Lecture - 01

(*) Principle of Electric Power Generation

The concept of electricity production is to get a grp. of electrons moving through a conductor in some desired direction.

This can be achieved by spinning a conductor in a magnetic field.

⇒ Commonly, industrial power production focuses on:
- → Creating rotary motion in turbine
- → Transferring K.E. from some high velocity fluid stream to turbine blades.

⇒ Nuclear & Coal-based Thermal power plants work on the same principles nearly. Difference is how we supply steam in the generator.

* Nuclear v/s Coal - Based

~~Conversations~~

Nuclear	Coal - Based
1. Nuclear → Thermal.	1. Chemical → Thermal
2. Rearrangement of protons and neutrons inside atoms.	2. Rearrangement of electrons inside molecules
3. Conservation of no. of sub-atomic particles.	3. Conservation of no. of atoms.

* Why Nuclear Power ?

1. No combustion → Significantly lesser greenhouse emission
2. Lesser operating cost.
3. Lesser volume of operating zone / reactor
   → Higher energy density
4. Highly reliable compared to wind and solar
   → Base load plant
5. Renewable
6. Possibility of near - infinite energy production through fusion.

⊛ Several Cons of Technology

1. Environmental effects associated to mining, refining, transporting radioactive fuel
2. Radioactive waste disposal
3. High capital cost involvement
4. Possible implication of nuclear accident
5. Finite nature of Uranium & similar fuels.

⊛ Atomic Structure

		Mass	Charge
	Electrons	9.109×10^{-31} kg	-1.602×10^{-19} C
Nucleons	Protons	1.672×10^{-27} kg	$+1.602 \times 10^{-19}$ C
	Neutrons	1.674×10^{-27} kg	–

$$\left.\begin{array}{l} A = \text{Mass Number (Nucleons)} \\ Z = \text{Atomic Number (Protons)} \end{array}\right\} \rightarrow {}^{A}_{Z}X \text{ or } {}^{A}X$$

$$\text{Radius } R \text{ (in cm)} \cong (1.4 \times 10^{-13}) A^{1/3}$$

⇒ <u>Atomic Mass unit (amu)</u> : $1/12^{th}$ mass of common Carbon atom $^{12}_{6}C$

1 amu = 1.6605×10^{-27} kg
Electron = 5.486×10^{-4} amu
Proton = 1.007825 amu
Neutron = 1.008665 amu

⇒ <u>Electron volt (eV)</u> : Amt. of energy gained / lost by a single electron while moving across an electric potential diff. = 1V.

1 eV = 1 electronic charge × 1 V
= 1.602×10^{-19} J
= 4.45×10^{-26} kWh

1 MeV = 1.602×10^{-13} J

⇒ Isotopes : Atoms having same atomic no. Z, but diff. mass number A, due to varying no. of neutrons.
Eg : C-12, C-13, C-14 ;
Hydrogen, Deuterium, Tritium.

Natural isotopes : H, Li, B, C, Sn, U

Chemical properties of isotopes are same.
But Nuclear characteristics vary.

⇒ How Protons stay together ?

$$F_e = k_e \frac{q_1 q_2}{r^2}$$

k_e = Coulomb's const.
r = distance b/w q_1 - q_2

Both attractive and repulsive forces have this same magnitude

Forces acting in Nucleus

Force	Interaction	Range
Gravitational	Very weak attractive force b/w all nucleons	Relatively long
Electrostatic	Strong repulsive force b/w like charged particles	Relatively long
Nuclear	Strong attractive force b/w all nucleons.	Extremely short.

(*) Binding Energy & Mass Defect

Existence of nucleus despite such opposing forces indicates towards the presence of a short range force, which overcomes electrostatic repulsion and binds nucleons together. The energy associated with this particular force is Binding Energy.

Alternatively, it can be viewed as the amt. of energy required to break the nucleus into its constituents.

Interestingly, the mass of nucleus is generally lesser from the combined mass of its constituents, and this diff. in mass is called Mass Defect.

