CHAPTER-13

NUCLEI

NUCLEI ⇒ The positively charged center of an atom is called nuclei.

Composition Of NUCLEI ⇒ The Nuclei of an atom Consist of following particle →

(I) Proton ⇒ (i) It was discovered by Rutherford
(ii) It is having charge of $+1.6 \times 10^{-19} C$
(iii) It is having Mass of $1.67262 \times 10^{-27} kg$
(iii) It is a stable particle

(II) Neutron ⇒ (i) It was discovered by James Chadwick
(ii) It is neutral particle and is having mass of $1.6749 \times 10^{-27} kg$
(iii) It is unstable particle
Neutron → Proton + Electron + Antineutrino

Atomic Number ⇒ Number of electron or proton in a nucleus is called atomic Number. It is represented by Z.

Mass Number ⇒ Sum of No. of proton and neutron is known as mass Number. It is represented by A

$A = Z + N$ { Z = Atomic No. N = No. of Neutron

Symbol Of NUCLEI $^{A}_{Z}X$ { X = Symbol of element, A = Mass No, Z = Atomic No.

Isotope ⇒ Isotopes are the atom of same element having same atomic No but different atomic mass.

Isotopes are having No of proton but they differ in Number of neutron.

Example → $^{1}_{1}H$ = protium $^{2}_{1}H$ = deuterium
$^{3}_{1}H$ = Tritium

Nucleon ⇒ Neutron + Proton

Isobar ⇒ Atoms of different element same mass number but different atomic number are known as isobar.

Example

$^{3}_{1}H$ and $^{3}_{2}He$ $\quad$ $^{40}_{19}K$ and $^{40}_{20}Ca$, $^{40}_{18}Ar$

Isotone ⇒ Nuclides with same neutron number but different proton are called isotone.

Example → Mercury $^{198}_{80}Hg$ and ~~Silver~~ Gold $^{197}_{79}Au$

SIZE OF NUCLEUS

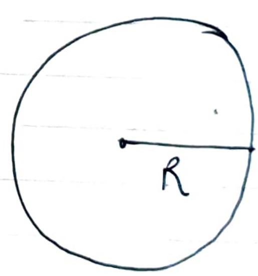
The size of Nucleus is less than 4.0×10^{-14} m.

The radius of nucleus is found to be directly proportional to mass number in the following way

$$R = R_0 A^{1/3} \qquad R_0 = 1.2 \times 10^{-15} m$$

Density of Nucleus

Density = $\dfrac{Mass}{Volume} = \dfrac{A}{\frac{4}{3}\pi R^3}$



$$R = R_0 A^{1/3}$$

Density = $\dfrac{A}{\frac{4}{3}\pi R_0^3 A}$

Density = $\dfrac{3}{4\pi R_0^3}$

Density = 2.3×10^{17} kg/m³

The density of all the ~~atom~~ ~~its~~ nucleus is same

MASS-ENERGY EQUIVALENCE

According to Einstein mass can be converted into energy and vice-versa according to following relationship

$$E = mc^2$$

where E = Energy
m = Mass
C = Speed of light.

Mass-Defect ⇒ The difference b/w the mass of nucleus and its constituent is called mass defect.

$$\Delta M = [Zm_p + (A-Z)m_n] - M$$

{ where Z = Atomic No.
A = Mass No.
m_p = mass of proton
m_n = Mass of Neutron
M = Mass of Nucleus. }

☆ The mass of nucleus is always less than the sum of mass of all the proton and neutron that together make the nucleus.

BINDING ENERGY ⇒ It is the amount of energy released when neutrons and protons are brought together to form a nucleus.

OR

It is the amount of energy supplied in order to break the nucleus into its constituent.

☆ Greater the binding more stable will be the nucleus.

