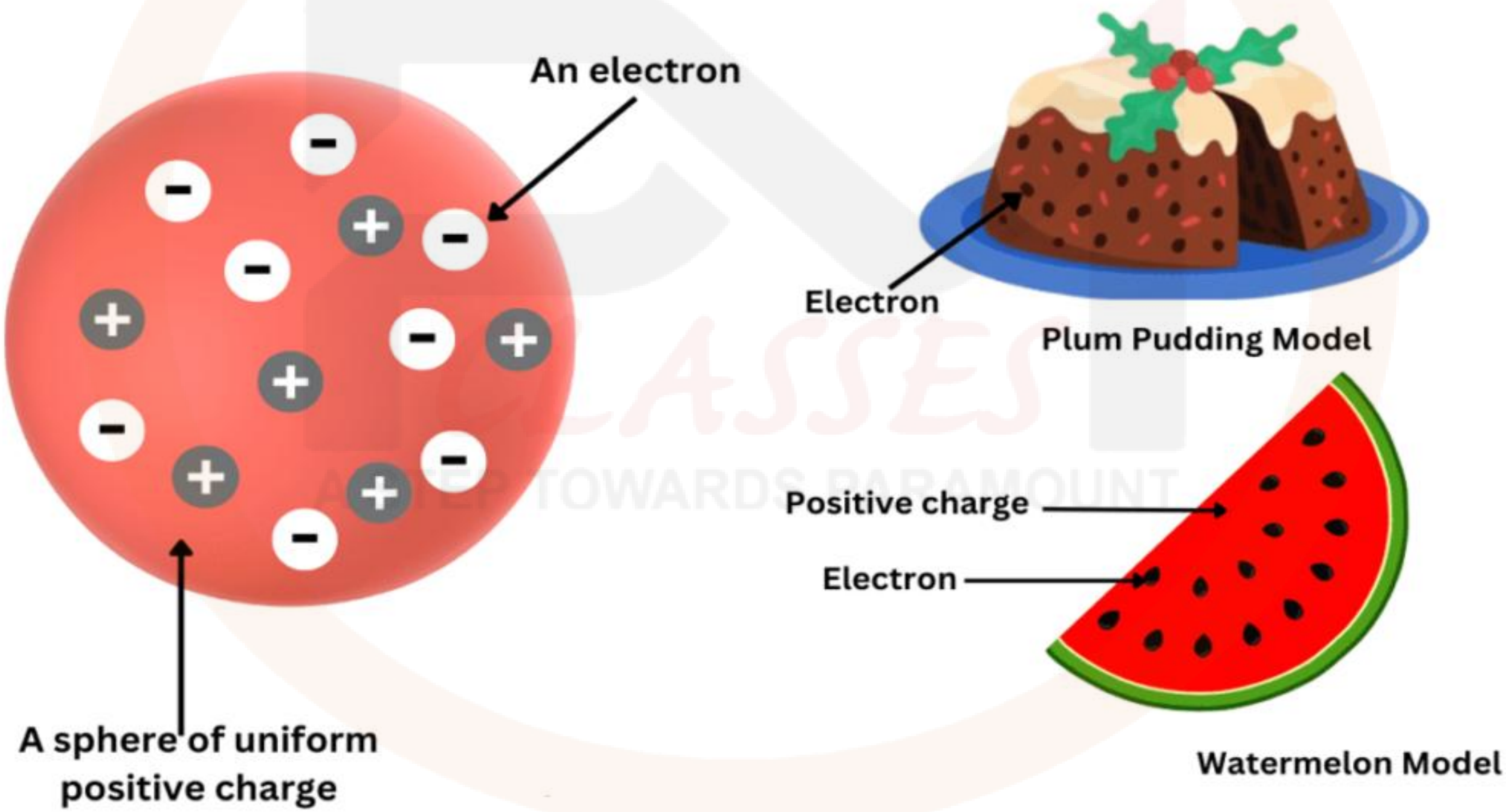
MODERN PHYSICS

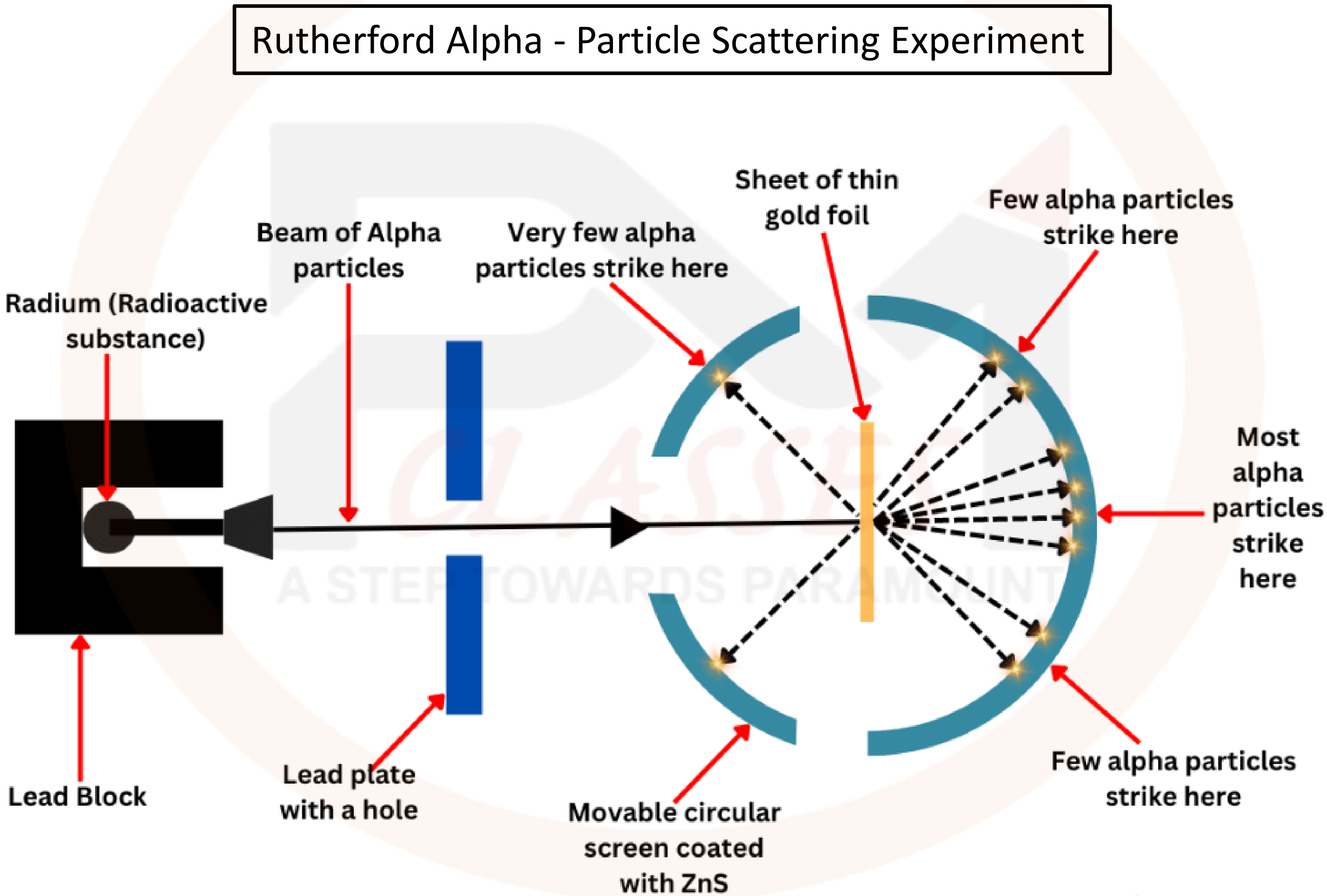
(MATTER + ATOMS + NUCLEI)

ATOM - atom is the smallest particle Which can take part in all physical and chemical reactions.

Thomson Model (Plum Pudding) of Atom



According to this model an atom consist of Nucleus in which there are protons and neutron and electron are embedded inside the nucleus like seeds in watermelon. But this theory was theory was wrong because electrons are not embedded inside nucleus.



