Date __/__/__

NUCLEAR PHYSICS

$^{A}_{Z}X_{n}$ — Z : atomic number (proton)

N : neutron number

A : mass number

$(N = A - Z)$

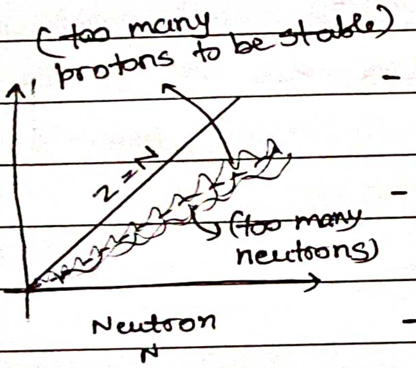
Isotopes - same Z, different N (^{35}Cl, ^{37}Cl)

Isotones - same N, different Z (^{2}H, ^{3}He)

Isobars - same mass number A

H → hydrogen, deuterium, Tritium

$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$



- light stable nuclides tend to lie close to line $N = Z$
- heavier nuclides tend to have more neutrons than protons
- no stable nuclides with $Z > 83$ (bismuth)

Length 1 fm = 10^{-15} m

Size range : 1 fm (single nucleon) - 7 fm (heaviest nucleon)

Time

nuclear reactions : 10^{-20} s

γ decays of nuclei : $10^{-9} - 10^{-12}$ s

Radioactive decay (α & β) : min / hrs / millions of years.

Energy nuclear energy : MeV

- β & γ decay : 1 MeV
- low energy nuclear reactions : kinetic energy of order 10 MeV

- Mass (a.m.u)

$$1\,u = \frac{1}{12} \times \text{mass of an atom of } {}^{12}C$$

$$= 1.66 \times 10^{-27}\ kg$$

- Mass energy $E = mc^2$ (Hiroshima bl)

$$\left\{ \begin{array}{l} 1\,u = 931.502\ MeV/c^2 \\ c^2 = 931.4940\ MeV/u \end{array} \right\}$$

In these units,

Mass of nucleons ~ 1 u

Mass energies of nucleons ~ 1000 MeV

- Nuclear Binding Energy

• (missing energy that keeps a nucleus together)

• (a nucleus is not a simple collection of protons and neutrons, but they strongly combine with each other through a strong interaction)

expected : $M(Z,N) = Z\,m({}^1_1H) + N\,m(n)$

actual : $M(Z,N) \neq Z\,m({}^1_1H) + N\,m(n)$

eg for deuterium $\left.\begin{array}{l} m_H = 1.0078\,u \\ m_n = 1.0087\,u \end{array}\right\}$ $(2.0165\,u)$

actual mass of deuterium = 2.0141 u

- Mass defect

(this missing mass is called as mass defect, Δm & it is the energy given off when a nucleus is formed from a free proton and neutron)

$$\Delta m = Z\,m({}^1_1H) + N\,m(n) - m({}^A_ZX)$$

Fusion

O + O → O + E

Date ___/___/_____

Fission

O → O + O + E

- The energy equivalent of the missing masses, corresponds to energy given off when a ^2_1H nucleus is formed from a free proton and neutron

$$(E_b = \Delta m \times 931.5 \text{ MeV}/u)$$

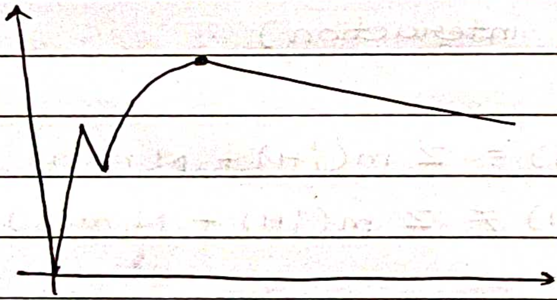
(High binding energy ⟶ stable nucleus) (greater BE ⇒ more energy to break up the nucleus)

- Binding energy per nucleon
  (total E_b / number of nucleons)

$$B.E/A \text{ for } ^2_1H = (2.224 \text{ MeV})/2$$
$$= 1.1 \text{ MeV/nucleon}$$

