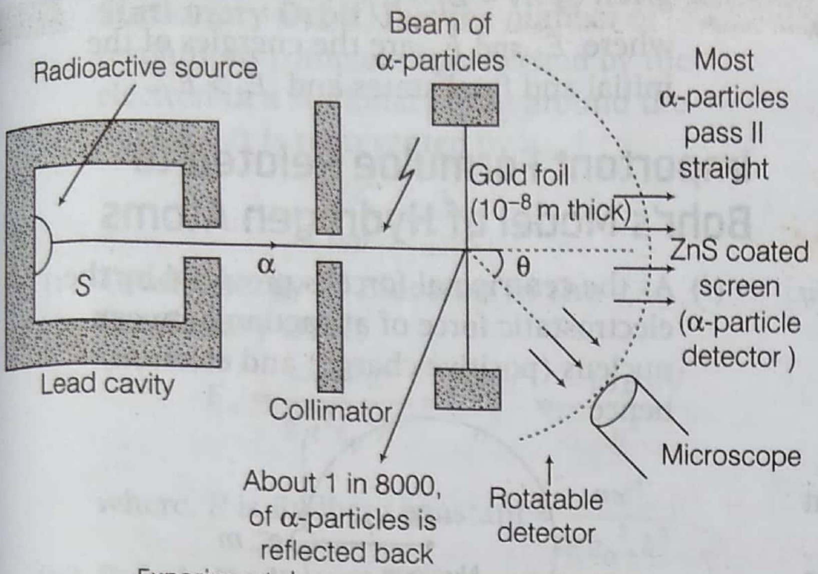
The smallest invisible particle of an element that can exist is known as atom. Atoms consist of a small dense nucleus of protons and neutrons surrounded by revolving electrons in different orbits. Every atom is a sphere of radius of the order 10^{-10}m. Atom is electrically neutral and contains equal amount of positive and negative charges.

1.1 α-Particle Scattering Experiment by Rutherford

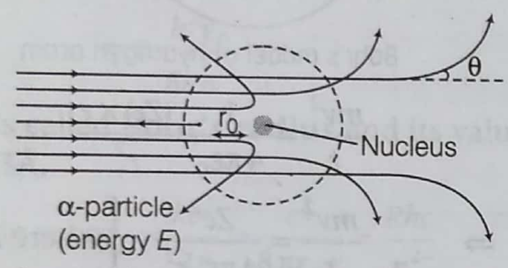
Experimental arrangement for α-scattering experiment and trajectory followed by α-particles

(i) This experiment was suggested by Rutherford in 1911.



Experimental arrangement for Rutherford's theory (Geiger-Marsden experiment)

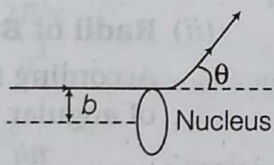
(ii)



Trajectory of α-particles in the coulomb field of a target nucleus. The impact parameter b and scattering angle θ are depicted.

Impact Parameter

The perpendicular distance of the velocity vector of α-particle from the central line of the nucleus of the atom is called **impact parameter** (b).



Impact parameter b

$$b = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Ze^2 \cot \theta/2}{K} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Ze^2 \cot\theta/2}{(1/2mv^2)} \Rightarrow b \propto \cot\theta/2$$

where, K is KE of α-particle, θ is scattering angle, Z is atomic number of the nucleus and e is charge of nucleus.

Distance of Closest Approach

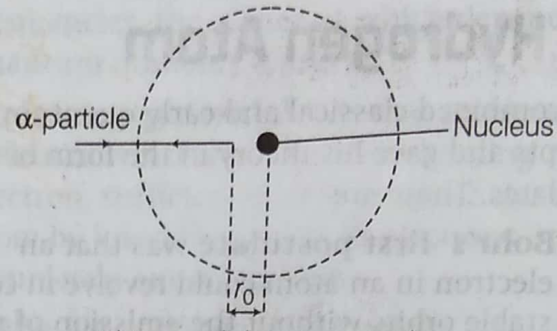
At a certain distance r_0 from the nucleus, whole of the KE of α-particle goes on converting into electrostatic potential energy and α-particle cannot go farther close to nucleus, this distance (r_0) is called distance of closest approach.

