NUCLEI

Nucleus: The nucleus of an atom is dense, positively charged core that contains protons and neutrons and holding most of the atom's mass.

* Protons + neutrons = nucleons

Terms related to Nucleus

1. Atomic Numbers: The number of protons in the nucleus of an atom of the element is called atomic number (Z) of the element.
2. Mass Number: The total number of protons and neutrons present inside the nucleus of an atom of the element is called mass number (A) of the element.

Z - Atomic number = number of protons
N - Neutron number = number of neutrons
A → Mass number = Z + N
= total no. of protons and neutrons

3. Nuclear Size: The radius of nucleus

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

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

where $R_0 = 1.2 \times 10^{-15} m = 1.2 fm$ $[1 fm = 10^{-15} m]$

* Volume of the nucleus $\propto R^3$ is $\propto$ to A. Thus density of nucleus is a constant, independent of A, for all nuclei.
* Density of a nuclear matter is approximately $2.3 \times 10^{17} kg\, m^{-3}$.
* Density of nuclear matter is very large as compared to ordinary matter. For example, water density is $10^3 kg\, m^{-3}$ which is very less than nuclear matter density.

Nuclear Density $\rho = \dfrac{\text{Mass of nucleus}}{\text{Volume of nucleus}}$

$$\rho = \frac{m}{\frac{4}{3}\pi R_0^3}$$

or

$$\boxed{\rho = \frac{3m}{4\pi R_0^3}}$$

$m \rightarrow$ Average mass of nucleus

*It is independent of mass number and therefore same for all nuclei.

Atomic Mass Unit It is defined as $\frac{1}{12}$ the mass of cabon nucleus. It is abbreviated as amu and denoted by u.

$$1\ \text{amu} = \frac{1.99 \times 10^{-26}}{12}$$

$$= 1.6 \times 10^{-27}\ \text{Kg} = 931\ \text{MeV}$$

<u>Isotopes</u> The atoms of an element having same atomic number but different mass numbers, are called isotopes.

*[Isotopes $\xrightarrow[\text{p for}]{}$ same p → no. of proton = atomic no.]

e.g. $_1H^1$, $_1H^2$, $_1H^3$ are isotopes of hydrogen.

<u>Isobars</u> The atoms of different elements having same mass numbers but different atomic numbers are called isobars.

*[Isobars $\xrightarrow[\text{a for}]{}$ same A → same mass no.]

e.g. $_1H^3$, $_2He^3$ and $_{18}Ar^{40}$, $_{20}Ca^{40}$ are isobars.

Isotones The atoms of different elements having different atomic numbers and different mass numbers but having same numbers of neutrons, are called isotones

* [Isotones → (n for) same neutrons]

e.g. $_1H^3$, $_2He^4$ and $_6C^{14}$, $_8O^{16}$ are isotones

Isomers Atoms having same mass numbers and the same atomic number but different radioactive properties.

Nuclear Force: The force acting inside the nucleus is called nuclear force.

* Nuclear forces are strongest forces in nature.
- It is very short range attractive force.
- It is non central and non conservative force.
- It is independent of charge.
- It is 100 times to electrostatic force and 10^{38} times of gravitational force.

Mass defect: The difference in mass of nucleus and its constituents is called mass defect.

It is given by

$$\text{Mass defect } \Delta M = [Zm_p + (A-Z)m_n] - M_n$$

$m_p \rightarrow$ mass of proton

$m_n \rightarrow$ mass of neutron

$M_n \rightarrow$ mass of nucleus

* Mass defect is due to binding energy which keeps the nucleus stable.

* It plays a critical role in nuclear reactions like fission and fusion.
* Mass defect showcases the concept of energy-mass equivalence (mass and energy are interchangeable)

Nuclear Binding Energy: The minimum energy required to separate the nucleons upto infinite distance from the nucleus, is called nuclear binding energy.

nuclear binding energy $E_b = \Delta M c^2$

Nuclear binding energy per nucleon = $\frac{\text{Nuclear binding energy}}{\text{Total number of nucleons}}$

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

where $E_b = \Delta M c^2 = [Z m_p + (A-Z) m_n - M_n] c^2$

Plot of binding energy per nucleons (E_{bn}) versus mass number (A)

