

## CLASS 12 PHYSICS CHAPTER 13 Nuclei

### INTRODUCTION

Atomic nucleus is the center of atom and has the entire positive charge and almost entire mass. Its radius is  $10^{-15}$  m to  $10^{-14}$  m. A nucleus contains neutrons and protons. Neutrons are neutral particles and protons have positive charge. Both are called nucleons.

**Atomic number** – No. of protons inside the nucleus. (Given by Z)

**Mass number** - No. of protons and neutrons. (Given by A)

**No. of neutrons** =  $A - Z$

**Size of a nucleus** - Volume of a nucleus is proportional to its mass number.

So  $\frac{4}{3}\pi R^3 \propto A$  or  $R \propto A^{1/3}$  or  $R = R_0 A^{1/3}$  where  $R_0 = 1.1 \times 10^{-15}$  m.

**Nuclear Density** – Volume of nucleus =  $\frac{4}{3}\pi R^3 = \frac{4}{3}\pi R_0^3 A$

So Density = Mass/Volume =  $\frac{mA}{\frac{4}{3}\pi R_0^3 A} = \frac{3m}{4\pi R_0^3}$

Mass of nucleus = m (average mass of nucleus) x Mass number (A)

Hence **density is independent of A and is constant for all atoms**. Putting values density is found to be  $10^{17} \text{ kg/m}^3$

**Atomic masses** - 1 atomic mass unit is defined as  $1/12^{\text{th}}$  of the mass of an atom of  ${}^{12}_6\text{C}$  isotope or  $1 \text{ amu} = \frac{1}{12} \times \frac{12 \text{ g}}{6.023 \times 10^{23} \text{ atoms}}$

or  **$1 \text{ amu} = 1.66 \times 10^{-27} \text{ kg}$**

Relating amu and eV:::  $1\text{eV} = 1.6 \times 10^{-19}\text{J}$

Since  $E = mc^2 = (1.66 \times 10^{-19})(3 \times 10^8)^2 = 1.49 \times 10^{-10}\text{J}$ .

Or  $E = 1.49 \times 10^{-10} / 1.6 \times 10^{-19} \text{ eV} = 931.25 \times 10^6 \text{ eV} \cong 931\text{MeV}$ .

Or **1amu = 931 MeV**

**Isotopes** – Atoms of an element having same value of atomic number but different atomic weight eg.  ${}_6\text{C}^{10}$ ,  ${}_6\text{C}^{11}$ ,  ${}_6\text{C}^{12}$  etc. Isotopes have same number of electrons and protons but different number of neutrons; have same chemical but different physical properties.

**Isobars** – Atoms of different elements having same atomic weight but different atomic number. These have different number of electrons, protons and neutrons eg.  ${}_{20}\text{Ca}^{40}$ ,  ${}_{18}\text{Ar}^{40}$

**Isotones** – Nuclides having same number of neutrons eg.  ${}_{17}\text{Cl}^{35}$  and,  ${}_{19}\text{Kr}^{39}$

### **P.E of a pair of nucleons as a function of their separation**

For a separation greater than  $r_0$ , the force is attractive and for separations less than  $r_0$ , the force is strongly repulsive.

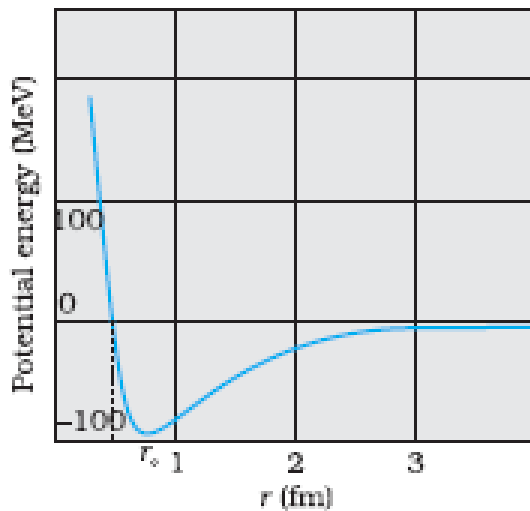


DIAGRAM COURTESY NCERT

### **CHARACTERISTICS OF NUCLEAR FORCES**

- 1 Strongest known forces which exist in the nucleus to overcome electrostatic repulsion between electrons.