$BE/A \Uparrow \longrightarrow$ stable $\Uparrow$

BE/A



A

→ at A = 4, exceptionally stable ^4_2He nucleus, which is Alpha particle

→ most stable nucleus $^{56}_{26}Fe$ (iron isotope)

Conclusions:

① Split a heavy nucleus into 2 medium sized ones (nuclear fission), each of new nuclei will have more binding energy per nucleon that the original did. The extra energy will be given off, and it can be a lot (Hiroshima knows)

② Joining 2 light nuclei together to give a single nucleus of medium size also means more binding energy per nucleon in the new nucleus

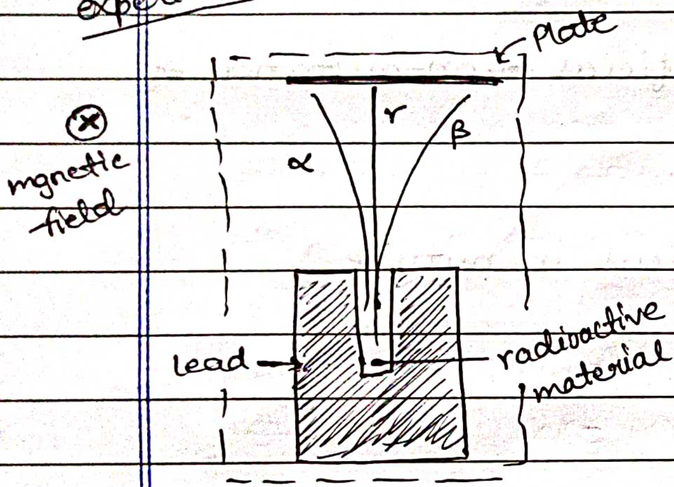
★★ Atomic masses of the nuclei can be measured with Mass Spectrometer.

Radioactivity

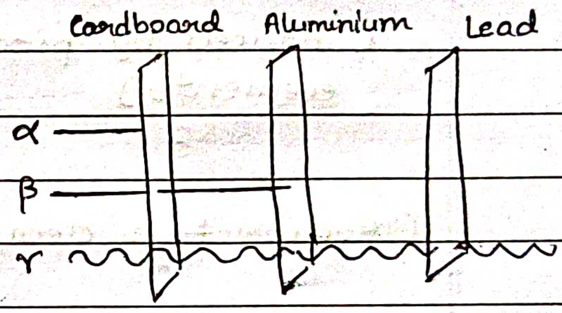
(unstable nuclei are transformed into other nuclear species by decay process)

- 1896, Becquerel discovered that crystals of uranium salt emitted rays similar to x-rays.
- 1898, curies (Marie & Pierre) discovered Polonium and Radium. The activity of radium as measured by intensity of the emitted rays was more than a million times that of uranium.

experiment 1



experiment 2



Alpha : ${}^4_2He$ nuclei

β-particle : electrons

γ-rays : high-energy photons

positron & electron capture were also added

① Gamma decay → emission of γ-ray → because nucleus has excess energy.

② Alpha decay → emission of α-particle → nucleus too large

③ Beta decay → emission of electron by neutron → nucleus has too many neutrons relative to no. of protons.
changes neutron to proton

(4) Electron capture $\longrightarrow$ capture of e^- by proton $\longrightarrow$ more protons relative to neutron.

changes proton to neutron

(5) Positron ~~capture~~ emission $\longrightarrow$ emission of e^+ by broton $\longrightarrow$ more protons relative to neutrons.

changes proton to neutron

- Radioactivity Types -

(1) Natural

(emission of radiation due to disintegration of naturally occuring heavy elements.)

(2) Induced / Artificial.