☆ When proton and neutron are brought together to form nucleus then there is decrease in the mass. That decrease in mass gets converted into energy

$$B.E = \Delta M C^2$$

where ΔM = mass deffect
C = speed of light

$$B.E = \{[Zm_p + (A-Z)m_N] - M\}C^2$$

Number of Nucleon = Mass No. = A

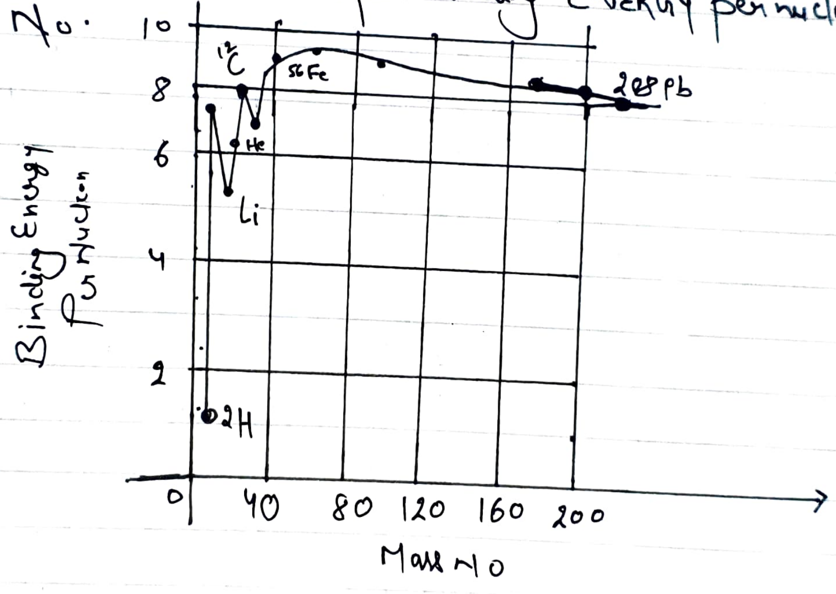
Binding ENERGY PER NUCLEON (E_{bn}) ⇒ It is the ratio of binding energy of a nucleus to the number of nucleons.

$$E_{bn} = \frac{E_b}{A}$$

{ where E_b = total binding energy
A = Mass No.
E_{bn} = Binding energy per Nucleon }

BINDING ENERGY PER NUCLEON VS Mass Number Curve

It is the curve drawn b/w binding ENERGY per nucleon and mass No.



CONCLUSIONS DRAWN FROM THE Curve

(i) Greater the binding energy per nucleon the more stable is nucleus.

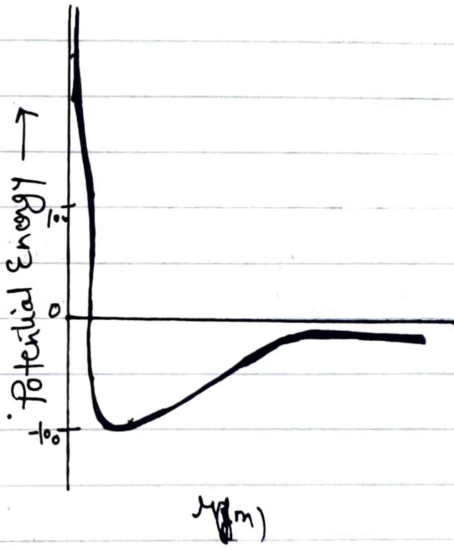
(ii) A very heavy nucleus A = 240 has lower binding energy per nucleon compared to that of a nucleus with A = 120. So if a nucleus A = 240 breaks into two nucleus of A = 120 nucleons will get more tightly bound. This implies more energy will be released. This implies that heavy element undergo fission. Eg → Uranium

ii) The light ~~ete~~ nucleus when fused together to form heavy nucleus then the heavy nucleus is having more Binding energy per nucleon then the light nuclei. That implies that energy will be released. This implies light elements undergo fusion to gain more stability.

NUCLEAR FORCE ⇒ The force of attraction that hold together nucleons in a nucleus is called nuclear force.

