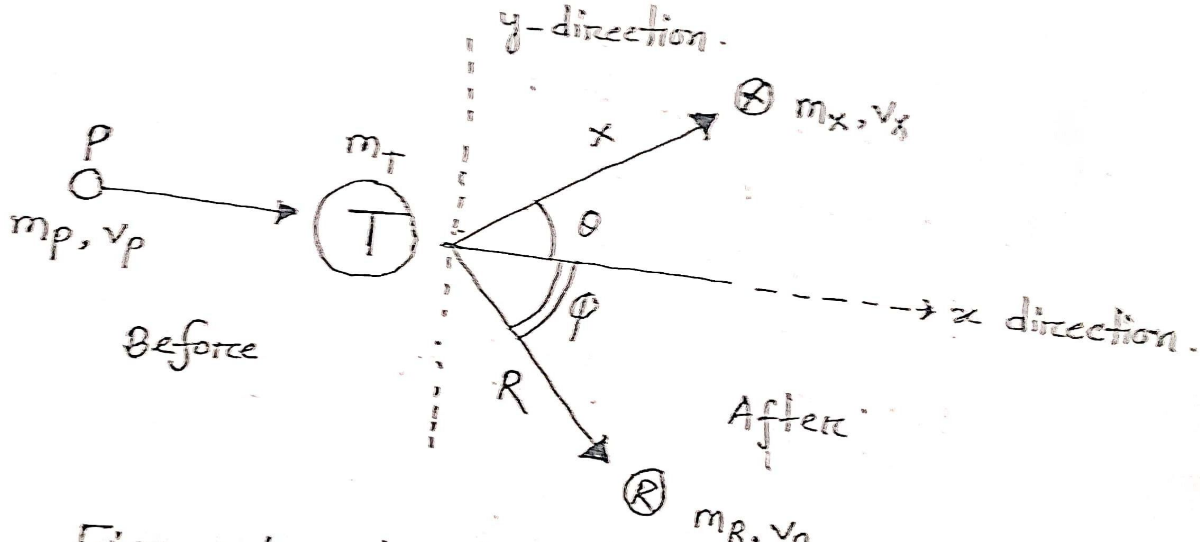


Fig: schematic diagram of a nuclear Reaction.

x-direction:

A+x → b+Y

$$m_p v_p = m_x v_x \cos\theta + m_R v_R \cos\varphi$$

$$\Rightarrow m_x v_x \cos\theta = m_p v_p - m_R v_R \cos\varphi \quad \text{—— (1)}$$

Y-direction:

$$0 = m_x v_x \sin\theta - m_R v_R \sin\varphi \quad \text{——}$$

$$\Rightarrow m_x v_x \sin\theta = m_R v_R \sin\varphi \quad \text{——— (ii)}$$

Sequaring (i) + (ii),

$$m_x^2 v_x^2 (\sin^2\theta + \cos^2\theta) = (m_p v_p - m_R v_R \cos\varphi)^2 + (m_R v_R \sin\varphi)^2$$

$$\Rightarrow m_x^2 v_x^2 = m_p^2 v_p^2 - 2 m_p v_p m_R v_R \cos\varphi + m_R^2 v_R^2 \cos^2\varphi + m_R^2 v_R^2 \sin^2\varphi$$

$$\Rightarrow m_x^2 v_x^2 = m_p^2 v_p^2 - 2 m_p v_p m_R v_R \cos\varphi + m_R^2 v_R^2 \quad \text{——— (iii)}$$

We know,

$$E = \tfrac{1}{2} m v^2$$

$$\therefore E_p = \tfrac{1}{2} m_p v_p^2$$

$$\Rightarrow v_p^2 = \frac{2E_p}{m_p}$$

$E_p = \frac{1}{2} m v^2$

$\sqrt{\frac{2E_p}{m}}$

Similarly, $v_x^2 = \dfrac{2E_x}{m_x}$, $v_R^2 = \dfrac{2E_R}{m_R}$

Putting value in (iii),

$$m_x^2 \frac{2E_x}{m_x} = m_p^2 \cdot \frac{2E_p}{m_p} - 2 m_p \cdot m_R \cdot \sqrt{\frac{2E_p}{m_p}} \cdot \sqrt{\frac{2E_R}{m_R}} \cos\varphi + m_R^2 \cdot \frac{2E_R}{m_R}.$$

