Alpha-Particle Scattering & Rutherford's Nuclear Model of Atom

1911 → H. Geiger & Ernst Marsden (on suggestion of Ernest Rutherford)

Conducted α-particle scattering experiment

Energy of α-particles (5 MeV - 7.7 MeV)

The gold foil is so thin as it contains only a single layer of gold atoms

Gold is highly malleable & can be beaten into very thin sheets
Observations

i) Most of the $\alpha$-particles pass undeviated ($\theta = 0^\circ$)

ii) Only 0.14% $\alpha$-particles deviate more than $1^\circ$ ($\theta > 1^\circ$)

iii) 1 in 8000 $\alpha$-particle deviate more than 90° ($\theta > 90^\circ$)

iv) 1 in 10,000 $\alpha$-particle deviate by 180° ($\theta = 180^\circ$) & returns back

The number of $\alpha$-particles scattered at angle $\theta$ are given by

$$N = \frac{KZ^2}{\sin^4(\frac{\theta}{2})}$$

$N$ → No. of $\alpha$-particles
$K$ → Constant
$Z$ → Atomic number of atom
$\theta$ → Scattering angle
(i) If 1000 α-particles deflects at 60°, find the number of α-particles that deflect at 90°.

Solution

\[ N = \frac{Kz^2}{\sin^4(\theta)} \]

1000 = \frac{Kz^2}{\sin^4(30°)} \quad (i)

\[ x = \frac{Kz^4}{\sin^4(45°)} \quad (ii) \]

\[ \frac{x}{1000} = \frac{\sin^4(30°)}{\sin^4(45°)} = \frac{1/2 \times 1/2 \times 1/2 \times 1/2}{1/2 \times 1/2 \times 1/2 \times 1/2} \]

\[ x = \frac{1000}{4} = 250 \]

**Rutherford's Nuclear Model of Atom**

(i) Since most α-particles pass unaltered, most part of atom is empty space (Atom is hollow from inside).

(ii) Some α-particles deflected by more than 1° (only 0.14%), this means there is a +ve charge inside atom as α is also +ve and this +ve
charge is concentrated in an extremely small space inside atom called nucleus. Calculation shows size of nucleus is around \(10^{-15}\) m whereas size of atom is around \(10^{-10}\) m.

3. For foils of different elements, the number of \(\alpha\)-particles deflected at angle \(\theta\) are different. This suggests different elements (metals as he used silver, platinum, etc.) have different +ve charge in their nucleus.

4. The electrons are attracted by nucleus due to electrostatic force but are not pulled towards it as they are constantly revolving in circular paths using this electrostatic force as centripetal force. (Just like planets revolve around sun)

(**Also called Solar System Model**)

\[
\begin{align*}
F_e & = F_c \\
& \text{electrostatic force} \\
& \text{centripetal force}
\end{align*}
\]
Nucleus Size Determination -
distance of closest approach ($r_0$)

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initial
\[ \alpha \]

final
\[ \alpha \rightarrow \text{nucleus} \rightarrow \text{charge} = Z e \]
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Suppose an $\alpha$-particle (initially at $\infty$ distance from nucleus) reaches till $r_0$ separation & stops due to repulsion from nucleus.

Applying Conservation of Mechanical Energy

\[
U_i + K_i = U_f + K_f
\]

\[
\frac{K_0 v_0^2}{\infty} + K = \frac{1}{2} m v_0^2 + 0
\]

\[
K = \frac{1}{2} \frac{(2e)(Z e)}{4 \pi \varepsilon_0} \frac{1}{r_0}
\]

\[
\gamma_0 = \frac{2 Z e^2}{4 \pi \varepsilon_0 K} \quad \text{initial kinetic energy of } \alpha
\]

Naturally, the most energetic $\alpha$-particle $K = 7.7$ MeV ($Z = 79$) putting this, we get

\[
\gamma_0 = 3 \times 10^{-14} \text{m} \approx 30 \text{fm (1 fm = 10^{-15}m)}
\]
so the size of nucleus must be less than 30fm as a-particle cannot enter inside nucleus.

*** The actual size of Gold Nucleus is 6fm
Impact Parameter : \( b \)

The 1st distance of the initial velocity vector of the \( \alpha \)-particle from the centre of the nucleus.

\[ b = \frac{KZe^2}{\text{K.E.} \sqrt{1 - \cos \theta}} \]

- \( b \rightarrow 0 \) Scattering Angle \( \theta \rightarrow \pi \)
- \( b \uparrow \uparrow \) " " \( \theta \rightarrow 0 \).

\( b \rightarrow \) Impact parameter in fermi
\( K \rightarrow \) Constant = 1.44 MeV
\( Z \rightarrow \) Atomic number
\( \text{K.E.} \rightarrow \) Initial K.E. of \( \alpha \)-particle (in eV)
\( \theta \rightarrow \) Scattering Angle
Failure of Rutherford Model

i) Stability of Atom

According to Maxwell, an accelerated charged particle emits radiation (energy).

In Rutherford's model of atom, e⁻ are moving in circular orbits thus having centripetal acceleration. So e⁻ should emit radiation & loose energy & ultimately pulled into nucleus & atom can't be stable. So Rutherford cannot explain stability of atom.

ii) Discrete spectrum of atoms (study later)

According to Rutherford e⁻ can revolve in any circular orbits. Using this logic, discrete atomic spectra cannot be explained.