- 2 These are charge independent and hence exist between neutron- neutron, neutron-proton and proton- proton.
- 3 Short range forces which exist between immediate neighbors only ,can only operate up to 10 fermi. If distance between nucleons is greater than 10 fermi, nuclear forces are very less and if distance between nucleons is less than 0.5 fermi ,nuclear forces become repulsive.
- 4 Nuclear forces are non central and do not follow inverse square law.

**NUCLEAR BINDING ENERGY** It is the work done to separate each nucleon an infinite distance apart from the nucleus.

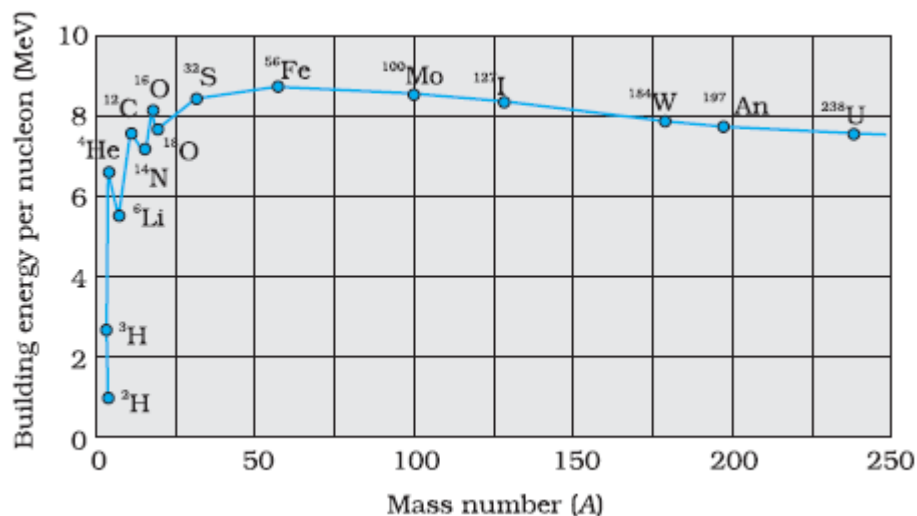
Since rest mass of nucleus is always slightly less than sum of rest masses of constituent neutrons and protons. This difference is called **MASS DEFECT**.

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

Z= Number of protons, A-Z=Number of neutrons,  $m_p$ = mass of proton,  $m_n$ =mass of nucleon,  $M_N$  =mass of nucleus.

As  $E = mc^2$  or Binding Energy=  $(Zm_p + (A-Z) m_n - M_N) c^2$

**Average B.E per nucleon** represents average energy required to pull a nucleon from nucleus to infinite distance away. It is total binding energy divided by number of nucleons. The curve of B.E/nucleon versus mass number A is given by



(i) the binding energy per nucleon, B.E is practically constant of the atomic number for nuclei of middle mass number ( $30 < A < 170$ ). The curve has a maximum of about 8.75 MeV for  $A = 56$  and has a value of 7.6 MeV for  $A = 238$ .

(ii) BE is lower for both light nuclei ( $A < 30$ ) and heavy nuclei ( $A > 170$ )

(iii) For  $A = 2$  to  $20$  there are certain peaks indicating He.C.O etc are relatively stable than neighboring nuclei.

(iv) For  $A = 30$  to  $120$  average value is 8.5 MeV.

(v) For high  $A$  B.E/nucleon decreases and falls to 7.6 MeV per nucleon for Uranium indicating lesser stability.

### **Significance of curve wrt explanation of Nuclear fission and fusion**

A very heavy nucleus, say  $A = 240$ , has lower binding energy per nucleon compared to that of a nucleus with  $A = 120$ . Thus if a nucleus  $A = 240$  breaks into two  $A = 120$  nuclei, nucleons get more tightly bound. This implies energy would be released in the process.

