# RUTHERFORD'S MODEL OF AN ATOM

## History:

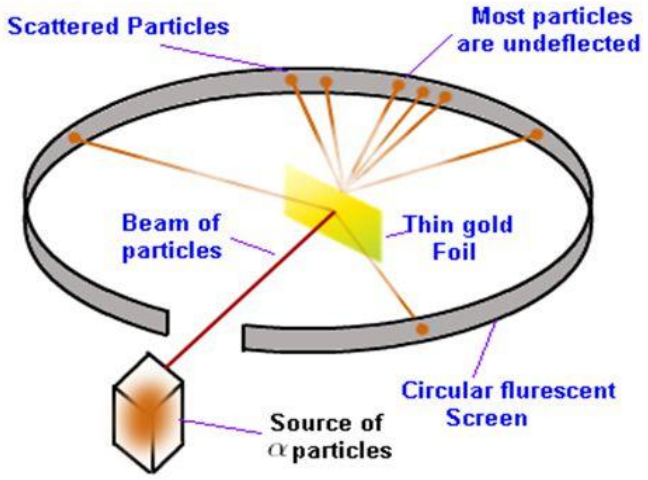
Classical electromagnetic theory rejected possibility of stable electron orbit.

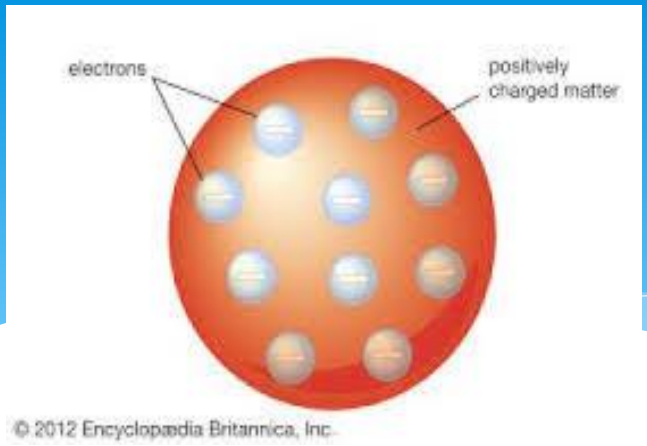
Neil Bohr applied quantum theory which is still a convenient mental picture of an atom

# RUTHERFORD'S SCATTERING EXPERIMENT

## The Experiment

- It was set up with a thick lead box with a small opening surrounding a source of heavy, alpha particles
- A small beam of the particles was formed pointing at an extremely thin piece of gold foil (approximately $3.4 \times 10^{-14}$m thick)






# Conclusion of Rutherford's Experiment

- Atoms are mostly empty space, thus explaining the lack of deflection of most of the alpha particles
- All the positive charge and almost all the mass of an atom are concentrated in a small region (nucleus)
- Nucleus – tiny central core of an atom composed of protons and neutrons
- Electrons are distributed around the nucleus and occupy almost all the volume of the atom (marble and football stadium)

# Formula obtained by Rutherford

- The formula that Rutherford obtained for alpha particle scattering by a thin foil on the basis of nuclear model is

$$N(\theta) = \frac{N_i\, nt Z^2 e^4}{(8\pi\varepsilon_o)^2\, r^2\, KE^2 \sin^4(\theta/2)} \qquad \ldots (1.1)$$

where $N(\theta)$ = Number of alpha particles per unit area that reach the screen at scattering angle $\theta$

$N_i$ = Total number of alpha particles that reach the screen

$n$ = Number of atoms per unit volume in the foil

$Z$ = Atomic number of the foil atom

$r$ = Distance of the screen from the foil

$KE$ = Kinetic energy of the alpha particle

$t$ = Foil thickness

- Prediction of equation (1.1) agrees with measurements of Geiger and Marsden. As $N(\theta) \propto \frac{1}{\sin^4(\theta/2)}$, the variation of $N(\theta)$ with $\theta$ is pronounced. Refer Fig. 1.3. Only 0.14% of incident alpha particles are scattered by more than $1^\circ$.