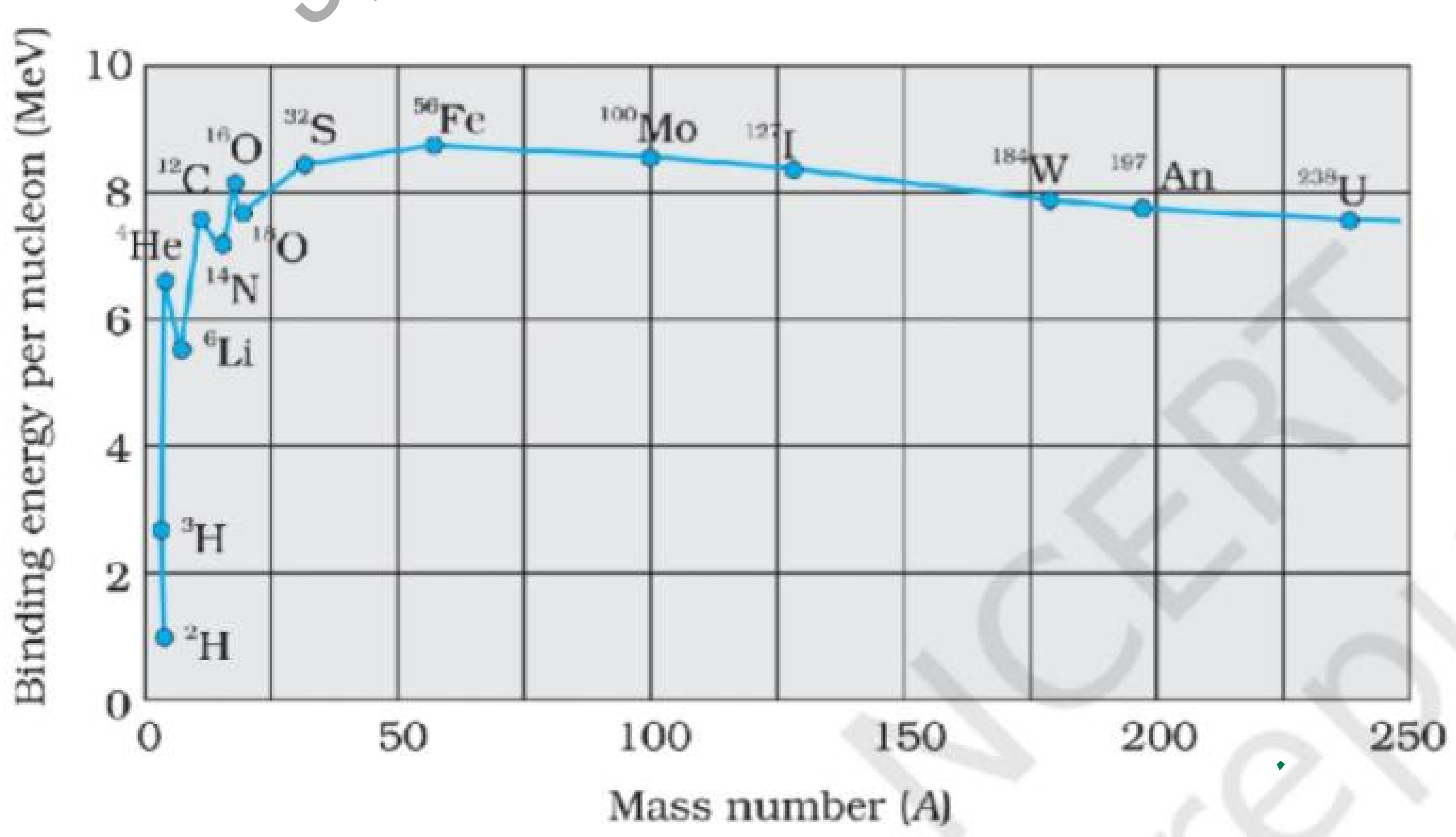


FIGURE 13.1 The binding energy per nucleon as a function of mass number.

* Binding energy curve shows how the energy needed to remove per nucleon (E_{bn}) varies with the atomic mass number.
* The curve is high in the middle (around Iron-56) and lower at both ends (lighter and heavier nuclei)
* Iron and Nickel (Fe & Ni) have the highest value of E_{bn}, making them the most stable elements.
* for lighter elements E_{bn} increases as nucleons are added. That's why fusion releases energy.
* for heavier elements E_{bn} decreases as the atomic mass number increases, making fission and energy releases.
* Fusion is efficient for lighter nuclei (like hydrogen isotopes) and fission is efficient for heavy nuclei (like uranium), both due to change in energy.
* Elements near the peak of the curve (like Fe) are most stable and elements far from peak are less stable and more likely to undergo nuclear reactions.
* for $A = 30$ to 170 E_{bn} is practically independent of mass no. A.
* E_{bn} is maximum for $A = 56$ (8.75 MeV)
* E_{bn} is lower for both $A < 30$ (light nuclei) and $A > 170$ (heavy nuclei)

Heavy nuclei are unstable due to strong repulsive forces between protons in the nucleus.

Nuclear Fission: In nuclear fission a heavy nucleus (like uranium) splits into two smaller nuclei when it absorbs a neutron.

Energy Release → Large amount of energy releases in this splittig of nucleus.

Example Splitting of Uranium - 235

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

Nuclear fusion: In nuclear fusion, two light nuclei (like hydrogen isotopes) combine to form heavier nucleus.

