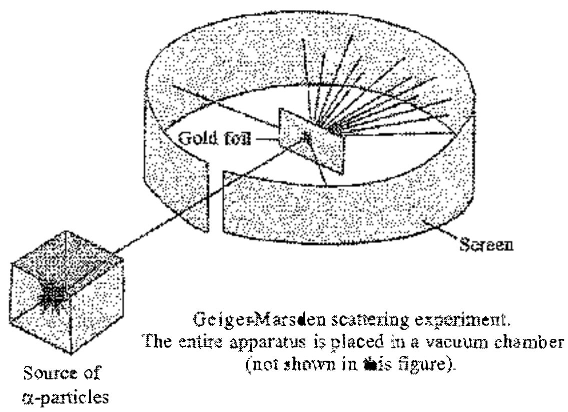
ALPHA-PARTICLE SCATTERING EXPERIMENT

- At the suggestions of Rutherford in 1911, Geiger and Marsden performed α-particle scattering experiment.

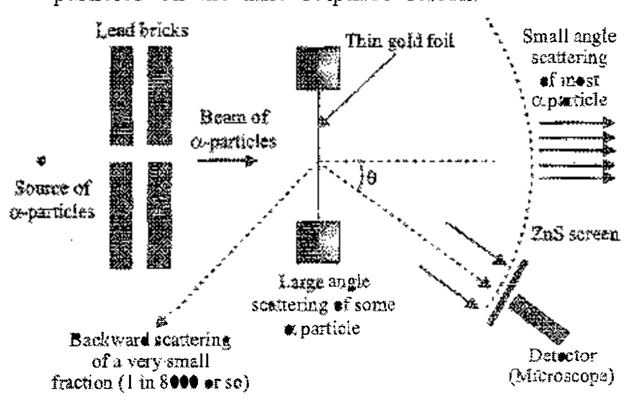


Geiger-Marsden scattering experiment.
The entire apparatus is placed in a vacuum chamber (not shown in this figure).

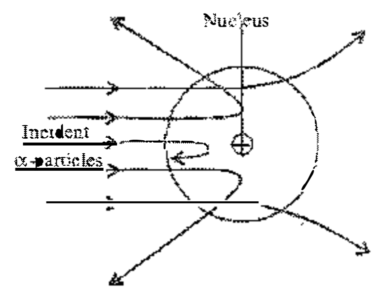
- They directed a beam of 5.5 MeV α-particles emitted from a $^{214}_{83}Bi$ radioactive source at a thin metal foil made of gold.
- The beam was allowed to fall on a thin foil of gold of thickness 2.1×10^{-7} m.

  Alpha particles emitted by radioactive source were collimated into a narrow beam by passing through lead bricks.

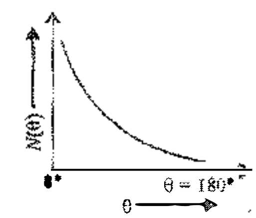
  The scattered α-particles were received by a rotatable detector with zinc sulphide screen and a microscope. Distribution of the number of scattered particles was studied as a function of angle of scattering by flashes or scintillations produced by striking α-particles on the zinc sulphide screen.



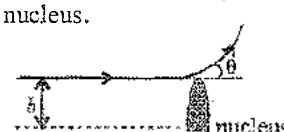
Schematic arrangement of the Geiger-Marsden experiment



- **Observation and Results**
  - Most of the α-particle pass through the gold foil without any deflection. This shows that most of the space in an atom is empty.
  - Few α-particles got scattered, deflecting at various angles from 0 to π. This shows that atom has a small positively charged core called 'nucleus' at centre of atom, which deflects the positively charged α-particles at different angles depending on their distance from centre of nucleus.



  - Very-very few α-particles (1 in 8000) suffers deflection of 180°. This shows that size of nucleus is very small, nearly 1/8000 times the size of atom. This graph shows deflection of number of particles with angle of deflection θ.
  - Impact parameter b is the distance of the initial velocity vector of the alpha-particle from the centre of the nucleus.



- The trajectory traced by an alpha particle depends on its impact parameter b. Rutherford had analytically calculated the relation between the impact parameter b and the scattering angle θ, given by

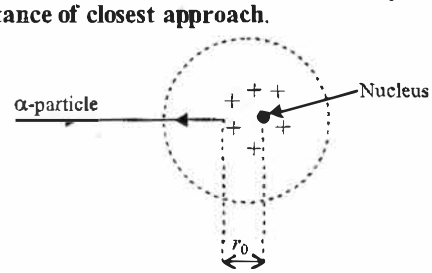
$$b = \frac{Ze^2 \cot \theta / 2}{4\pi\varepsilon_0 K_\alpha}$$

where K_α is the kinetic energy of the incident alpha particle.

