Chapter - 13
Nuclei

Nuclear mass ⇒ (1 atomic mass unit
The device which use to determine the nuclear mass is called the spectrometers.
The unit to be used for measuring nuclear masses is called the atomic mass unit (amu)
1 atomic mass unit is defined as the $\frac{1}{12}$ th of the mass of an atom of ^{12}C isotopes

Discovery of Neutron - Acc to James Chadwick bombarded Berellium with alpha- particle from polonium having energy in the range about 5 MeV. He found that table product of Reaⁿ was $^{12}C_6$.

$$_4Be^9 + _2He^4 \longrightarrow {}^{12}C_6 + x + Q.$$

Where Q = energy of Reaⁿ
The unknown particle x produced in the reaⁿ had very good penetrat. power and couldn't

be defected by either E.f. or M.f.
Its mass was found to be nearly same as that of proton. But obviously carried no charge.
Also the ionisation power is possessed was very poor.
Chadwick called this particle, the neutron, represented by $_0n^1$.

Composition of Nucleus.

The nucleus is made up of elementary particles called neutrons & proton. Neutrons are electrically neutral whereas a proton carries +ve charge (1.6×10^{-19} C).
The no. of protons in nucleus of an atom is called the ~~Ato~~ Atomic Number (Z)
The no. of neutrons and protons present in the nucleus is called its mass no. (A).

Atomic No. (Z) = No. of proton = no. of $\bar{e}$

Mass no. (A) = no. of protons + no. of neutron

Therefore
No. of neutrons = A − Z.

Date
Page

Size of Nucleus – The volume of nucleus is directly proportional to its mass no.
Then, we have,

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

$$R^3 \propto A$$

$$R \propto A^{1/3}$$

$$R = R_\circ A^{1/3}$$

$R_\circ$ = Empirical constant having the value of 1.1×10^{-15} m.

Q Prove the nuclear density is same for all the nuclei.
'or'
Prove that the ratio of mass of nucleus to the volume of nucleus is constant of all nuclei.

Sol^n Let us consider m be the mass of nucleons in the nuclei of mass no. A and radius R we know that

$$R = R_\circ A^{1/3}$$

Volume of nucleus $= \frac{4}{3}\pi r^3$

$$= \frac{4}{3}\pi (R_\circ A^{1/3})^3$$

$$= \frac{4}{3}\pi R_\circ^3 A.$$

Now the density of nuclei $\rho = \frac{\text{mass}}{\text{volume}}$

$$\rho = \frac{mA}{\frac{4}{3}\pi R^3 A}$$

$$\rho = \frac{3m}{4\pi R^3} = \text{constant.}$$

The density doesn't depend on mass no. so the density of nucleus is same for all the nuclei which is equal to 2.29×10^{17} kg/m^3.

Q Define the term of isotopes, isobars and isotones with ex.

Isotopes :- Isotopes are nuclei having the atomic no. but different atomic mass.

eg→ The isotopes of carbon - ${}_6C^{13}$, ${}_6C^{12}$, ${}_6C^{11}$, ${}_6C^{10}$, ${}_6C^{9}$.

Isobars - Isobars are nuclei having the same mass no. but different atomic no.

eg→ ${}_{20}Ca^{40}$ and ${}_{18}Ar^{40}$

${}_6C^{14}$ and ${}_7N^{14}$

Isotones - Isotones are nuclei having same no. of neutrons (A-Z).

eg→ ${}_6C^{14}$ and ${}_8O^{16}$

${}_1H^{13}$ and ${}_2He^{14}$

Date
Page

Q Write the relation of mass energy equivalence. Also determine the energy of MeV for 1 amu.

Acc to Einstein mass-energy equivalence relation.

$$E = mc^2$$

where m_0 is the rest mass of particle and c= speed of light (3×10^8 m/s)

$\because$ 1amu = 1.67×10^{-27} kg.

Now from the above relation

$$E = 1.67 \times 10^{-27} \times (3 \times 10^8)^2$$

$$E = 1.67 \times 10^{-27} \times 9 \times 10^{16}$$

$$E = \frac{1.67 \times 10^{-27} \times 9 \times 10^{16}}{1.6 \times 10^{-19} \times 10^6} \text{ MeV}$$

$$E = 9.3125 \times 10^2 \text{ MeV}$$

$$E = 931.5 \text{ MeV}.$$

Therefore 1amu is equivalence to 931.5 MeV.

