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Nuclei

Representation of an element :

$^{A}_{Z}X$ or $_{Z}X^{A}$

Where, X = element
Z = Atomic number
A = Atomic mass / Mass number

Atomic number = Number of Proton = Number of e^-
Atomic mass = Number of Proton + Number of Neutron

$\boxed{\text{No. of Nutron} = A - Z}$

* Some Important Terms to know :-

↳ Isotopes :-

The atoms of an element, which constitute the same atomic number but different mass numbers are termed isotopes.

Examples are :-

(i) $^{12}_{6}C$ $^{13}_{6}C$ $^{14}_{6}C$

(ii) $_{8}O^{16}$ $_{8}O^{17}$ $_{8}O^{18}$ (iii) $_{82}Pb^{206}$ $_{82}Pb^{207}$ $_{82}Pb^{208}$

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↳ Isotones :-

The atoms whose nuclei constitute the same number of neutrons are termed isotones.

eg:- $^{12}_{5}B$ and $^{13}_{6}C$

both have
$A-Z = 12-5 = 7$
$A-Z = 13-6 = 7$
neutrons.

Number of neutron = A-Z

↳ Isobars :-

The atoms which constitute the same mass numbers but different atomic numbers are termed isobars. Some examples are :

$_{1}H^{3}$ and $_{1}He^{3}$ $^{14}_{6}C$ and $^{14}_{7}N$

$_{2}Li^{7}$ and $_{4}Be^{7}$

↳ Nuclite :-

In this atomic number is equal to number of neutrons.

eg:- $^{12}_{6}C$ and $^{16}_{8}O$

Atomic number = Z = 6
Atomic mass = 12 = A
Number of neutron = 12 - 6 = 6

So, here Atomic number equal to number of neutron.

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Note :-

$$1 \text{ amu} = 1.660565 \times 10^{-27} kg = \frac{5}{3} \times 10^{-24} g$$

↳ Size of Nucleus :-

The size of an atomic nucleus is very small compared to the size of the whole atom. It is typically on the order of femtometres (1 femtometre = 10^{-15} metres).

It was found that volume of nucleus is directly proportional to the atomic mass.

So, $V \propto A$

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

$$R^3 \propto A$$

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

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

$$\boxed{R = R_0 A^{1/3}} \qquad R_0 = 1.1 \times 10^{-15} m$$

where R_0 is constant of proportionality called empirical constant.

↳ Nuclear Density :-

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

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

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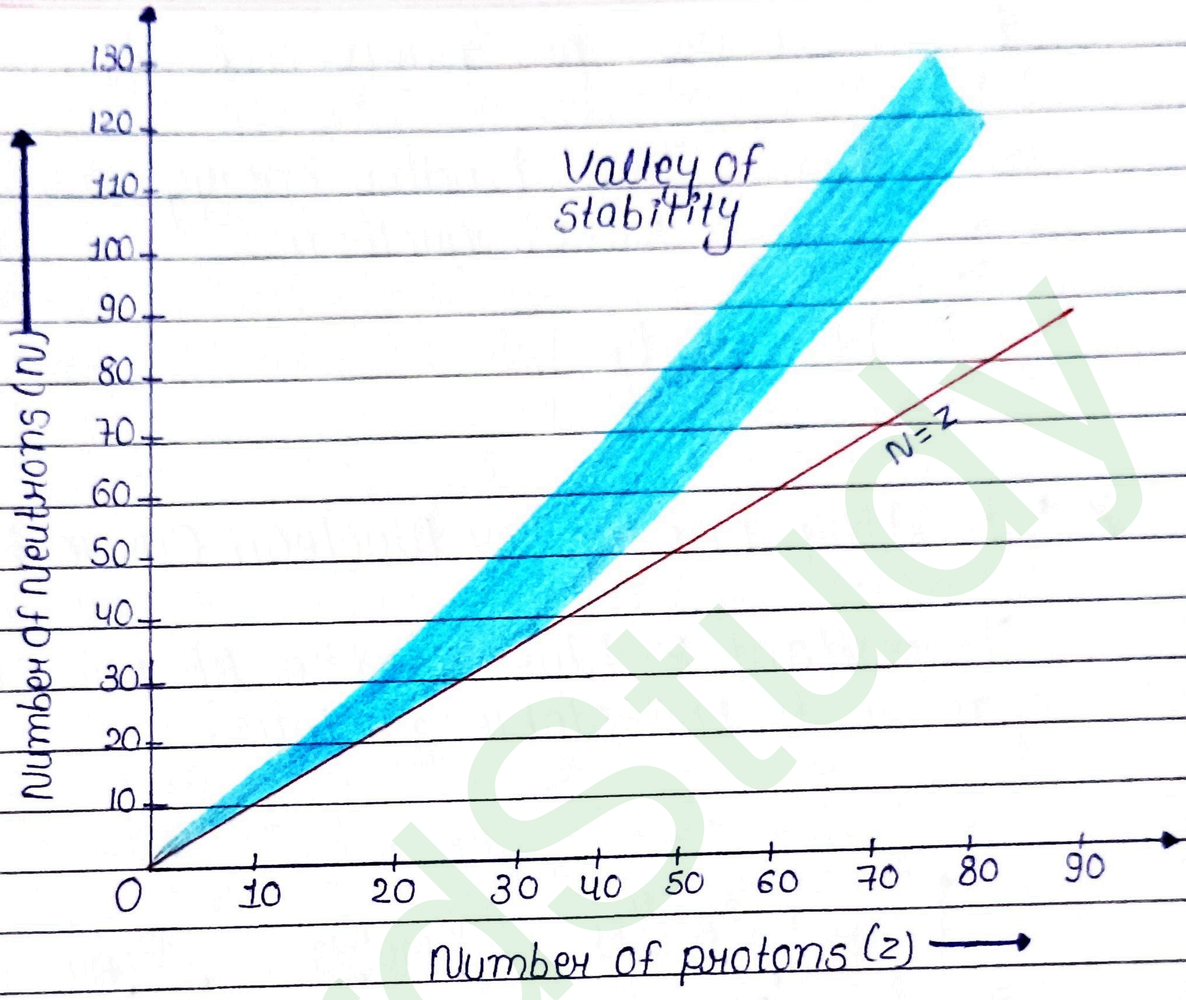
Where m is the average mass of a nucleon. Thus we get,