Following are the observations made through this experiment:

1) Most of a-particles were seen to pass through the fold foil without any appreciable deflection.

2) The various a particles, on passing through the gold foil, undergo different amounts of deflections. A large number of a particles caused fairly large deflections.

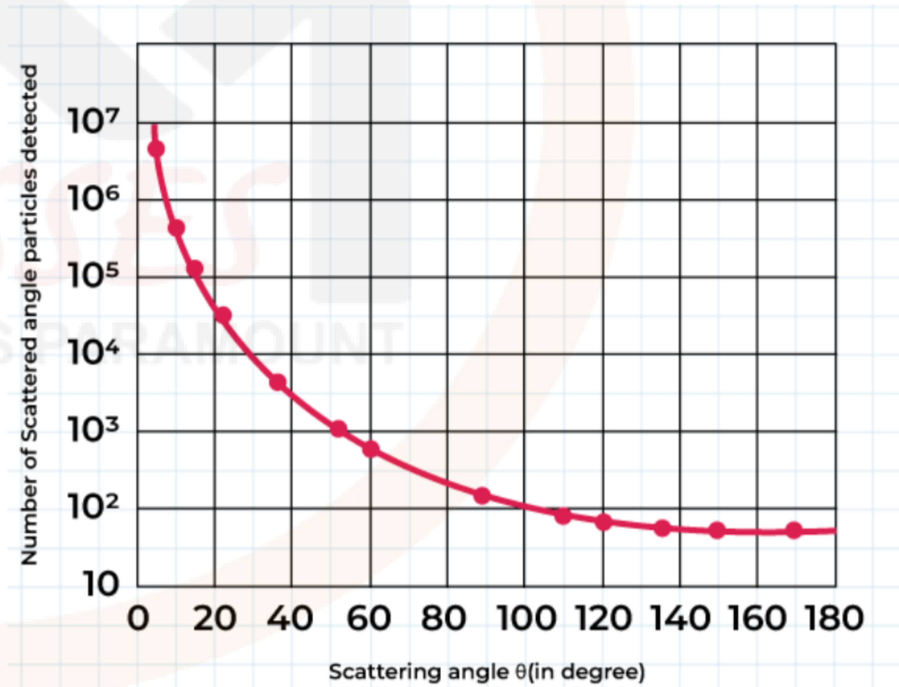
3) A very small number of a-particles (about 1 in 8000) practically retracted their paths or Suffered deflection of nearly 180°.

CONCLUSIONS

- There is some empty space in between the gold foil.

- There is some change present on nucleus.

- There is a dense nucleus present of the centre because the &- particle which retraces its path moving along the central line.



Rutherford's Atom Model

On the basis of the results of a scattering experiment, Rutherford suggested the Following picture of an atom:

1. Atoms can be regarded as spheres of diameters 10^{10}m but whole of the positive charge and almost the entire mass of these atoms are concentrated in small central area called nuclei having diameters of about 10^{4} m.
2. The nucleus is neighbored by electrons. In other wards, the electrons are distributed over the remaining part of the atom le Leaving plenty of empty space in the atom.