It has very important implications for energy production through fission, also consider two very light nuclei ( $A = 10$ ) joining to form a heavier nucleus. The binding energy per nucleon of the fused heavier nuclei is more than the binding energy per nucleon of the lighter nuclei. This means that the final system is more tightly

bound than the initial system. Again energy would be released in such a process of fusion. This is the energy source of sun.

E.g. Calculate B.E per nucleon of,  ${}_{83}\text{Bi}^{209}$  Given mass of,  ${}_{83}\text{Bi}^{209} = 208.980388$  amu, mass of neutron = 1.008665 amu, mass of proton = 1.007825 amu. Take 1 amu = 931 MeV.

So B.E =  $[ 83 \times 1.007825 + (209 - 83) 1.008665 - 208.980388 ] \times 931 \text{ MeV}$

$$= [ 83.649475 + 127.09179 - 208.980388 ] \times 931 \text{ MeV}$$

$$\text{B.E/nucleon} = 1.760877/209 \times 931 \text{ MeV} = 7.84 \text{ MeV}$$

**RADIOACTIVITY** – Disintegration (Spontaneous) of a heavy element eg  $\alpha$ ,  $\beta$ ,  $\gamma$  Rays –

Important properties

$\alpha$  **rays** –

1. Carries charge equal to helium nucleus (+2e).
2. Mass is 4 times that of hydrogen atom.
3. Velocity  $\sim 10^7 \text{ m/s}$ .
4. Small penetrating power.
5. Large ionizing power.
6. Causes fluorescence.
7. Affect photographic plate.
8. Are deflected by electric and magnetic fields.
9. Cause heating effect.

**$\beta$  rays**

1. Carry unit negative electronic charge (-1e).
2. Mass is  $9.1 \times 10^{-31} \text{ Kg}$ .
3. Speed is 33% to 99% of 'C'.
4. High penetrating power.
5. Small ionizing power.
6. Can produce fluorescence.

7. Can affect photographic plate.
8. Are deflected by electrical and magnetic fields.

### **$\gamma$ rays**

1. Travel with speed of light.
2. Are not affected by electric /magnetic fields.
3. Cause florescence.
4. Highest penetration.
5. Small ionizing power.
6. Affect photographic plates.
7. Are em waves.

### **Laws of radioactive decay :**

1. Radioactivity is a spontaneous phenomenon.
2. During disintegration a  $\alpha$ particle or  $\beta$ particle is emitted.
3. If  $\alpha$ particle is emitted then the new atom is,  ${}_{Z-2}X^{A-4}$
4. If  $\beta$  particle is emitted ,new atom is  ${}_{Z+1}X^A$  .
5. Number of atoms disintegrated per second is proportional to no. of atoms present.

### **Radioactive decay law**

i.e  $-dN/dt \propto N$  or  
 $dN/dt = -\lambda N$  where  $\lambda$  is a decay constant.  
 Or  $dN/N = -\lambda dt$

$$\log_e N = -\lambda t + C$$

At  $t = 0$   $N = N_0$   
 therefore  $C = \log_e N_0$   
 or  $\log_e N = -\lambda t + \log_e N_0$   
 Or  $\log_e N/ N_0 = -\lambda t$

$$\text{or } N = N_0 e^{-\lambda t}$$

## Half-life of radioactive sample

is time in which half of initially present atoms decay.

i.e when  $t = T$ ,  $N = N_0 / 2$  or  $N_0 / 2 = N_0 \exp(-\lambda T)$

$$\frac{1}{2} = \exp(-\lambda T)$$

$$\text{or } 2 = \exp(\lambda T)$$

$$\text{or } \lambda T = \log_e 2 = 2.3026 \log_e 2$$

or

$$T = 2.3026 \times .301/\lambda = .6931/\lambda$$

Radioactivity is measured in terms of 1. 1 Curie =  $3.7 \times 10^{10}$  disinteg/sec.

2. 1 Rutherford =  $10^6$  disintegration/sec.

Nuclear reactions – 1.fusion 2.fission

**Nuclear fission:** - Spitting of heavy nucleus ( $>230$ ) into 2 or more lighter nuclei.

**Nuclear fusion** Fusing two or more light nuclei to form a single heavy nucleus