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

$\because$ Nuclear density is independent of atomic mass.

↳ Nuclear stability :-

- Stability of a nucleus depends on the ratio of protons to neutrons.
- For light nuclei ($Z < 20$), a roughly equal number of protons and neutrons ensures stability.
- For heavier nuclei, the optimal ratio of neutrons to protons increases.



Nuclear Binding Energy :-

Nuclear binding energy is the energy required to hold the nucleus of an atom together. It is the difference between the energy of the separate nucleons (protons and neutrons) and energy of the nucleus when these nucleons are combined.

when nucleons come together to form a nucleus, they lose some mass due to the binding energy. This energy is what keeps the nucleus stable.

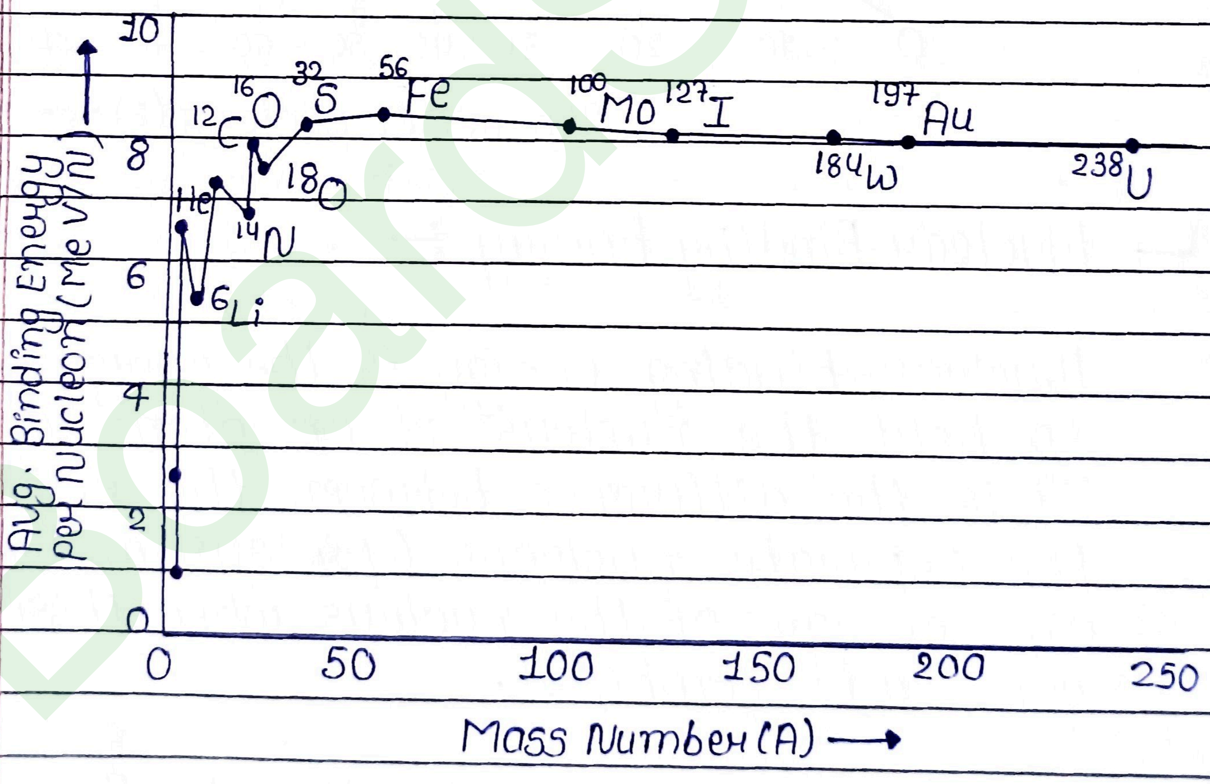
Binding energy per nucleon :- E_{bn}

$$E_{bn} = \frac{\text{Total binding energy}}{\text{No. of nucleon}}$$

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

Binding Energy Per Nucleon Curve :-

Important :- More is the BE per nucleon, more is the stable nucleus.



(1) **Initial Increase :-** Binding energy per nucleon increases sharply for light nuclei (low A), Indicating increasing stability with size.

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2) Peak Stability :-
It reaches a peak around $A \approx 56$ (Iron, Fe), Signifying that nuclei around this mass number are the most stable. The binding energy per nucleon is highest here (around 8.8 MeV/nucleon).

3) Gradual Decrease :-
For heavier nuclei ($A > 56$), the binding energy per nucleon gradually decreases, implying lower stability.

4) Implications :-
This curve explains why :

- Fusion of lighter nuclei (to the left of the peak) can release energy as they move towards higher binding energy per nucleon.
- Fission of heavier nuclei (to the right of the peak) can release energy as they split into fragments with higher binding energy per nucleon.

In essence, nuclei tend to undergo reactions that move them toward the region of maximum binding energy per nucleon, thus increasing their stability and releasing energy.

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↳ Expression of Binding Energy : E_b

Consider an element ${}_{Z}^{A}X$ and let M is the experimented mass of element.

m_p = mass of proton
m_n = mass of neutron
Actual mass $= Zm_p + (A-Z)m_n$

$$\boxed{\begin{array}{l}\text{Mass defect} = \text{Actual mass} - \text{experimented mass} \\ \Delta m = [Zm_p + (A-Z)m_n] - m\end{array}}$$

Now this mass is converted into binding energy.

$$B.E = \Delta mc^2$$
$$B.E = \{[Zm_p + (A-Z)m_n] - M\}c^2$$

In MeV, $B.E = \Delta mc^2 \times \frac{931}{c^2}$ MeV