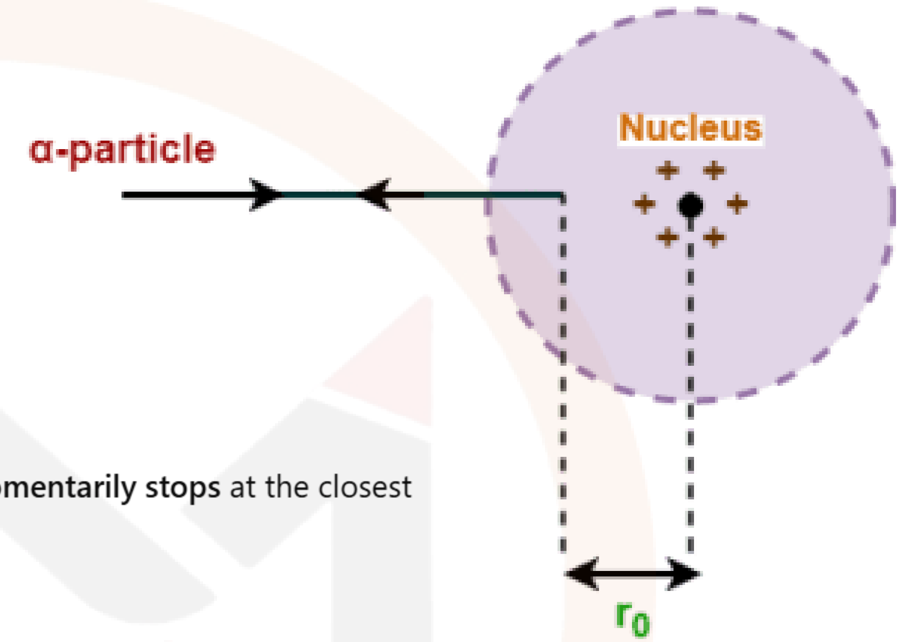
Drawbacks of Rutherford's Atom Model

1. When the electrons revolve around the nucleus they get continuously accelerated towards the centre of the nucleus. According to Lorentz. an accelerated changed particle must radiate energy continuously. Thus, in the atom, a revolving electron must continuously emit energy and hence the radius of its path must go on decreasing and finally, it must fall into the nucleus However, electrons revolve around the nucleus without falling into it. Clearly, Rutherford's atom model couldn't explain the stability of the atom.

2. Suppose if Rutherford's atom model is true, the electron could revolve in orbits of all possible radii and thus it should emit a continuous energy spectrum. But, atoms like hydrogen possess a line. Spectrum

Distance of closest approach

Note- Alpha particle retraces its path when kinetic energy of a particle get converted into electric potential energy.



When an **alpha particle** approaches a nucleus:

- It is **positively charged** $(+2e)$
- The nucleus is also **positively charged** $(+Ze)$

Due to **electrostatic repulsion**, the particle slows down and finally **momentarily stops** at the closest point.

At that point:

- **Kinetic Energy (KE) = 0**
- Entire initial KE is converted into **Electrostatic Potential Energy (PE)**

$$\text{Initial Kinetic Energy} = \text{Electrostatic Potential Energy at } r_0$$

Using formulas:

$$\frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{(2e)(Ze)}{r_0}$$

$$(2e)(Ze) = 2Ze^2$$

So the equation becomes:

$$\frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2Ze^2}{r_0}$$

Rearranging:

$$r_0 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2Ze^2}{\frac{1}{2}mv^2}$$

Let kinetic energy $K = \frac{1}{2}mv^2$

Then:

$r_0 = \frac{2Ze^2}{4\pi\varepsilon_0 K} = \frac{Ze^2}{2\pi\varepsilon_0 K}$

$$r_0 \propto \frac{Z}{K}$$

Meaning:

- Higher **atomic number** Z → larger r_0
- Higher **kinetic energy** K → smaller r_0

Impact Parameter (b)

Definition

The **Impact Parameter (b)** is defined as the perpendicular distance of the initial velocity vector of the α-particle from the central line (or center) of the nucleus.

Key Characteristics

- **Trajectory Influence:** The path (trajectory) of an alpha-particle depends on this distance b.
- **Scattering Angle (θ):**
  - If b is **small** (close to the nucleus), the particle experiences a strong repulsive force, leading to a **large** scattering angle.
  - If b is **large** (far from the nucleus), the repulsive force is weak, and the particle passes through with **little to no** deflection ($\theta \approx 0$).
  - If $b = 0$ (head-on collision), the particle rebounds back at $\theta = 180°$.

The mathematical relationship between the impact parameter (b) and the scattering angle (θ) is:

