CHAPTER

13 Nuclear Physics

Nucleus

The atomic nucleus is the small, dense region consisting of protons and neutrons at the center of an atom.

Atomic Number (Z): Number of protons in a nucleus.

Mass Number (A): Number of protons + neutrons.

Propteries of Nucleus:

- Radius of nucleus, $R = R_0A^{1/3}$ (Where $R_0 = 1.2 \times 10^{-15}$m)
- Volume of Nucleus, $V = \dfrac{4\pi R_0^3 A}{3}$
- Density of Nucleus, $d = \dfrac{m}{v} = \dfrac{3m}{4\pi R_0^3} = 2.3 \times 10^7$ Kg/m^3

Mass Energy Equivalence Relation

According to Einstein; $[E = mc^2]$

1 amu = 1.66×10^{-27} kg = 931.5 MeV

(where E is total energy of mass m, c is speed of light)

Mass Defect: It is difference between total mass of nucleons and nucleus.

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

Binding Energy: The Energy required to bring the nucleons from infinity to form the nucleus.

- Binding Energy = $(\Delta m) \times 931.5$ MeV
- Packing fraction = $\dfrac{\text{Mass excess}}{\text{Mass number}}$

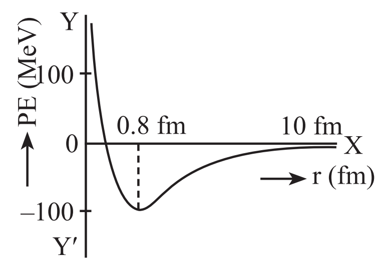
Nuclear Force

- Strongest force in nature.
- Short range force.
- Charge independent.
- Depends on spin or angular moment of nuclei.
- Non-central force.

Plot of Potential Energy Vs Distance

Important Features:

- Attraction is maximum at $r_0 = 0.8$ fm.
- For $r < r_0$, Force is repulsive.
- For $r > r_0$, Force is attractive.



Radioactivity

- **Radioactive Decays :** Generally, there are three types of radioactive decays
  - (i) α decay
  - (ii) β^- and β^+ decay
  - (iii) γ decay
- **α decay :** By emitting α particle, the nucleus decreases it's mass number and move towards stability. Nucleus having A > 210 shows α decay.
- **β decay :** In beta decay, either a proton is converted into neutron and position (β^+) or neutron is converted into proton and electron (β^-).
- **γ decay :** When an α or β decay takes place, the daughter nucleus is usually in higher energy state, such a nucleus comes to ground state by emitting a photon or photons called as γ-rays.
- Order of energy of γ photon is 100 keV.

Laws of Radioactive Decay

- The rate of disintegration is directly proportional to the number of radioactive atoms present at that time i.e., rate of decay $\propto$ number of nuclei.

  Rate of decay = λ (number of active nuclei) i.e., $\dfrac{dN}{dt} = -\lambda N$.

  where λ is called the decay constant.

  $N = N_0e^{-\lambda t}$ where λ = decay constant

  - Half life $t_{1/2} = \dfrac{ln 2}{\lambda}$

- Average life $t_{av} = \frac{1}{\lambda}$
- Activity $R = \lambda N = R_0 e^{-\lambda t}$
- Units of activity 1Bq = 1 decay/s,
  1 curie = 3.7×10^{10} Bq,
  1 rutherford = 10^6Bq
- After n half lives Number of nuclei left = $\frac{N_0}{2^n}$
- Probability of a nucleus for survival of time t = $\frac{N}{N_0} = \frac{N_0 e^{-\lambda t}}{N_0} = e^{-\lambda t}$

Nuclear Fission

By bombarding a particle on a heavy nucleus (A > 230), it splits into two or more light nuclei. In this process certain mass disappears which is obtained in the form of energy (enormous amount)

$$A + p \rightarrow B + C + Q$$

Nuclear Fusion

It is the phenomenon of fusing two or more light nuclei to form a single heavy nucleus.

$$A + B \rightarrow C + \text{Energy}$$

The product (C) is more stable then reactants (A and B) and $m_c < (m_a + m_b)$ and mass defect $\Delta m = [(m_a + m_b) - m_c]$ amu

Energy released is $E = (\Delta m)\ 931$ MeV