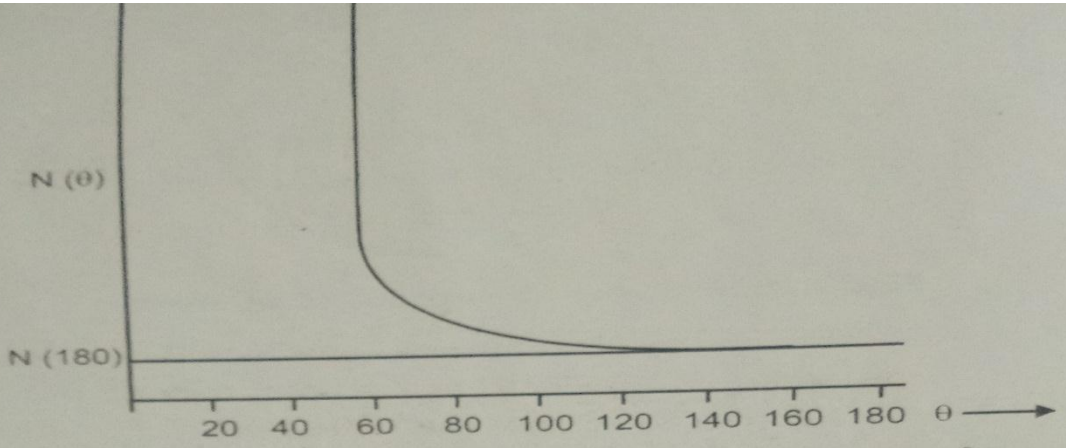



**Fig. 1.3 : Rutherford's scattering N(θ) versus θ**

- In the derivation of equation (1.1), Rutherford assumed that size of target nucleus is small compared with the minimum distance R to which incident alpha particles approach the nucleus before being deflected away. Thus, Rutherford's scattering gives us a way to find an upper limit of nuclear dimension.
- Let us calculate distance of closest approach R for an alpha particle. Alpha particle will have smallest R when it approaches to a nucleus head on, which will be followed by a 180° scattering. At the instant of closest approach, the initial kinetic energy KE of particle is entirely converted to electric P.E. so that

$$\text{K.E. (initial)} = \text{P.E.} = \frac{1}{4\pi\varepsilon_o}\frac{2\,Ze^2}{R}$$

Charge on α particle = 2e and that of nucleus = Ze

∴ Distance of closest approach,

$$R = \frac{2\,Ze^2}{4\pi\varepsilon_o\,KE_{initial}} \qquad \ldots (1.2)$$

In natural origin, max. K.E. = 7.7 MeV = $1.2 \times 10^{-12}$ J

Taking $\frac{1}{4\pi\varepsilon_o} = 9 \times 10^9\ Nm^2/l^2$

$$R = \frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2}{1.2 \times 10^{-12}} Z$$

$$= 3.8 \times 10^{-16}\,Z \text{ meter}$$

For gold, Z = 79. R (AU) = $3 \times 10^{-14}$ m

- Radius of gold nucleus is less than $3 \times 10^{-14}$, well under $10^{-4}$ the radius of an atom as a whole.

# Home Work

* **Questions**
* **What did Rutherford's gold foil show about the structure of an atom?**
* **Why was Rutherford's gold foil experiment important?**
* **Why were alpha particles deflected by the Rutherford's gold -foil experiment?**
* **What did Rutherford's gold-foil experiment tell about the atom?**
* **What did Rutherford's gold foil experiment demonstrate?**
* **How does the kinetic energy of the alpha particles affect the angle of deflection?**
* **How did Rutherford's gold foil experiment differ from his expectations?**
* **How did Rutherford's gold foil experiment change the model of the atom?**
* **How did Hans Geiger and Ernest Marsden help to the Rutherford gold foil experiment?**
* **Who were Hans Geiger and Ernest Marsden?**
* **Did Rutherford's gold foil experiment change the view of the atom?**
* **What are alpha particles?**
* **Obtain the radius of gold nucleus using formula used by rutherford.**