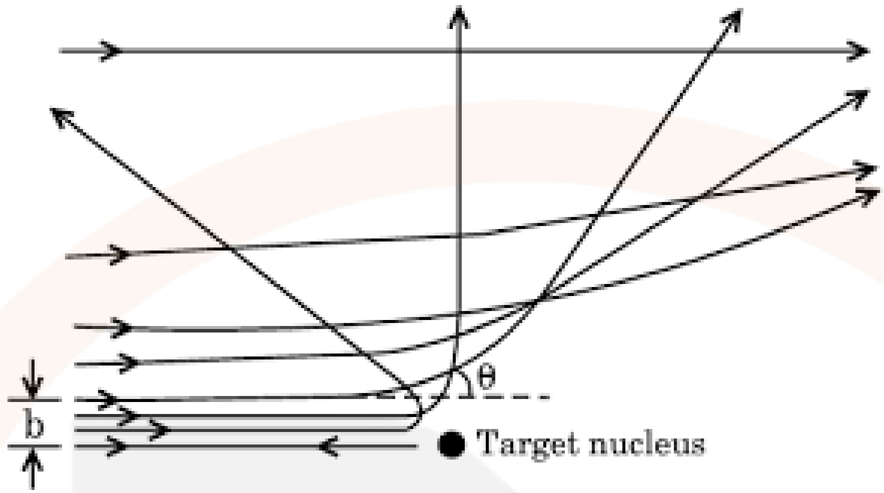
$$b = \frac{1}{4\pi\epsilon_0} \cdot \frac{Ze^2 \cot\left(\frac{\theta}{2}\right)}{\frac{1}{2}\, mv^2}$$

Variables Explained:

- $\boldsymbol{b}$: Impact parameter.
- $\boldsymbol{Z}$: Atomic number of the target nucleus.
- $\boldsymbol{e}$: Charge of an electron.
- $\boldsymbol{\theta}$: Scattering angle.
- $\boldsymbol{m}$: Mass of the α-particle.
- $\boldsymbol{v}$: Initial velocity of the α-particle.
- $\boldsymbol{\frac{1}{2}mv^2}$: Initial kinetic energy of the α-particle.
- $\boldsymbol{\frac{1}{4\pi\epsilon_0}}$: Electrostatic constant ($\approx 9 \times 10^9\ \mathrm{N \cdot m^2/C^2}$).

Alpha-particle Trajectory

- The path of an α- particle depends on the impact parameter, which is the distance from the particle's starting point to the centre of the nucleus.
- In a beam of α- particles, each particle has a different impact parameter, causing them to scatter in various directions. They all have nearly the same energy.
- An α- particle that comes very close to the nucleus (small impact parameter) scatters a lot. If it hits the nucleus head-on (very small impact parameter), it bounces back ($\theta \approx 180°$).
- If the impact parameter is large, the α- particle barely changes direction ($\theta \approx 0°$).
- The fact that few α- particles bounce back means that head-on collisions are rare, showing that most of the atom's mass and positive charge is concentrated in a small area. This helps determine the size of the nucleus.



*** Electron Orbits (Rutherford Model):-**

1. Rutherford's Nuclear Model :

The atom is modelled as a small, dense, positively charged nucleus with electrons revolving around it in fixed orbits.

The force of attraction between the nucleus and the electrons provides the necessary centripetal force to keep the electrons in stable orbits.

2. Centripetal Force :

The electrostatic force (F_e) between the electron and the nucleus equals the centripetal force (F_c):

$$F_e = F_c = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2} = \frac{mv^2}{r}$$

Where :

- ε_0 = permittivity of free space
- e = electron charge
- r = orbit radius
- m = electron mass
- v = velocity of the electron

3. Relation between orbit Radius and Electron velocity :

The radius r of the electron's orbit is related to its velocity v by the formula :

$$r = \frac{e^2}{4\pi\varepsilon_0 m v^2}$$

4. Kinetic Energy (K) :

The kinetic energy K of the electron is given by :

$$K = \frac{1}{2} m v^2 = \frac{e^2}{8\pi\varepsilon_0 r}$$

5. Electrostatic Potential Energy (U) :

The potential energy U of the electron due to the nucleus is :

$$U = -\frac{e^2}{4\pi\varepsilon_0 r}$$

The negative sign indicates that the force is attractive.

6. Total Energy (E) :

The total energy E of the electron in the hydrogen atom is the sum of its kinetic and potential energy :

$$E = K + U = \frac{e^2}{8\pi\varepsilon_0 r} - \frac{e^2}{4\pi\varepsilon_0 r}$$

$$E = -\frac{e^2}{8\pi\varepsilon_0 r}$$

The total energy is negative, meaning the electron is bound to the nucleus.