This mass defect is actually the source of the nuclear energy.

$\Rightarrow$ $Z = m_p$, $N = A - Z = m_n$, $Z = m_e$.

Then, mass defect can be calculated as,

$$\Delta m = Z(m_p + m_e) + N m_n - {}^{A}_{Z}m$$

Here ${}^{A}_{Z}m$ represents the mass of original atom.

Accordingly,

$$\Delta m = Z(1.007825) + (A - Z)(1.008665) - {}^{A}_{Z}m$$

(in amu)

Energy associated with such Mass defect (Δm) is the Binding Energy (B.E). The "missing" mass can be viewed to have converted to energy and acting as a glue to bind nucleons together, thereby forming nucleons.

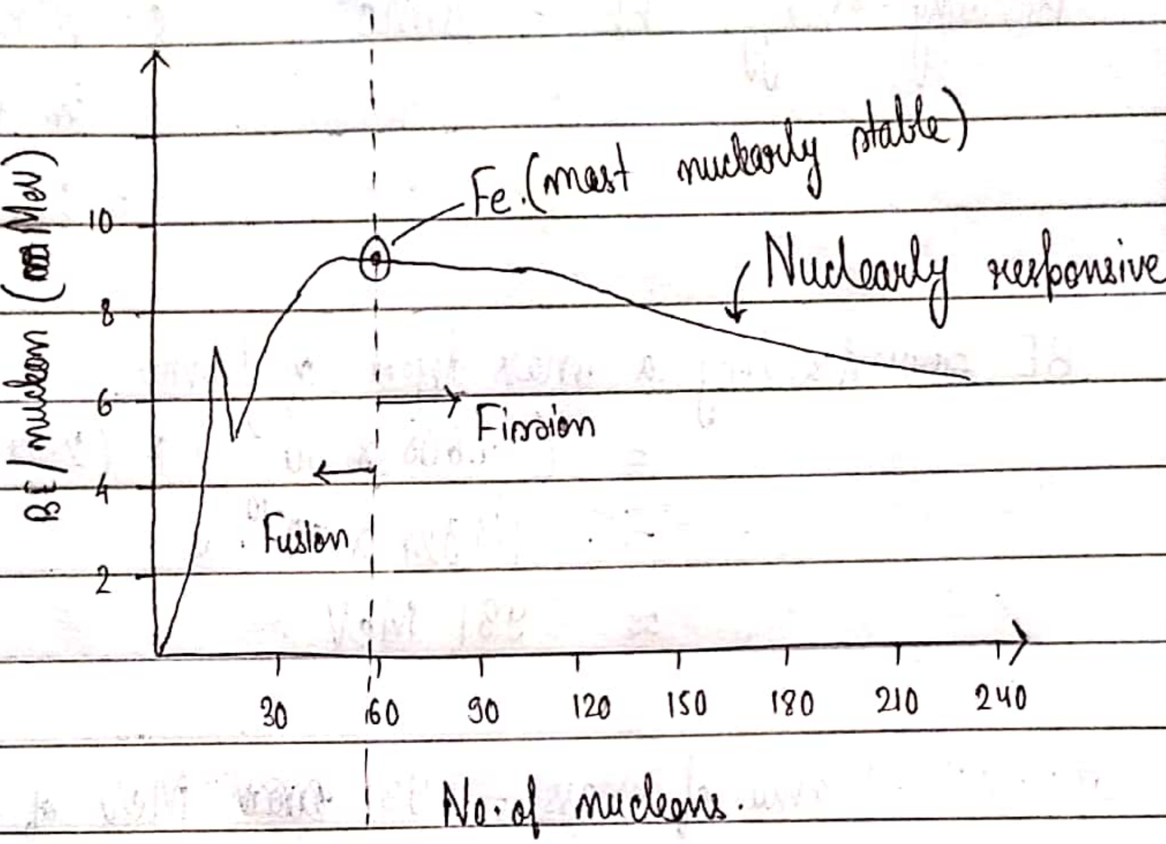
Binding energy, $BE = \Delta mc^2$, c = velocity of light in vacuum
$= 2.9979 \times 10^8$ m/s.