Q Define the term of mass defect and nuclear binding energy and also determine the formula for binding energy & Binding energy per neutron.

Sol^n Mass Defect (Δm) $\Rightarrow$ The difference b/w the sum of masses of the neutrons & the proton in the nuclei and the actual mass of nucleid (M_n) is called mass defect. i.e.

$$\Delta m = Zm_p + (A-Z) M_n - M_N$$

The energy equivalence of this mass defect is called the Binding energy of the nucleus.
The expression of B.E. can be written as.

$$B.E. = \Delta mc^2$$

$$B.E. = (Zm_p + (A-Z) m_n - M_n) c^2$$

to determine the B.E. per nucleon we divide the total B.E. by the mass no. of the nucleid.

$$B.E. \text{ per nucleon} = \frac{B.E}{A}$$

B.E. per nucleon Curve -
The B.E. per nucleon is the avr. energy required to remove a single nucleon from nucleus. It equal the total B.E. per nucleons of nucleus divided by mass no. of the nuclid.

Observations -
→ The average $\frac{B.E}{A}$ is small for very

light nuclei like $_1H^1$, H^2, $_3Li^7$ etc.

→ The peak $\frac{B \cdot E}{A}$ is 8.85 $\frac{MeV}{A}$ for $_{26}Fe^{56}$

→ Nuclid having mass no. in the range of 30 - 120, shows good stability because of their high B.E. corresponding to an avg. of approx. 8.5 MeV/A.

→ As the mass no. increases ↑ beyond 56, the B.E/A decreases ↓ and reaches a low value of 7.6 MeV/A for $_{92}U^{238}$. This is shown because in such large nuclei, the attractive for b/w distant nucleons are smaller.

Importance of B.E. curve -:

→ The B.E. curve is an indicator of the stability of the nucleus. the greater the B.E./A of the nucleus the more stable the nucleus with be and vice-versa.

→ Very small nuclei tend to fuse together to form a more stable nucleus. It is called Nuclear fusion.

→ The large nucleus like $_{92}U^{238}$ have a tendency to become small either by emitting α - particle, β - particle or by splitting into two smaller nuclei. It is called nuclear fission.

Q What do you mean by Nuclear forces? Write their important properties.

→ Nuclear forces → The strong forces of attraction which firmly hold the nucleons (protons + neutrons) inside the tiny nucleus are called nuclear forces.

Properties →

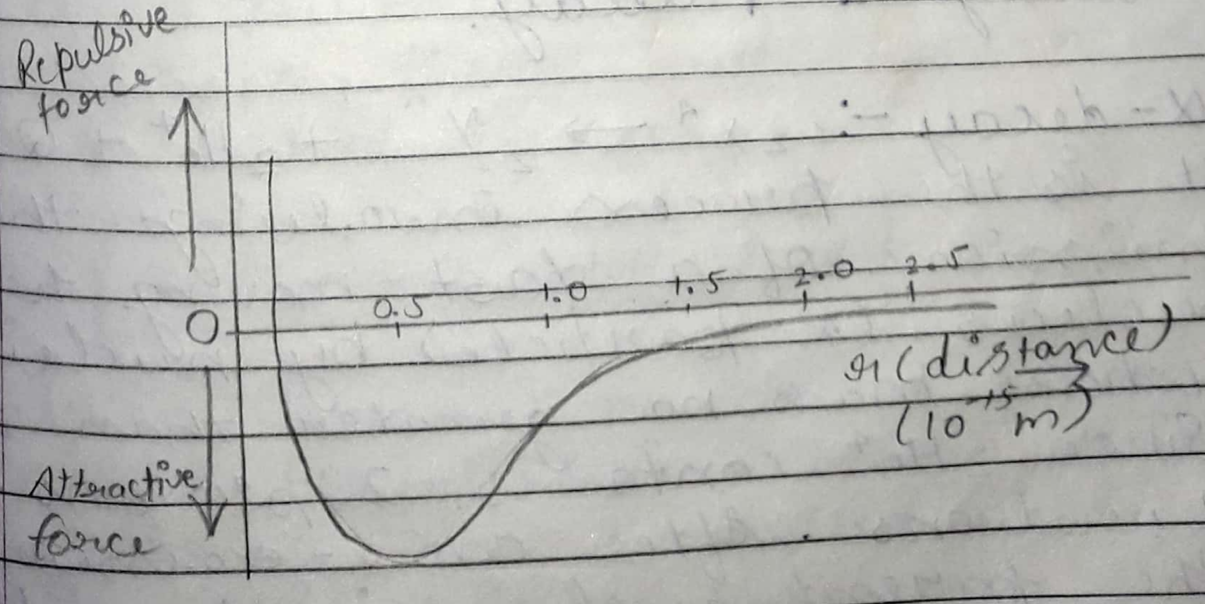
→ Nuclear forces are strong attractive forces.