Characteristics of Nuclear force

i) It is the strongest Natural force.
ii) It is short range
iii) The nuclear force b/w two nucleons falls to zero as their distance is more than few femtometers.
iv) It does not depend upon the charge.



Reason Behind Nuclear force ⇒ Nuclear forces are exchanged forces which are produced by the exchange of new particle called π - mesons. There are three type of π-mesons, π^+, π^- and π^0.

There is a continuous of exchange π-mesons b/w proton and neutrons due to which they continue to be converted into one another.

$$p - \pi^+ \rightarrow n$$
$$n + \pi^+ \rightarrow p$$
$$n - \pi^- \rightarrow p$$
$$p + \pi^- \rightarrow n$$

The exchange π^+, and π^- into proton and neutron is responsible for the origin of nuclear force.

α = +ve
β = -ve
γ = 0

RADIOACTIVITY

Radioactivity is a nuclear phenomenon in which an unstable nucleus undergoes a decay.

~~Natural Radioactivity~~ → When naturally occurring nuclei are unstable then we call it natural radioactivity. Example → Uranium.

Artificial Radioactivity ⇒ The process by which radioactivity is induced in certain stable nucleus by bombarding them by suitable high energy particle is called artificial radioactivity.

$$Ex \Rightarrow {}^{10}_{5}B + {}^{4}_{2}He \longrightarrow {}^{13}_{7}N + {}^{1}_{0}n$$

There are three type of Radioactive decay
(i) α-decay (ii) β-decay (iii) γ-Decay.

Alpha (α) Decay

An alpha particle consist of nucleus of helium.

In α-decay a nucleus emits α particle during the atomic number of nucleus decreases by 2 and mass number by 4.

$${}^{A}_{Z}X \xrightarrow{\alpha\ decay} {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

$${}^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

$${}^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

After emission of one β particle isobar is produced.

BETA (β) Decay

A nucleus that decays spontaneously by emitting an electron or positron is said to undergo beta decay.

There are two type of Beta decay

(i) Beta negative (β^-) decay ⇒ In β^- decay a neutron in the nucleus transforms into a proton, an electron and an anti neutrino

$$n \longrightarrow p + e^- + \bar{\nu}$$

During β^- decay the mass number increases by one and atomic Number remain Constant.

$$^{A}_{Z}X \xrightarrow{\beta^-} {}^{A}_{Z+1}Y$$

example ⇒ $^{14}_{6}C \xrightarrow{\beta^-} {}^{14}_{7}N + e^- + \bar{\nu}$

(ii) Beta-Positive (β^+) decay ⇒ In β^+ decay a proton Changes into a neutron with emission of positron and a neutrino

$$p \longrightarrow n + e^+ + \nu$$

During β^+ decay the mass number decreases by one and atomic Number remain same.

$$^{A}_{Z}X \xrightarrow{\beta^+} {}^{A}_{Z-1}X +$$

Example $^{13}_{7}N \rightarrow {}^{13}_{6}C + e^+ + \nu$

★ After emission of one α particle and two β particles ... produced.

Electron Capture ⇒ Electron capture is competitive with positron emission since both processes lead to the same nuclear transformation. This occurs when a parent nucleus captures one of its own orbital electrons and emits a neutrino.

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

In most of the case K-shell electron is captured and that is why it is known as K-capture.

$$ {}^{7}_{4}Be + \bar{e} \longrightarrow {}^{7}_{3}Li + \nu $$

Gamma (γ) Decay

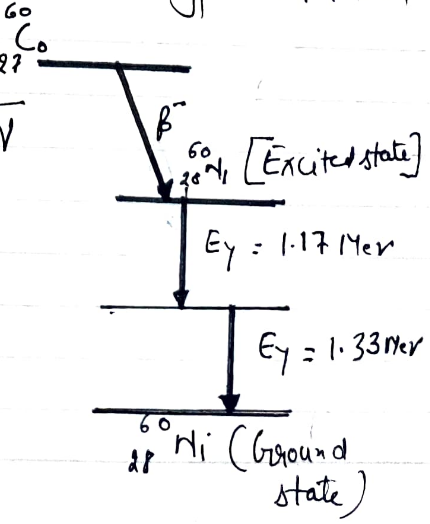
A nucleus undergoing α decay or β-decay left in excited state. The typical half life of an excited state of nucleus is 10^{-10} s.

