

13. Nuclei

Nucleus

Entire mass & +ve charge of an Atom is concentrated into a very small volume called nucleus.

Nucleus contain most (more than 99.9%) of the mass of atom and is about 10^{12} times the volume of the atom.

NOTE :- Atomic mass unit

It is a mass unit used for expressing atomic masses.

This is defined as $1/12$ th of the actual mass of a carbon atom of isotope ^{12}C . It is denoted by amu or just by u.

1 amu = mass of one ^{12}C atom

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$$1 \text{ amu} = 1.992647 \times 10^{-26} \text{ kg}$$

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$$1 \text{ amu} = 1.660565 \times 10^{-27} \text{ kg}$$

The energy equivalent of 1 amu is 931 MeV

Nucleus is made up of neutrons & proton. Together they are called nucleons.

Proton: Charge = $+e = +1.6 \times 10^{-19} \text{ C}$

$$\text{Mass} = 1.6726 \times 10^{-27} \text{ kg} = 1 \text{ amu} = 1 \text{ u}$$

Symbol = ^1_1H

mass is 1840 times that of an electron.

Neutron:

Charge = 0 (neutral)

$$\text{Mass} = 1.6749 \times 10^{-27} \text{ kg} \approx 1 \text{ amu} \approx 1 \text{ u}$$

Symbol = ^1_0n

Atomic number (Z) No. of protons in nucleus
No. of e^- (in neutral atom)

Mass number (A)

$A = \text{No. of protons} + \text{no. of neutrons} = \text{no. of nucleons}$

Atomic mass $\rightarrow$ Nuclear mass = mass of protons + neutrons
i.e.

$\Rightarrow (\text{no. of protons} + \text{no. of neutrons}) \times 1 \text{ amu}$

$\Rightarrow A \times \text{amu}$

Symbol / representation

$Z = \text{no. of protons, atomic number}$

$A = \text{mass number}$

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

~~A
 Z~~

Ex - ${}^{16}_8\text{O} \rightarrow 8p, 8n$

NOTE:- Accurate measurement of atomic masses is carried out with a mass spectrometer.

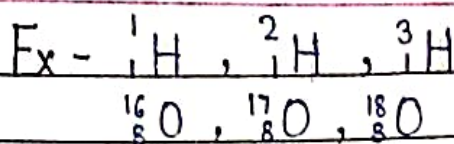
Classification of Nuclei :-

- ① Isotopes : Atoms of same element whose nuclei have same number of protons but different number of neutrons.

Characteristics - Z (atomic number) $\rightarrow$ same

A (Mass number) $\rightarrow$ Different

Similar chemical properties due to same electronic configuration & different physical properties as they have different masses.



Fractional atomic mass $\rightarrow$ Due to isotopes

$$\text{Average atomic mass} = A_1n_1 + A_2n_2 + A_3n_3 + \dots$$

$A_1 \rightarrow$ atomic mass of 1st isotope

$A_2 \rightarrow$ atomic mass of 2nd isotope

$n_1 \rightarrow$ fraction of 1st isotope

$n_2 \rightarrow$ fraction of 2nd isotope

Ex - Cl $\rightarrow$ atomic mass = 35.5 amu

In nature ${}^{35}_{17}\text{Cl}$ is 75% and ${}^{37}_{17}\text{Cl}$ is 25%

$$\text{Average atomic mass} = \frac{35 \times 75}{100} + \frac{37 \times 25}{100} = \frac{105 + 37}{4}$$

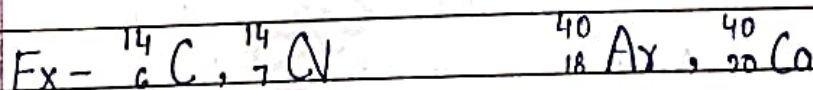
Isobars = 35.5 amu.

Atoms of different elements whose nuclei have same number of nucleons but different number of neutrons & protons.

Characteristics - Z (atomic number) $\rightarrow$ different

A (mass number) $\rightarrow$ same

Different chemical properties & same physical properties.

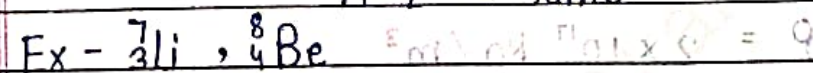


Isotones: Atoms of different elements whose nuclei have same number of neutrons but different no. of protons.

Characteristic: Z (atomic number) $\rightarrow$ different

A (mass number) $\rightarrow$ different

$A - Z \rightarrow$ same



Nucleus shape, size & Density

Shape - For all practical purpose shape of nucleus is regarded as "spherical" deviation $\leq 10\%$.

Size - Experimentally shown that

Volume of nucleus $\propto$ No. of nucleons in nucleus.

Volume of nucleus $\propto$ Mass number

$$V \propto A$$

$$\Rightarrow \frac{4}{3}\pi R^3 \propto A \Rightarrow R^3 \propto A \text{ (as } \frac{4}{3}\pi \text{ is constant)}$$

$$\Rightarrow R \propto (A)^{1/3}$$

$$\Rightarrow R = R_0 (A)^{1/3}$$

$R \rightarrow$ Radius of Nucleus

$A \rightarrow$ Mass number

$R_0 \rightarrow$ Constant for all nuclei $= 1.2 \times 10^{-15} \text{ m}$

$$\approx 1.2 \text{ fermi} = 1.2 \text{ fm}$$

$$\therefore R = 1.2 (A)^{1/3}$$

$\hookrightarrow$ In fermi

Density : Nuclear density

$$\rho = \frac{\text{mass of nucleus}}{\text{volume of nucleus}} = \frac{A \times \text{amu}}{V}$$

$$\rho = \frac{A \times 1.67 \times 10^{-27} \text{ kg}}{\frac{4}{3}\pi R^3} = \frac{A \times 1.67 \times 10^{-27} \text{ kg}}{\frac{4}{3}\pi [R_0 (A)^{1/3}]^3}$$

$$\rho = \frac{1.67 \times 10^{-27} \text{ kg}}{\frac{4}{3}\pi \times (1.2 \times 10^{-15} \text{ m})^3}$$

$$\rho = 2 \times 10^{17} \text{ kg/m}^3$$

Density of nuclear matter is 10^{14} times of density of water. $[\rho_{\text{water}} = 10^3 \text{ kg/m}^3]$

Mass - Energy equivalence

Einstein proved that it is necessary to treat mass as another form of energy. He gave the mass energy equivalence relation. i.e.

$$E = \Delta mc^2$$

where m is the mass and c is the speed of light in vacuum.

Mass defect: - The difference between the rest mass of a nucleus and the sum of rest masses of its constituent nucleons is called its mass defect. It is given by

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

Nuclear forces

- (1) These are the strong attractive forces which hold protons and neutrons together in a tiny nucleus.
- (2) These are short range forces which operate over very short distance of about 2-3 fm of separation between any two nucleons.
- (3) The nuclear force does not depend on the charge of nucleon.