$$m_X E_X = m_P E_P + m_R E_R - 2\,(m_P m_R \cdot E_P E_R)\cos\phi$$

$$\Rightarrow m_X E_X = m_P E_P + m_R E_R - 0$$

$$\Rightarrow m_X E_X = m_P E_P + m_R E_R$$

$$\Rightarrow E_X = \frac{m_P}{m_X}\cdot E_P + \frac{m_R}{m_X}\cdot E_R .$$

Now,

$$Q = E_X + E_R - E_P$$

$$\Rightarrow Q = \frac{m_P}{m_X}\cdot E_P + \frac{m_R}{m_X}\cdot E_R + E_R - E_P$$

$$\Rightarrow Q = \frac{m_P}{m_X} E_P - E_P + \frac{m_R}{m_X}\cdot E_R + E_R$$

$$\therefore \boxed{Q = E_R\left(1+\frac{m_R}{m_X}\right) - E_P\left(1-\frac{m_P}{m_X}\right)}.$$

$\therefore$ This is the equation of Q value mass conservative.

Threshold Energy :-

$$a + \underset{0,\, v_c}{X} = \underbrace{Y + b}_{c}$$

Let,

$$M_c = M_a + M_x .$$

We know.

$$P + T = X + R$$

$$Y + b = C .$$

then,

$$M_a V_a = M_e V_e$$

$$V_e = \frac{M_a V_a}{M_e} = \frac{M_a V_a}{(M_a + M_x)}$$

$$\Rightarrow V_e = \left(\frac{M_a}{M_a + M_x}\right) \cdot V_a$$

Threshold Energy:- In nuclear physics, the threshold energy is the minimum kinetic energy a pair of travelling particles must have when they collide

We know,

$$Q = E_y + E_b - E_a$$

$$\Rightarrow Q = E_e - E_a$$

$$\Rightarrow -Q = E_a - E_e$$

∵ We know,
$P + T = X + R$
$\hookrightarrow a + \dot{x} = Y + b.$
$Q = E_X + E_R - E_P$

$$\Rightarrow -Q = \frac{1}{2} M_a V_a^2 - \frac{1}{2} M_e V_e^2$$

$$\Rightarrow -Q = \frac{1}{2} M_a V_a^2 - \frac{1}{2}(M_a + M_x)\left(\frac{M_a}{M_a + M_x}\right)^2 \cdot V_a^2$$

$$\Rightarrow -Q = \frac{1}{2} M_a V_a^2 - \frac{1}{2} M_a^2 \cdot V_a^2 \cdot \frac{1}{M_a + M_x}$$

$$\Rightarrow -Q = \frac{1}{2} M_a V_a^2 - \frac{1}{2} M_a \cdot V_a^2 \left(\frac{M_a}{M_a + M_x}\right)$$

$$\Rightarrow -Q = \frac{1}{2} M_a V_a^2 \left(1 - \frac{M_a}{M_a + M_x}\right)$$

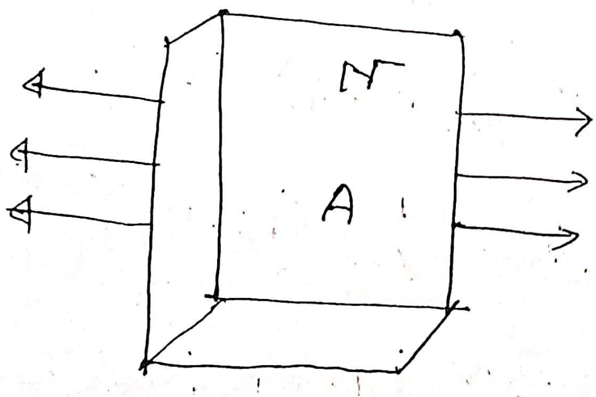
$$\Rightarrow -Q = \frac{1}{2} M_a V_a^2 \left(\frac{\cancel{M_a} + M_x - \cancel{M_a}}{M_a + M_x}\right)$$

