

**VOLUME-21 Part B and C****CONTENTS****X. Nuclear and Particle Physics**

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## **X. Nuclear and Particle Physics**

### **X.1. Basic nuclear properties: size, shape, charge distribution, spin and parity:**

Nucleus contains number of protons and number of neutrons. The total number of particles in nucleus is called as nucleons.

Number of protons  $\rightarrow$  atomic number  $\rightarrow Z$

Number of neutrons  $\rightarrow N$

Number of nucleons  $\rightarrow$  mass number  $\rightarrow A$

$$\therefore A = N + Z$$

Two nuclei with identical number of protons  $Z$  and identical number of neutrons  $N$  belong to the same nuclear species.

A nuclear species is called as nuclide. It is denoted by  ${}_Z X^A$  where,  $X \rightarrow$  chemical element.

E.g.  ${}_6 C^{12}$ ,  ${}_{11} N^{23}$ ,  ${}_{92} U^{238}$

Nuclides are classified into three groups.

**(I) Isotopes:** It has same number of protons but different number of neutrons. i.e. same atomic number ( $Z$ ) but different neutron number ( $N$ ) (i.e. different mass number ( $A$ )).

E.g.  ${}_{11} Na^{22}$  and  ${}_{11} Na^{23}$

i.e.  $Z = 11$  but  $N = 22$  and  $N = 23$ .

**(II) Isotones:** It has same neutron number ( $N$ ) but different atomic number ( $Z$ ) or number of protons and hence a different mass number ( $A$ ).

E.g.  ${}_6 C^{14}$ ,  ${}_7 N^{15}$

i.e.  $N = 8$  but  $Z = 6$  for carbon and  $Z = 7$  nitrogen.

**(III) Isobars:** It has same total number of nucleons ( $A$ ) but different atomic number ( $Z$ ) and neutron number ( $N$ ).

E.g.  ${}_6 C^{14}$ , and  ${}_7 N^{14}$  are isobars i.e.  $A = 14$ .

#### **The Atomic Mass Unit (a.m.u):**

The mass of a nucleus is given in terms of a unit called as atomic mass unit (a.m.u).

$$\therefore 1 \text{ a.m.u} = \frac{1}{12} \times \text{mass of one } C^{12} \text{ atom}$$

$$\therefore \text{Mass of one } C^{12} \text{ atom in kg} = \frac{12 \times 10^{-3}}{N_A}$$

where  $N_A$  = Avogadro's number =  $6.023 \times 10^{23}$ /mole

$$\therefore 1 \text{ a.m.u} = \frac{1}{12} \times \frac{12 \times 10^{-3}}{6.023 \times 10^{23}} = 1.66 \times 10^{-27} \text{ kg.}$$

Atomic mass of carbon is not 12.00000 a.m.u. but 12.0115 a.m.u. due to the presence of different carbon isotopes in nature. According to Einstein's relation,

$$E = mc^2$$

$$E = 1 \text{ amu} \times C^2$$

$$= 1.66 \times 10^{-27} \times 9 \times 10^{16} \dots (\because C = 3 \times 10^8 \text{ m/s})$$

$$= 1.494 \times 10^{-10} \text{ joules}$$

$$\therefore E = 931.478 \text{ Mev}$$

$$\therefore 1 \text{ amu} = 931.5 \text{ Mev}$$

Particle	Rest mass in (kg)	Rest mass in (a.m.u)	Rest Energy (ev)
Electron (Me)	$9.10953 \times 10^{-31}$	$5.48580 \times 10^{-4}$	$5.11003 \times 10^5$
Proton (Mp)	$1.67265 \times 10^{-27}$	1.0072765	$9.38280 \times 10^8$
Neutron (Mn)	$1.67495 \times 10^{-27}$	1.0086650	$9.39573 \times 10^8$