Energy Release Fusion releases even more energy than fission because the resulting nucleus is more stable.

Example In the sun two hydrogen nuclei ($_1H^2$ & $_1H^3$) fuse to form helium and releases a huge energy.
Fusion is also the principle of hydrogen bomb.

$$_1H^2 + _1H^3 \longrightarrow _2He^4 + _0n^1 + \text{Energy}$$

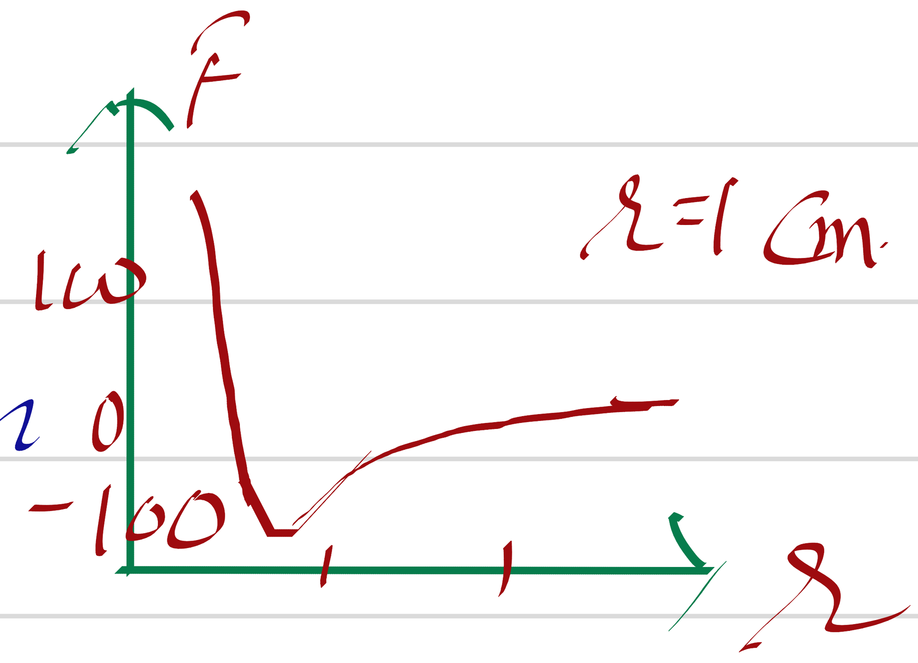
* Both reactions are the way moving towards stability by releasing nuclear energy.

Nuclear force: The force acting inside the nucleus or acting between nucleons is called nuclear force.

OR

It is the strong attractive force that binds protons and neutrons (nucleons) together in an atomic nucleus.

* It is the short range force, act only over distances of about 10^{-15} meters.
* It is attractive at typical nucleon distances but repulsive if nucleons get too close.
* It is charge independent, acts equally between proton-proton, neutron-neutron or proton-neutron.



* It is 10^{38} times of gravitational force and 100 times of electrostatic force.
* Nuclear forces are strongest forces in nature.

According to Yukawa the nuclear force act between nucleons due to contineous change of meson particles.

Radioactivity: The phenomenon of disintegation of heavy elements into lighter elements by the emission of radiation is called radio activity.
This is discovered by Becquerel in 1896.
The three types of radiations emitted by radioactive elements.

(I) α-decay in which a helium nucleus $_2^4He$ is emitted.
(II) β-decay in which electrons or positrons
(III) γ-ray in which high energy (hundreds of KeV or more) photons are emitted.

Each of these decay will be considered in subsequent sub-sections.

Controlled Thermonuclear Fusion

It is a process where light atomic nuclei such as isotopes of hydrogen (deuterium and tritium) are combined under extremely high temperature and pressure to form a heavier nucleus (like helium) releasing a large amount of energy.

* Unlike uncontrolled fusion, controlled fusion aims to harness this energy safely for human use

Examples of

Nuclear Fusion : (i) Sun and other star
(ii) Hydrogen Bomb
(iii) Future fusion reactors ITER

Nuclear Fission : (i) Atomic Bomb
(ii) Nuclear power plant
(iii) Nuclear submarines
(iv) Chernobyl and Fukushima

Nuclear Fission	Nuclear Fusion
When the nucleus of an atom splits into lighter nuclei through a nuclear reaction the process is termed nuclear fission.	Nuclear fusion is a reaction through which two or more light nuclei collide with each other to form a heavier nucleus.
When each atom split, a tremendous amount of energy is released	The energy released during nuclear fusion is several times greater than the energy released during nuclear fusion.
Fission reactions do not occur in nature naturally	Fusion reactions occur in stars and the sun
Little energy is needed to split an atom in a fission reaction	High energy is needed to bring fuse two or more atoms together in a fusion reaction
Atomic bomb works on the principle of nuclear fission	Hydrogen bomb works on the principle of a nuclear fusion bomb.