$$\Rightarrow -Q = E_{th}\left(\frac{M_x}{M_a + M_x}\right)$$

$$\Rightarrow E_{th} = -Q\left(\frac{M_a + M_x}{M_x}\right)$$

$$\therefore \boxed{E_{th} = -Q\left(1 + \frac{M_a}{M_x}\right)}$$

Cross-Sectional Area of Nuclear Reaction



$$\frac{n_r}{n_i} = \frac{\sigma N A t}{A}$$

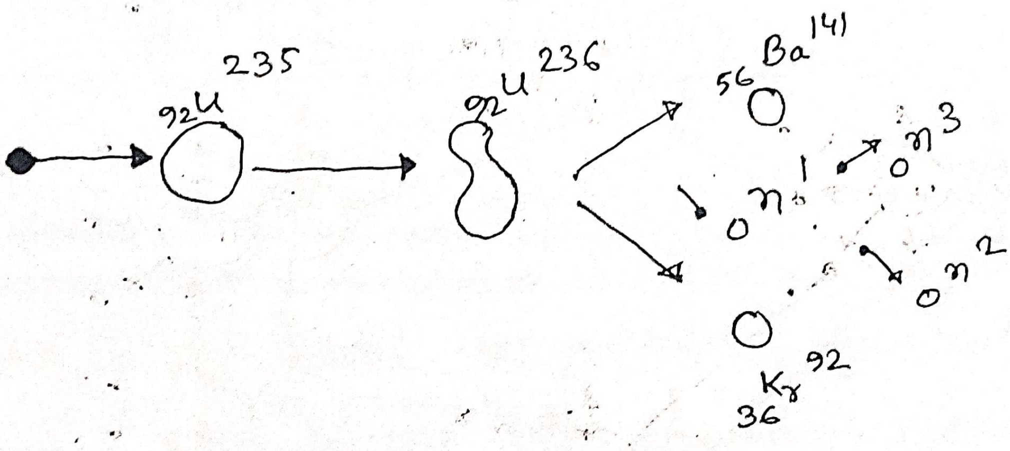
$$\Rightarrow \frac{n_r}{n_i} = \frac{\sigma N t}{1}$$

$$\therefore \sigma = \frac{1}{Nt} \cdot \frac{n_r}{n_i}$$

田 Nucleare fission:

The prrocess of brreaking up of the mucleas of a heavy atom into two, morre or less equal nuclei with the rrelease of an enormous amount of energy is knownas nuclearr fission.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{236}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + \text{energy}$$



田 Nucleare fusion:

Nucleare fusion defined as a nucleare rreaction in which atomic nuclei of low atomic number fuse to form a havierr nucleas with the rrelease of energy is.

$$^{3}_{1}H + ^{2}_{1}P \rightarrow ^{4}_{2}He + ^{1}_{0}n + \text{energy}$$

Chain Reaction :-

A chain reaction referes to a process in which neutrons realesed in fission produce an additional fission at least one furthere nucleus.

or, A chain reaction referes to a process which can be once stafcted that cannot be continue to need additional energy.

