SHORT NOTES: CLASS 12
CHAPTER 13: NUCLEI

RELATIVE ATOMIC MASS:

- The 'Relative Atomic Mass' could be obtained by fixing mass of some atom of a particular element as standard mass. The masses of other atoms could be compared relative to it.
- The 'Relative Atomic Mass' is expressed in units known as 'Atomic Mass Unit' (a.m.u.) or simply represented as unified mass(u).
- **Relative Atomic Mass of an element** = $\frac{Mass\ of\ 1\ atom\ of\ the\ element}{\frac{1}{12}Mass\ of\ 1\ atom\ of\ C-12}$

ATOMIC MASS UNIT:

- One atomic mass unit or unified mass unit is defined as 1/12th of the mass of an atom of C-12 isotope.
- **1 amu = 1.66056 x 10^{-27} Kg = 1.66056 x 10^{-24} g**
- Mass of an atom of hydrogen = 1.6736 x 10^{-24} g

  ∴ Mass of Hydrogen (amu) =1.0078 amu ≈1.0080amu

1 ELECTRON VOLT:

- 1eV is the energy gained by an electron, when accelerated through a potential difference of 1 Volt.
- W.D. = charge x potential

  1 eV = 1.602 x 10^{-19} C x 1V ⇨ **1 eV = 1.602 x 10^{-19} J**

RELATION BETWEEN 1 a.m.u. AND MeV (It is used as a standard conversion.)

As, E = mc^2

Taking m = 1 a.m.u. = 1.66056 x 10^{-27} Kg, c = 3 x 10^8 m/s

E = (1.66056 x 10^{-27}) x (3 x 10^8)^2 = 1.49 x 10^{-10} J

⇨ E = (1.49 x 10^{-10}) / (1.6 x 10^{-13}) MeV ⇨ **E = 931.25 MeV ≈ 931 MeV**

NUCLEONS: protons and neutrons are collectively called nucleons these are fermions and obey the Pauli exclusion principle like electrons. No two protons or two neutrons can have the same quantum state but one proton and one neutron can exist in the same quantum state.

Protons

- ☐ Number of protons = At No.
- ☐ Unit positive charge
- ☐ Q = 1.6 x 10^{-19} C
- ☐ M = 1.6729 X 10^{-27} Kg = 1.007825 u
- ☐ L = ½(h/2π)
- ☐ Magnetic moment = 2.79 nuclear magneton.

Neutrons

- ☐ No charge
- ☐ M = 1.6743 X 10^{-27} Kg = 1.008665 u
- ☐ L = ½(h/2π)
- ☐ Magnetic moment = 2.79 nuclear magneton.
- ☐ Neutron has low ionising power.
- ☐ Inside the nucleus: neutron is stable.
- ☐ Outside the nucleus: Neutron is unstable having a mean life of 1000s.
- ☐ It decays into a proton, an electron and antineutrino.

Nuclear spin: The total angular momentum of the nucleus is the resultant of all the spin and orbital angular momentum of the individual nucleons. This total angular momentum of a nucleus is called nuclear spin of that nucleus.

Nuclear forces Nuclear forces are the strong forces of attraction which hold together the nucleus in the tiny nucleus of an atom in spite of strong electrostatic force of repulsion between protons.

Nuclear force is much stronger than gravitational and electromagnetic forces, if the separation between the interacting nucleons is of the order of 1fm.

Types of nuclear forces: strong nuclear force and weak nuclear force

Some of the important characteristics of these forces are

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a) Nuclear forces are independent of charge.
b) Nuclear forces are the strongest forces in nature.
c) Nuclear forces are very short range forces.
d) the variation of nuclear forces with the distance between nucleons is not known exactly however
   i) Nuclear forces are negligible when distance between nucleons is more than 10 fermi.
   ii) when nucleons are brought closer, nuclear force of attraction develops which goes on increasing rapidly with decreasing distance and however nuclear forces do not obey inverse square law
   iii) When distance between nucleons become less than 0.8 fermi nuclear forces become strongly repulsive
e) Nuclear forces are non-central forces.
f) Nuclear forces are dependent on spin or angular momentum of nucleons. Nuclear forces are due to exchange of π mesons between the nucleons. This is why they are called exchange forces

NUCLEAR SIZE

- ☐ Volume of a nucleus, V is proportional to its mass number, A.
- ☐ If R is the radius of the nucleus assumed to be spherical.
- ☐ $V = 4/3\, \pi R^3$
- ☐ $V \propto A$
- ☐ $4/3\, \pi R^3 \propto A$
- ☐ $R^3 \propto A$
- ☐ **$R = R_o A^{1/3}$**
- ☐ R_o is an empirical constant.
- ☐ $R_o = 1.2 \times 10^{-15}$ m.