→ Nuclear forces are charge independent.

→ Nuclear forces are non-central.

→ They don't obey the inverse square law.

Nuclear forces are short range form i.e., they act only over a short range of distances.



It has been found that nuclear forces are quiet strong when the distance b/w the nucleon is of the order of 1 fermi(fm) [10^{-15} m] but becomes zero at an internucleon distance ~~at~~ of 10^{-14} m [10 fm]
fig. shows how nuclear forces change with distance b/w the nucleons.
When the distance b/w two nucleon is more than 10^{-15} m. the nuclear forces is negligible.
As the Internucleon distance decreases the nuclear force increases rapidly. At an internucleon distance of about 0.75×10^{-15} m, the nuclear force becomes maximum.
It may be noted that nuclear force doesn't have any effect on electron in the atom.

Q What do you mean by α-decay, β-decay & γ-decay.

1- α-decay :- ${}_{Z}X^{A} \longrightarrow {}_{Z-2}Y^{A-4} + {}_{2}He^{4} + Q$
It is the process involving the emission of a fast moving helium nucleus (α-particle) by nuclei, whose mass no. greater than 210. Since ${}_{2}He^{4}$ contains 2 protons and 2 neutrons. After an α-emission the parent nucleus is transfered

into daughter nucleus which has an atomic no. reduced by 2 and the atomic mass no. reduced by 4.

$$_ZX^A \longrightarrow {}_{Z-2}Y^{A-4} + {}_2He^4 + Q$$

β-decay :- The emission of $\bar{e}$ from nucleus is called β-decay ~~is given by~~ and the $\bar{e}$, they emitted are called β- particle. The eq^n. defecting β-decay is given by -

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

Where $_{Z+1}Y^A$ is the daughter nuclei and $_{-1}e^0$ is the β- particle.
Q = energy released.
the symbol $\bar{\nu}$ represents the particle called Antinutrino.
If the atomic no. inc^n by and extra particle (Antinutrino) is released then such type of decay is called β- decay.

$$_ZX^A \longrightarrow {}_{Z+1}Y^A + B^- + \bar{\nu}$$

If the atomic no. dec^n by 1 and extra particle (Nutrino) is released then such type of decay is called B^+ decay is called B^+ decay.

Date
Page

$$ {}_{Z}X^{A} \rightarrow {}_{Z+1}Y^{A} + \beta^{+} + \nu $$

<u>Note</u>:- Since Nutrino has zero charge and zero rest mass. so experimental it is difficult to identify.

<u>γ- decay</u> -: The process of emission of γ- ray (photons) during the radioactive disintegration of nucleus is called γ- decay.
eg. Cobalt (Co) radiate energy to gain stability.

$$ {}_{Z}X^{A} \rightarrow {}_{Z}X^{A} + \gamma $$

excited state — ground state

<u>Q</u> What do you mean by Radioactivity? Write its units & laws of radio activity (Decay law) and with the help of this law prove that $N = N_0 e^{-\lambda t}$

<u>Radioactivity</u> -: It is the phenomenon of spontaneous disintegration of the nucleus of an atom. with the emission of α, β or γ- particle.
Its S.I. unit is curie, Bacural and Rutherford.

1 curie = 3.7×10^{10} decay/sec.
1 curie = 3.7×10^{10} Bacural.
1 rutherford = 10^{6} disintegration/sec.

Radioactive decay law -:

1- No individual atom can simultaneously emitt both α and β particle.