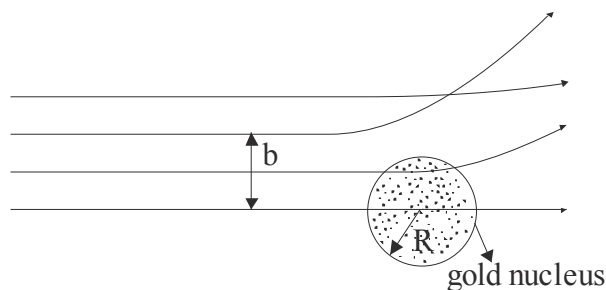
## Properties of the Nucleus

### 1. Size:

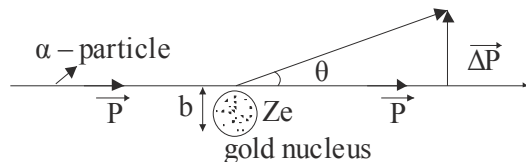
Nucleus is assumed to be in spherical shape so that its size can be estimated by Rutherford's  $\alpha$ -scattering experiment.

Let 'R' be the radius of the gold nucleus.

Let 'b' be the impact parameter (An  $\alpha$ -particle trajectory can be specified by its impact parameter)



For  $b > R$ , the deflection of  $\alpha$ -particle is less due to the less coulomb repulsion. When  $b < R$ , the  $\alpha$ -particle goes through the nuclear positive charge distribution. So that nuclear charge above trajectory and one below the trajectory work in opposite direction and the deflection produced in  $\alpha$ -particle just grazes the nucleus and consider as positive charged sphere, i.e. the coulomb repulsion is maximum. As the  $\alpha$ -particle approaches the gold nucleus, it is slowed down by the coulomb repulsion and is speeded up on its own way out-away from the nucleus.



The coulomb repulsion is given by,

$$F = \frac{1}{4\pi\epsilon_0} \frac{(2e)(Ze)}{b^2}$$

where,  $2e$  = charge of  $\alpha$ -particle for gold  $Z = 79$ .

The force operates during time,

$$\Delta t = \frac{b}{v}$$

where,  $v$  = velocity of particle.

This force produces a momentum  $\Delta P$  in a direction perpendicular to the incident direction.

$\therefore$  By Newton's law,

$$F = \frac{\Delta P}{\Delta t}$$

$$\therefore \Delta P = F \cdot \Delta t$$

$$\therefore \Delta P = \frac{1}{4\pi\epsilon_0} \frac{2Ze^2}{b^2} \cdot \frac{b}{v}$$

$$\therefore \Delta P = \frac{1}{4\pi\epsilon_0} \frac{2Ze^2}{bv}$$

From diagram,

$$\theta = \frac{\Delta P}{P}$$

$$\therefore \theta = \frac{1}{4\pi\epsilon_0} \cdot \frac{2Ze^2}{bv} \cdot \frac{1}{P}$$

$$\therefore \theta = \frac{1}{4\pi\epsilon_0} \cdot \frac{2Ze^2}{bmv^2}$$

where,  $m$  = mass of  $\alpha$  – particle

$$\therefore b = \frac{1}{4\pi\epsilon_0} \cdot \frac{2Ze^2}{mv^2} \cdot \frac{1}{\theta}$$

Which is the relation between deflection and impact parameter. Occasionally, there were deflection close to radians.

Substituting  $\theta = 1$  and  $b = R$ .

$$\therefore R = \frac{1}{4\pi\epsilon_0} \cdot \frac{2Ze^2}{mv^2}$$

Putting values,

$Z = 79$  for gold

$M = 6 \times 10^{-27}$  kg for  $\alpha$  – particle

$v \approx 10^7$  m/s for  $\alpha$  – particle,  $e \approx 1.6 \times 10^{-19}$  C

$$R = 10^{-14} \text{ m}$$

The density of the charge (protons) in the nucleus is distributed according to the formula,

$$\rho = \frac{\rho_o}{1 + e^{(r-R)/b}}$$

where  $\rho_o$  is the density at the nuclear centre.

R is the radius at which  $\rho$  falls to  $\frac{\rho_o}{2}$

$b$  is a measure of the surface thickness

*Continued with...Page 5 Onwards.... It's So Gooooood!!!, Buy it now...!*