(induced by producing artificial transmutation of elements)

(Radioactive decay is statistical in nature)

- Radioactive decay -

λ : probability per unit time for decay of each nucleus of a given nuclide

N : undecayed nuclei

dN : the number dN that decay in a time

$(dN = -N\lambda\, dt)$ minus because N decreases ~~with increasing time~~

$$\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int_{0}^{t} dt$$

$$\left\{ N = N_0 e^{-\lambda t} \right\}$$ Radioactive decay

- <u>Activity</u>

(activity of a sample of any radioactive nuclide is the rate at which the nuclei of its constituent atoms decay)

SI unit : Becquerel (Bq) $\quad 1\ Bq = 1$ decay/s

Traditional unit : Curie (Ci) $\quad 1\ Ci = 3.70 \times 10^{10}$ decays/s

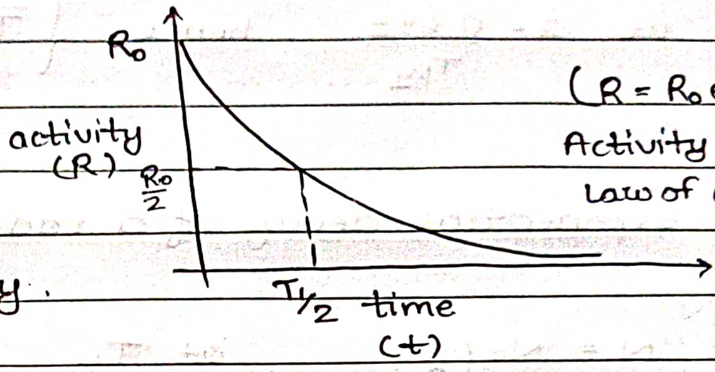
$= 37$ GBq

$$R = -\frac{dN}{dt}$$

$$R = -\frac{d(N_0 e^{-\lambda t})}{dt}$$

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

$\{R = \lambda N\}$ <u>Activity.</u>



$(R = R_0 e^{-\lambda t})$

Activity law / Law of disintegration

- <u>Half-life</u> $(T_{1/2})$

(the half-life is the time needed for an initial activity to drop by half)

$$\frac{R_0}{2} = R_0 e^{-\lambda T_{1/2}}$$

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

$$\left\{ T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda} \right\}$$ Half-life

($T_{1/2}$ is the time required for 50% of the radioactive atoms to undergo a radioactive decay)

- <u>Decay constant, λ</u>

(defined as reciprocal of time during which number of atoms left are equal to $1/e$ times (~37%) of original number of atoms)

$$N/N_0 = 1/e$$

$$e^{-\lambda t} = e^{-1}$$

$\left\{ \lambda = \frac{1}{t} \right\}$ decay constant

(The larger the decay constant, the greater the chance a given nucleus will decay in certain period of time)

- the decay constanst of the radionuclide whose half-life is 5.00 h is

$$\lambda = \frac{0.693}{T_{1/2}} = \frac{0.693}{5h \times 3600 s/h} = 3.85 \times 10^{-5}\ s^{-1}$$

- Mean Time (LifeTime)

$$\left\{ \bar{T} = \frac{1}{\lambda} \right\}$$ mean lifetime

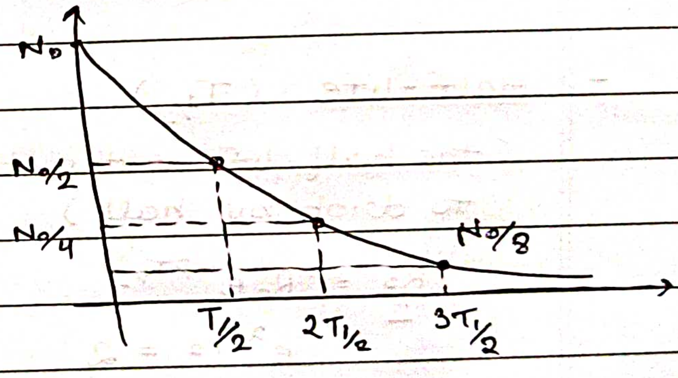
as, $\lambda = \frac{0.693}{T_{1/2}}$, hence $\left\{ \bar{T} = 1.44\, T_{1/2} \right\}$

- Exponential decay of a radionuclide

$N = N_0\left(\frac{1}{2}\right)^1$ at $T_{1/2}$

$N_0 = N_0\left(\frac{1}{2}\right)^2$ at $2T_{1/2}$

⋮



$N = N_0\left(\frac{1}{2}\right)^n$, at $nT_{1/2}$

$$\left\{ n = \frac{t}{T_{1/2}} \right\}$$