The excited nucleus (X^*) then undergoes to a lower energy state by emitting high energy photon called γ ray photon.

The following sequence of events represents a typical situation in which γ decay occur

$$ {}^{12}_{5}B \rightarrow {}^{12}_{6}C^* + \bar{e} + \bar{\nu} $$

$$ {}^{12}_{6}C^* \rightarrow {}^{12}_{6}C + \gamma $$



γ-ray Photon is having zero rest mass and carry no charge.

(SI unit of Radioactivity is ~~becqu~~ becquerel)

Law Of Radioactive Disintegration

(i) Radioactive is a spontaneous phenomenon and is not affected by the external condition such as temp and pressure etc.

(ii) When a radioactive element decay by emitting α-particle atomic number decreases by 2 and mass number by four.

(iii) In β decay the atomic number may increase or decrease by 1.

(iv) In γ decay atomic number as well as mass number remain same.

(v) The rate of disintegration of radioactive substance is directly proportional to the number of atoms remained undecayed in the substance. [Radio active decay law]

Mathematical form Of Radioactive Decay law

N_0 = No. of radioactive nuclei present at time $t = 0$

N = No. of radioactive nuclei present in the sample at time $t = t$

dN = No. of radioactive nuclei which disintegrate in small time dt

According to Radioactive decay law

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

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

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

integrating both side

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

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

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

$$\log N_0 = C \quad \text{--- (2)}$$

Putting the value of C in eqn (1)

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

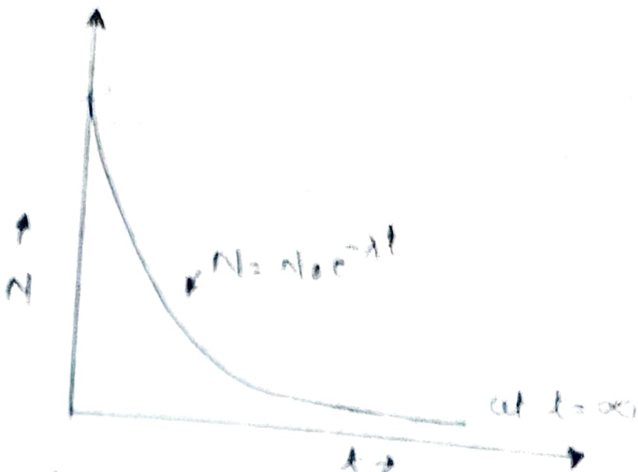
$$\log N - \log N_0 = -\lambda t$$

$$\log \frac{N}{N_0} = -\lambda t$$

taking antilog on both side

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

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



Half Life ⇒ It is the time required to reduce the parent nuclei by half of its original value.

$N = N_0 e^{-\lambda t}$ when $t = T_{1/2}$ $N = \frac{N_0}{2}$

$\frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}}$

$\frac{1}{2} = e^{-\lambda T_{1/2}} \Rightarrow 2 = e^{\lambda T_{1/2}}$

$\log_e 2 = \lambda T_{1/2} \log_e e$

$2.303 \log_{10} 2 = \lambda T_{1/2}$

$2.303 \times .3010 = \lambda T_{1/2}$

$0.693 = \lambda T_{1/2}$

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

Mean Life = It is defined as the sum of lives of all the atom divided by total No. of atom

$$T_{av} = \frac{\text{Sum of lives of all atoms}}{\text{Total No. of atoms}}$$

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

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

$dN = -\lambda N_0 e^{-\lambda t} dt$

→ It means dN atoms have lived for time t before decaying