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 $_6C^{12}$. It is denoted by amu or just by u.

$$1 \text{ amu} = \frac{\text{mass of one } ^{12}C \text{ atom}}{12}$$

$$1 \text{ amu} = \frac{1.992647 \times 10^{26} \text{ kg}}{12}$$

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

The energy equivalent of 1 amu is 931 MeV

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

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

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

Symbol $= {}^1_1H$

mass is 1840 times that of an electron.

Neutron :

Charge $= 0$ (neutral)

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

Symbol $= {}^1_0n$

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

Mass number (A)
A = No of protons + no of neutrons = no of nucleons

Atomic mass ⟶ Nuclear mass = mass of protons + neutrons
i.e
⇒ (no of protons + no of neutrons) x 1 amu
⇒ A x amu.

Symbol / representation $^{A}_{Z}X$
Z = no of protons, atomic number
A = mass number.
A − Z = No of neutrons

Ex − $^{16}_{8}O$ → 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) ⟶ same
A (Mass number) ⟶ Different

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

Ex - ${}^{1}_{1}H$, ${}^{2}_{1}H$, ${}^{3}_{1}H$ ${}^{35}_{17}Cl$, ${}^{37}_{17}Cl$

${}^{16}_{8}O$, ${}^{17}_{8}O$, ${}^{18}_{8}O$

Fractional atomic mass → Due to isotopes

Average atomic mass = $A_1 n_1 + A_2 n_2 + A_3 n_3 + \dots$

A_1 → atomic mass of 1st isotope

A_2 → atomic mass of 2nd isotope

n_1 → fraction of 1st isotope

n_2 → fraction of 2nd isotope

Ex - Cl → atomic mass = 35.5 amu

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

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

$= 35.5$ amu.

Isobars

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

Characteristics - Z (atomic number) ⟶ different

A (mass number) ⟶ same

Different chemical properties & same physical properties.

Ex - ${}^{14}_{6}C$, ${}^{14}_{7}N$ ${}^{40}_{18}Ar$, ${}^{40}_{20}Ca$

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

Characteristic : Z (atomic number) ⟶ different

A (mass number) ⟶ different

A−Z → same

Ex - ${}^{7}_{3}Li$, ${}^{8}_{4}Be$

Nucleus shape, size & Density

Shape – For all practical purpose shape of nucleus is regarde as "spherical" deviation $\lesssim 10\%$.

Size – Experimentally shown that
Volume of nucleus $\propto$ No of nucleons ~~of~~ nucleus.

Volume of nucleus $\propto$ Mass number

$$V \propto A$$

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

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

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

$R \rightarrow$ Radius of Nucleus
$A \rightarrow$ Mass number
$R_0 \rightarrow$ Constant for all nuclei $= 1.2 \times 10^{-15}\,m$
$\simeq 1.2$ fermi $= 1.2\,fm$

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

↳ In fermi

Density : Nuclear density

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

$$\rho = \frac{A \times 1amu}{\frac{4}{3}\pi R^3} = \frac{A \times 1amu}{\frac{4}{3}\pi [R_0 (A)^{1/3}]^3}$$

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

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

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

Mass - Energy equivalence

Einstine 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 vaccum.

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 overy very short distance of about 2-3 fm of seperation between any two nucleons.

(3) The nuclear forces does not depend on the charge of nucleon.