NUCLEAR DENSITY

- ☐ Density of nuclear matter = $\frac{mass\ of\ nucleus}{Volume\ of\ nucleus}$
- ☐ m : average mass of a nucleon
- ☐ R : nuclear radius
- ☐ Mass of nucleus = mA
- ☐ Volume of nucleus = $V = 4/3\, \pi R^3 = 4/3\, \pi R_o{}^3 A$
- ☐ $\rho = \frac{mA}{4/3\, \pi\, Ro3A}$
- ☐ $\boldsymbol{\rho = \frac{3mA}{4\pi\, Ro3A} = \frac{3m}{4\pi\, Ro3}}$
- ☐ m and R_o are constants. Therefore, density ρ of nuclear matter is the same for all nuclei. **ISOTOPES ISOBARS ISOTONES**

MASS ENERGY RELATION

- ☐ When a certain mass m disappears, an equivalent amount of energy E appears and vice versa.
- ☐ m_o = Rest mass
- ☐ The rest mass energy of the particle = m_oc^2
- ☐ $E = mc^2 = m_oc^2 + T$ (Let T be the kinetic energy of the particle.)
- ☐ $T = mc^2 - m_oc^2$
- ☐ **$T = \Delta mc^2$**

NUCLEAR BINDING ENERGY:

Nuclear binding energy can be explained on the basis of Einstein's theory of mass energy equivalence.

Mass defect:

- Rest mass of a nucleus is always slightly less than the sum of the rest masses of free neutrons and protons composing the nucleus that is as if certain mass disappears in the formation of nucleus.
- The difference between the sum of the masses of neutrons and protons forming a nucleus and mass of the nucleus is called **mass defect**.

$$\boldsymbol{\Delta m = \{[Z\, m_p + (A-Z)\, m_n] - M_{nucleus}\}}$$

Z = Atomic Number, A = Mass Number,

m_p = Mass of proton, m_n = Mass of neutron, $M_{nucleus}$ = mass of nucleus.

BINDING ENERGY: The nucleons are bound together in a nucleus and energy must be supplied to the nucleus to separate the constituent nucleons to large distances. The

PHYSICS INDUCTION

amount of energy needed to do this is called the binding energy of the nucleus. If the nucleons are initially well separated and are brought to form the nucleus, this much energy is released.

Binding energy of a nucleus is the energy with which nucleons are bound in the nucleus. It is measured by the work required to be done to separate the nucleons an infinite distance apart from the nucleus so that they may not interact with each other. This work done is a measure of binding energy of the nucleus.

$$\textbf{B.E.} = \Delta mc^2$$

Note: B.E. = mass defect x 931.5 MeV, if mass is expressed in a.m.u.

Average binding energy per nucleon: It is the average energy we have to spend to remove a nucleon from the nucleus to infinite distance. It is given by total binding energy divided by the mass number of the nucleus.

$$\textbf{B.E. per nucleon = Binding Fraction} = \frac{Binding\ Energy}{Mass\ Number} = \frac{\Delta m \times 931\ MeV}{A}$$

The stability of a nucleus:

a) The stability of a nucleus is determined by the value of its binding energy per nucleon. Higher the binding energy per nucleon, more stable is the nucleus.

b) The stability of a nucleus is also determined by its neutron to proton ratio. Heavy nuclei are stable only when they have more neutrons than protons.

Note: An unstable nucleus emits some kind of particle and changes its constitution. A stable nucleus maintains its constitution all the time. For light stable nuclides, the neutron number is equal to the proton number so the ratio N/Z is equal to 1. The ratio N/Z increases for the heavier nuclides and becomes about 1.6 for heaviest stable nuclides.

Packing fraction: Packing fraction of a nucleus is defined as the mass excess per nucleon. Mass excess is the difference between the mass of a nucleus and mass number of the nucleus. Packing fraction measures the stability of a nucleus. Smaller the packing fraction, larger is the stability of the nucleus.

$$\textbf{Packing Fraction} = \frac{\Delta m}{A} = \frac{M-A}{A}$$

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