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

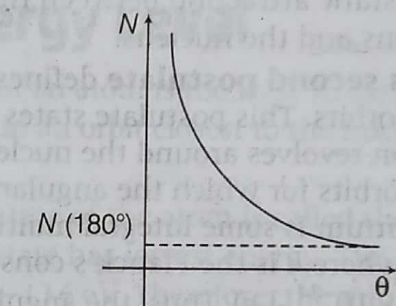
KE of α-particle in terms of r_0 is given by

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

because $\frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{(Ze)Ze}{r_0} \left(k = \frac{1}{4\pi\varepsilon_0}\right)$



Graph showing total numbers of α-particles scattered at different angles.



Angle of Scattering

Angle by which α-particle gets deviated from its original path around the nucleus is called angle of scattering.

Basic Assumption of Rutherford's Atomic Model

(i) Atom consists of small central core, called atomic nucleus in which whole mass and positive charge is assumed to be concentrated.

(ii) The size of nucleus is much smaller than the size of the atom, in the order of 10^{-15} m ≈ 1 fermi.

(iii) The nucleus is surrounded by electrons and atom is electrically neutral.

(iv) The electrons revolve around the nucleus in various orbits. The centripetal force required for their revolution is provided by the electrostatic attraction between the electrons and the nucleus.

Drawbacks of Rutherford's Model

(i) Could not explained stability of atom clearly.
(ii) Unable to explain line spectrum.

1.2 Bohr's Model of Hydrogen Atom

Bohr combined classical and early quantum concepts and gave his theory in the form of three postulates. These are

(i) **Bohr's first postulate** was that an electron in an atom could revolve in certain stable orbits without the emission of radiant energy, contrary to the predictions of electromagnetic theory. The centripetal force required for their rotation is provided by the electrostatic attraction between the electrons and the nucleus.

(ii) **Bohr's second postulate** defines these stable orbits. This postulate states that the electron revolves around the nucleus only in those orbits for which the angular momentum is some integral multiple of $h/2\pi$, where h is the Planck's constant $(= 6.6 \times 10^{-34}$ J-s). Thus, the angular momentum (L) of the orbiting electron is quantised, i.e. $L = \frac{nh}{2\pi}$.

As, angular momentum of electron $(L) = mvr$

$\therefore$ For any permitted (stationary) orbit,

$$mvr = \frac{nh}{2\pi}$$

where, n = any positive integer i.e. 1, 2, 3, ...
It is also called **principal quantum number.**

Stationary orbits While revolving in the permissible orbits, an electron does not radiate energy. These non-radiating orbits are called stationary orbits.

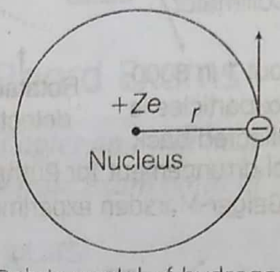
(iii) **Bohr's third postulate** states that an electron might make a transition from one of its specified non-radiating orbits to another of lower energy. When it does so, a photon is emitted having energy equal to the energy difference between the initial and final states. This is known as frequency condition.

The frequency of the emitted photon is then given by $h\nu = E_i - E_f$.

where, E_i and E_f are the energies of the initial and final states and $E_i > E_f$.

Important Formulae Related to Bohr's Model of Hydrogen Atoms

(i) As the centripetal force is provided by the electrostatic force of attraction between nucleus (positive charge) and electron, hence



Bohr's model of hydrogen atom

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

$$\Rightarrow \quad \frac{mv^2}{r} = \frac{Ze^2}{4\pi\varepsilon_0 r^2} \quad \left[\text{where } K = \frac{1}{4\pi\varepsilon_0}\right]$$

Hence $$\frac{Ke^2Z}{r^2} = \frac{mv^2}{r} \quad \text{...(i)}$$

(ii) **Radii of Bohr's Stationary Orbits**

According to Bohr's quantization condition of angular momentum

$$mvr = \frac{nh}{2\pi} \quad \Rightarrow \quad r = \frac{nh}{2\pi mv} \quad \text{...(ii)}$$

From Eq. (i)

$$r = \frac{KZe^2}{mv^2} \quad \text{...(iii)}$$

Equating Eqs. (ii) and (iii),

$$\frac{nh}{2\pi mv} = \frac{KZe^2}{mv^2} \quad \Rightarrow \quad v = \frac{KZe^2 \cdot 2\pi}{nh} \quad \text{...(iv)}$$