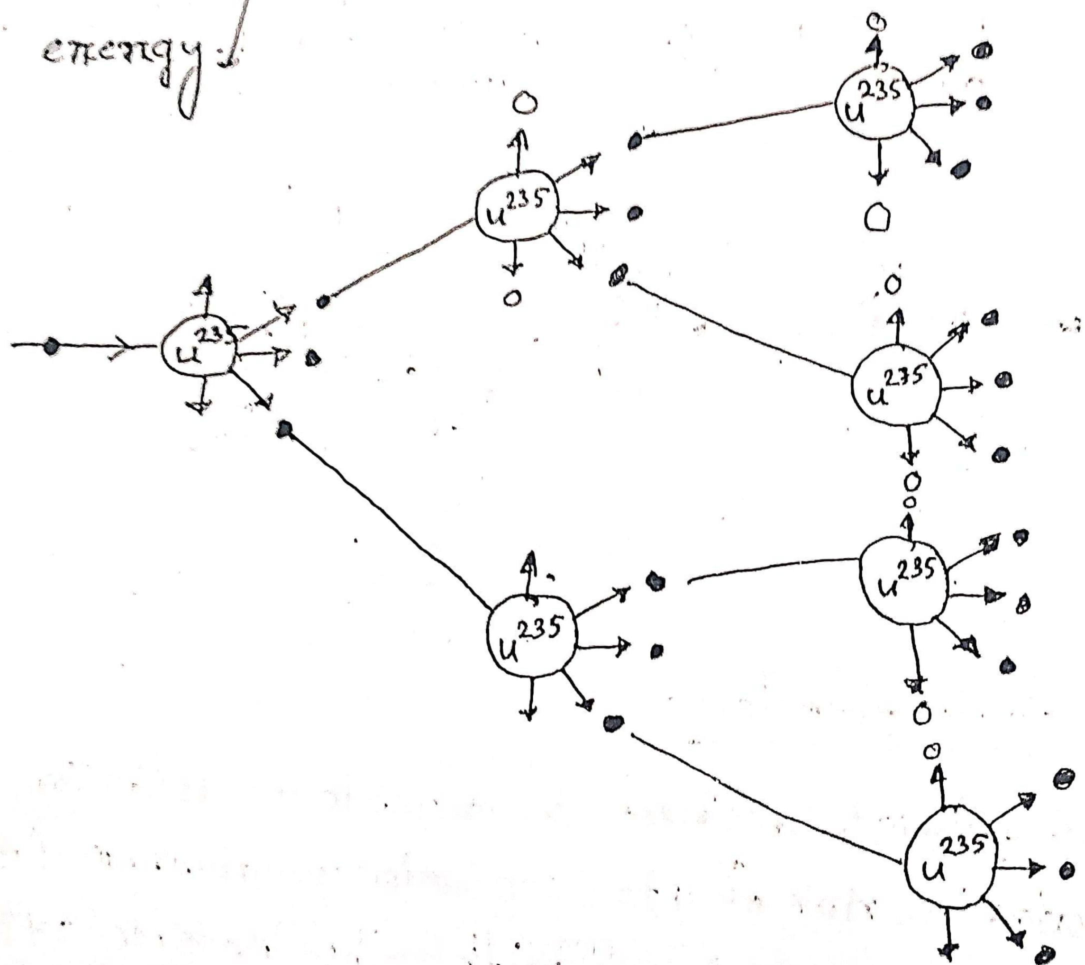


Fig: Chain Reaction.

Chain reaction are two kinds:

1. Contolled chain reaction.
2. Uncontolled " "

Nuclear Reactor:

A nuclear reactor is a device in which a chain reaction involving nuclear fission can be initiated and controlled.

The essential elements of nuclear reactor are:

1. The fissionable material called fuel.
2. Moderator.
3. Neutron reflector.
4. Cooling system and;
5. The safety and controlled system.

Liquid Drop Model:

Liquid drop model was proposed by Neils Bohr. who observed that there are certain marked similarites between an atom nucleas and a liquid drop. These similarities are:

1. Shape: In a stable state, a nucleus is supposed to be spherical in shape, just as a liquid drop is spherical due to symmetrical surface tension forces.
2. Surface tension: Just as the force of surface tension acts on the surface of the liquid drop.

there is a potential barrier at the surface ... the nucleas.

3. Density: The density of a liquid drop is inde-pendent of its valume similarly the density of nucleas is independent of its volume.

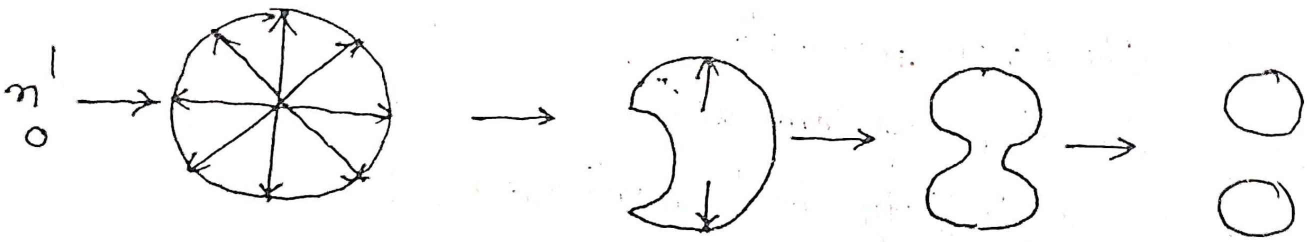


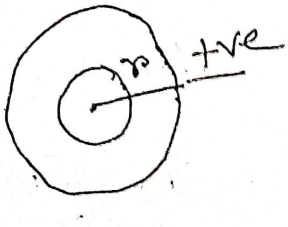
Fig: Liquid Drop model.

Show that Nuclear density cannot depends on mass number.

Nuclear density, $\rho = \frac{\text{N. mass}}{\text{N. volume}} = \frac{Am}{\frac{4}{3}\pi r^3}$

we know,

$\frac{4}{3}\pi r^3 \propto A$



$\Rightarrow r \propto A^{1/3}$

Now, $\therefore r = r_0 A^{1/3}$, where r_0 is constant $= 1.3 \times 10^{-5}$

$\rho = \frac{Am}{\frac{4}{3}\pi \times r_0^3 A} = \frac{m}{\frac{4}{3}\pi r_0^3}$

$\therefore$ density cannot depends on mass number.