BE corresponding a mass defect of 1 amu
$= (1.6605 \times 10^{-27}) \times (2.9979 \times 10^8)^2$
$= 1.4924 \times 10^{-10}$ J
≈ 931 MeV.

$\therefore$ 1 amu of mass = 931 MeV of energy

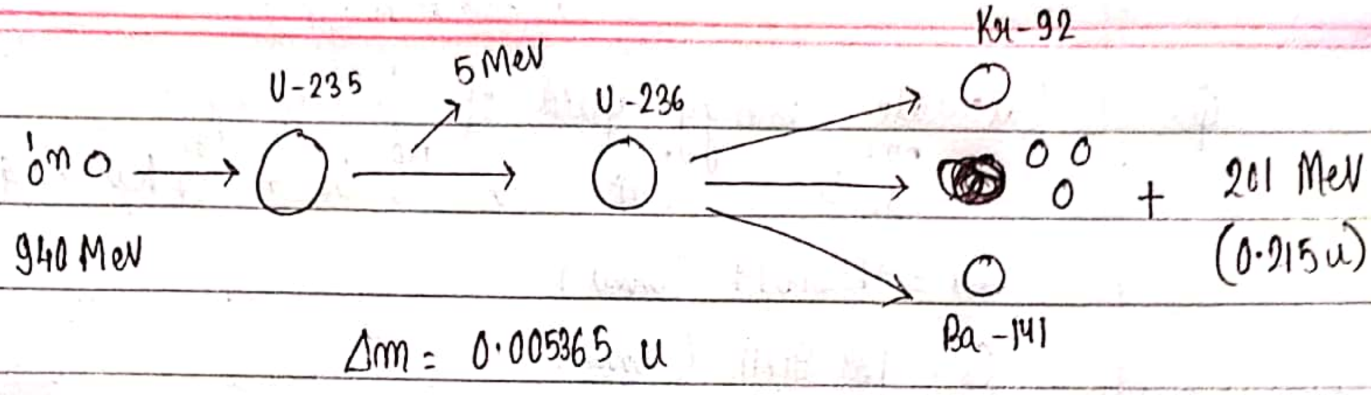
Eg: A typical nuclear reaction : ${}^1_1H + {}^1_0n \longrightarrow {}^2_1H$
$\Delta m = 0.00239$ amu
BE for ${}^2_1H = 2.2251$ MeV
BE/nucleon = 1.1126 MeV

Higher the value of BE/nucleon, more stable is nucleus.
Thus, B.E. determines the stability of the nucleus.



(*)

Fission	Fusion
→ Less natural	More natural (in stars)
→ Confined to heavy nuclei	Confined to lighter nuclei
→ Chain reaction is controllable.	Can't be controlled with present technology
→	Requires higher temperature than fission
→	Larger amt. of energy as compared to fission



$\Delta m = 0.215405\,u$

<u>Eg. of typical fission reaction</u>

$$\text{Ratio of energy release} = \frac{\text{Nuclear reaction involving } ^{235}U}{\text{Chemical reaction involving } ^{12}C}$$

$$= \frac{O(10^{-3})}{O(10^{-10})} \approx 10^{7}$$

Thus, energy of nuclear reaction is nearly 10^7 times that of general combustion reaction.

Q. Calculate energy yield of following:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{140}_{55}Cs + ^{92}_{37}Rb + 4\,^{1}_{0}n$$

$Rb = 91.91914$ (amu)

$Cs = 139.91711$ (amu)

$U = 235.0493$ (amu)

Ans.

$$m_{LHS} = 235.0493 + 1.008665$$

$$m_{RHS} = 139.91711 + 91.91914 + 4(1.008665)$$

$$\Delta m = m_{LHS} - m_{RHS} = 0.187055 \text{ amu.}$$

$$B.E. = 174 \text{ MeV.}$$