2- The no. of nuclei disintegrate/sec of a radioactive sample at any instant is directly proportional to the no. of un-decayed nuclei present in the sample at that instant.

i.e., $-\frac{dN}{dt} \propto N$

$$-\frac{dN}{dt} = \lambda \cdot N$$

λ = disintegration constant or decay constant. and $-\frac{dN}{dt}$ (rate of decay) is called the activity of the nucleus.

$$\boxed{R = \lambda . N}$$

denoted by R.

$$-\frac{dN}{dt} \propto N$$

$$-\frac{dN}{dt} = \lambda N$$

$$\frac{dN}{dt} = -\lambda N$$

$$\frac{dN}{N} = -\lambda dt$$

Taking integration both side.

$$\int \frac{1}{N} dN = -\lambda \int dt$$

$$\log N = -\lambda \times t + c \quad \text{—} (1)$$

at $t = 0$, $N = N_0$.

from above eq^n.

$$\log N_0 = -\lambda \times 0 + c$$

$$c = \log N_0.$$

putting c in eq^n (1)

$$\log N = -\lambda t + \log N_0$$

$$\log N - \log N_0 = -\lambda t$$

$$\frac{N}{N_0} = e^{-\lambda t}$$

$$\boxed{N = N_0 e^{-\lambda t}}$$

Q What do you mean by Half life? Determine the relation b/w half life and decay constant.

Sol^n Half life -: The time interval in which half of radioactive nuclei originally present in radioactive substance.

Relation b/w half life and decay constant.

at $t = t^{1/2}$

$$N = \frac{N_o}{2}$$

from $N = N_o e^{-\lambda t}$

$$\frac{N_o}{2} = N_o e^{-\lambda t}$$

$$(2)^{-1} = e^{-\lambda t_{1/2}}$$

$$2 = e^{\lambda t^{1/2}}$$

$$\log(2) = \lambda t^{1/2}$$

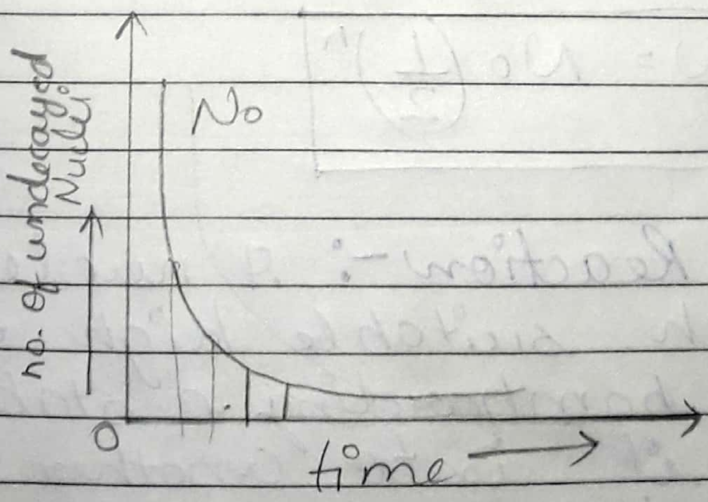
$$2.303 \log_e (2) = \lambda t^{1/2}$$

$$2.303 \times 0.03010 = \lambda t^{1/2}$$

$$0.6932 = \lambda t^{1/2}$$

$$t^{1/2} = \frac{0.6932}{\lambda}$$

The graph b/w no. of undecayed nuclei & time t may be shown as.



Date
Page

Q. Define the term of mean life. Write the relation b/w mean life and half life.

Ans Mean life -: The reciprocal of decay constⁿ is called the mean life. Denoted by τ and written as

$$\tau = \frac{1}{\lambda}$$

$$\lambda = \frac{0.6932}{t_{1/2}}$$

$$\tau = \frac{1}{0.6932} \times t_{1/2}$$

$$\boxed{\tau = 1.44\, t_{1/2}}$$

Important formula related to radioactivity -:

Activity $\boxed{(R) = N\lambda}$

Total time, $\boxed{T = n \times t_{1/2}}$ n = no. of half life time

$$\boxed{N = N_0 \left(\frac{1}{2}\right)^n}$$

Nuclear Reaction -: A nuclear reaⁿ in which suitable high energy particles bombarding a stable nucleus change it into another nucleus is called Nuclear Reaⁿ.

They are mainly two types.

1- Nuclear Fission -: The splitting of a heavy nucleus like $_{92}U^{238}$ ($A \geq 230$) into two medium mass nuclei in a nuclear Rea^n with the release of a huge amount of energy due to mass defect is called Nuclear fission.

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

where Q = 200.4 mev.

2- Nuclear Fusion -: Process of combining two light nuclei to form a heavy nucleus to release huge amount of energy due to mass defect is k/as Nuclear fusion.