- If $b = 0$, then by above relation
  $\cot\theta/2 = 0$ or $\theta/2 = 90°$ or $\theta = 180°$
  i.e., in case of head on collision, the impact parameter is zero and the alpha-particle rebounds back.
- If $b = \infty$, then by above relation
  $\cot\theta/2 = \infty$ or $\theta/2 = 0°$ or $\theta = 0°$
  i.e., the alpha particle goes nearly undeviated for a large impact parameter.

DISTANCE OF CLOSEST APPROACH : ESTIMATION OF NUCLEAR SIZE

- Suppose an α-particle of mass m and initial velocity v moves directly towards the centre of the nucleus of an atom. As it approaches the positive nucleus, it experiences Coulombic repulsion and its kinetic energy gets progressively converted into **electrostatic potential energy**. At a certain distance r_0 from the nucleus, the α-particle stops for a moment and then begin to retrace its path. The distance r_0 is called the **distance of closest approach.**



Distance of closest approach

- Let, initial kinetic energy of α-particle, $K_\alpha = \frac{1}{2}mv^2$
  Electrostatic potential energy of α-particle and nucleus at distance r_0,
  $$U = \frac{q_1q_2}{4\pi\varepsilon_0 r_0} = \frac{2e.Ze}{r_0}\frac{1}{4\pi\varepsilon_0}$$
  At the distance r_0, $K_\alpha = U$
  $$\text{or}\quad \frac{1}{2}mv^2 = \frac{2e.Ze}{r_0}\frac{1}{4\pi\varepsilon_0}$$
  $$r_0 = \frac{Ze^2}{\pi\varepsilon_0 mv^2}$$
  Hence radius of nucleus must be smaller than r_0.

Illustration 1

In a Geiger-Marsden experiment, what is the distance of closest approach to the nucleus of a 7.7 MeV α-particle before it comes momentarily to rest and reverses its direction?

Soln.: The key idea here is that the total mechanical energy of the system consisting of an α-particle and a gold nucleus is conserved.

The initial energy E_i is just the kinetic energy K of the incoming α-particle. The final energy E_f is just the electric potential energy U of the system T.

Let d be the centre-to-centre distance between the α-particle and the gold nucleus when α-particle is at its stopping point. Then we can write the conservation of energy $E_i = E_f$ as

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

distance of closest approach

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

here $K_\alpha = 7.7$ MeV $= 1.2 \times 10^{-12}$ J

$$\frac{1}{4\pi\varepsilon_0} = 9\times10^9 \text{ MKS unit}$$

$Z = 79$ for Gold

$$\text{So,}\quad r_0 = \frac{2\times9\times10^9\times79\times(1.6\times10^{-19})^2}{1.2\times10^{-12}}$$

$r_0 = 3 \times 10^{-14}$ m $= 30$ fm.

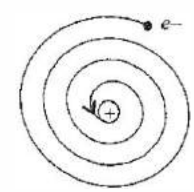
Radius of gold nucleus in actual is 6 fm where distance of closest approach is 30 fm. This discrepancy is due to the fact that distance of closest approach α is larger than sum of radii of the gold nucleus and the α particle.

Atomic Model from α-Particle Scattering Experiment

- The whole positive charge of atom is concentrated in its nucleus, which is of very small size as compared to size of atom. Atom has a diameter of the order of 10^{-10} m, whereas nucleus has a diameter of the order of 10^{-14} m.
- Electrons are situated in the large empty space around nucleus and are revolving, such that the centripetal force is provided by electrostatic force of attraction between electron and nucleus.
- The atom is neutral overall, so the total positive charge on nucleus is equal to the total negative charge on electrons.

Drawbacks of Rutherford s Model

- Rutherford's atomic model is inconsistent with classical physics. According to electromagnetic theory, an electron is a charged particle moving in the circular orbit around the nucleus and has an accelerated motion, so it should emit radiation continuously and thereby loose energy. Due to this, radius of the electron would decrease continuously and also the atom should then produce continuous spectrum, and ultimately electron will fall into the nucleus and atom will collapse in 10^{-8} s. But the atom is fairly stable and it emits line spectrum.



- Rutherford's model is not able to explain the spectrum of even most simplest H-spectrum.