$$\boxed{E_b = B.E = \Delta m \times 931 \text{ MeV}}$$

↳ Nuclear Forces :-

- Nuclear forces are responsible for binding protons and neutrons together within the nucleus.
- These forces are strong but short-range in nature.

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- They overcome the electrostatic repulsion between positively charged protons.
- They are charge independent.
- They are strongest force in nature.
- They do not obey inverse square law.

↳ Nuclear reactions :-
They are two type of Nuclear reactions —

(i) Nuclear Fission :-
A heavy nucleus splits into two or more lighter nuclei, releasing a large amount of energy. This process is used in nuclear reactors and atomic bombs.

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + \text{energy}$$

(ii) Nuclear Fusion :-
Two or more light nuclei combine to form a heavier nucleus, also releasing a significant amount of energy. This is the process that powers the sun and stars, and is the basis of hydrogen bombs.

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + \text{energy}$$

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In fusion the energy released is more as compared to fission reaction.

Type of Nuclear fission :-

There are two type of fission reaction :

(1) Uncontrolled fission reaction :-

In uncontrolled chain reaction, the number of neutron multiplies indefinitely and cause fission in large amount of fissile material. This result in release of large amount of heat (energy) within a fraction of second.

eg:- Atom boms follow an uncontrolled nuclear fission process when explode.

(2) Controlled Fission reaction :-

A controlled chain reaction, we can control the speed of reaction and there by control the rate of release of energy.

eg:- Nuclear powerplant use a controlled nuclear fission reaction to electrical energy.

* **Nuclear Reactor :-** It is a device which convert nuclear energy into electrical energy.

Principle :-

It is based on the principle of controlled fission reaction.

Uses of Nuclear Reactor :-

(1) Electricity Generation :-

Nuclear reactors produce heat through controlled fission. This heat converts water into steam, which drives turbines connected to generators, thus producing electricity in nuclear power plants.

(2) Research :-

Reactors serve as a source of neutrons for scientific research in various fields like physics, chemistry, and materials science. They help in producing radioactive isotopes for experiments.

(3) Production of Radioisotopes :-

Nuclear reactors are used to create radioisotopes that have applications in medicine (e.g., cancer treatment, medical imaging), agriculture, and industry.