Substituting the value of v in Eq. (ii),

$$r = \frac{n^2h^2}{4\pi^2e^2mKZ}$$

Hence $r_n \propto n^2$

(iii) **Velocity of Electron in Bohr's Stationary Orbit**

$$v_n = \frac{2\pi Zke^2}{nh} = \frac{e^2}{2\varepsilon_0 nh} = \frac{c}{137}$$

(iv) **Frequency of Electron in Bohr's Stationary Orbit** It is the number of revolutions completed per second by the electron in a stationary orbit around the nucleus. It is represented by ν.

$$\nu = \frac{kZe^2}{nhr} = \frac{v}{2\pi r}$$

(v) **Total Energy of Electron in the Stationary Orbit**

$$E_n = \frac{-me^4Z^2}{8n^2\varepsilon_0{}^2h^2} = \frac{-Rhc}{n^2} = \frac{-13.6\ \text{eV}}{n^2}$$

where, R is Rydberg constant $= \dfrac{me^4}{8\,\varepsilon_0{}^2ch^3}$

(vi) **Bohr's Radius** The radius of the first orbit ($n = 1$) of hydrogen atom ($Z = 1$) will be

$$r_1 = \frac{h^2\varepsilon_0}{\pi me^2}$$

This is called **Bohr's radius** and its value is 0.53Å.

(vii) Kinetic energy $= \dfrac{ke^2}{2r} = \dfrac{e^2}{8\pi\varepsilon_0 r} = \dfrac{Rhc}{n^2}$

(viii) Total energy $(E_n) = -(\text{kinetic energy}) = -\dfrac{Rhe}{n^2}$

(ix) Potential energy $= -\dfrac{ke^2}{r} = -\dfrac{2Rhc}{n^2}$

(x) Potential energy

$= -2\,(\text{kinetic energy}) = -\dfrac{Ze^2}{4\pi\varepsilon_0 r}$

(xi) When an atom makes a transition from higher energy level (E_2) to lower energy level (E_1), then $E_2 - E_1 = h\nu$,

where, $\nu = \text{frequency} = \dfrac{kZe^2}{nhr}$

(xii) Wave number, $\bar{\nu} = \dfrac{1}{\lambda} = R\left[\dfrac{1}{n_1^2} - \dfrac{1}{n_2^2}\right] = \dfrac{v}{c}$

[As $c = \nu\lambda$ wave number

$$\bar{\nu} = \frac{2\pi^2mk^2e^4}{ch^3}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

where, $R = \dfrac{2\pi^2mk^2e^4}{ch^3}$ = Rydberg constant]

where, R is the constant called Rydberg constant $= 1.097 \times 10^7\ \text{m}^{-1}$

This formula indicates that the radiation emitted by the excited hydrogen atom consists of certain specific wavelengths or frequencies, the values of which depend on quantum numbers n_1 and n_2.

(xiii) **Ionisation potential** It is that accelerating potential which gives to a bombarding electron, sufficient energy to ionise the target atom by knocking one of its electrons completely out of the atom.

Ionisation potential of hydrogen

$= 0 - (-13.6) = 13.6\ \text{V} = \left(-\dfrac{13.6}{n^2}\right)\text{eV}$

1.3 Energy Level

The energy of an atom is the least when its electron is revolving in an orbit closest to the nucleus i.e. for which $n = 1$.

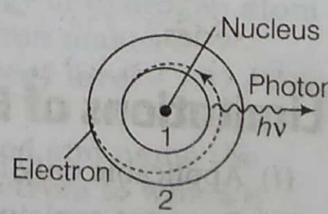
The lowest state of the atom is called the **ground state**, this state has lowest energy. The energy of this state is −13.6 eV. Therefore, the minimum energy required to free the electron from the ground state of the hydrogen atom is −13.6 eV.

(i) **Emission Spectrum** Hydrogen spectrum consists of discrete bright lines a dark background and it is specifically known as hydrogen emission spectrum.

(ii) **Absorption Spectrum** There is one more type of hydrogen spectrum exists where we get dark lines on the bright background, it is known as absorption spectrum.

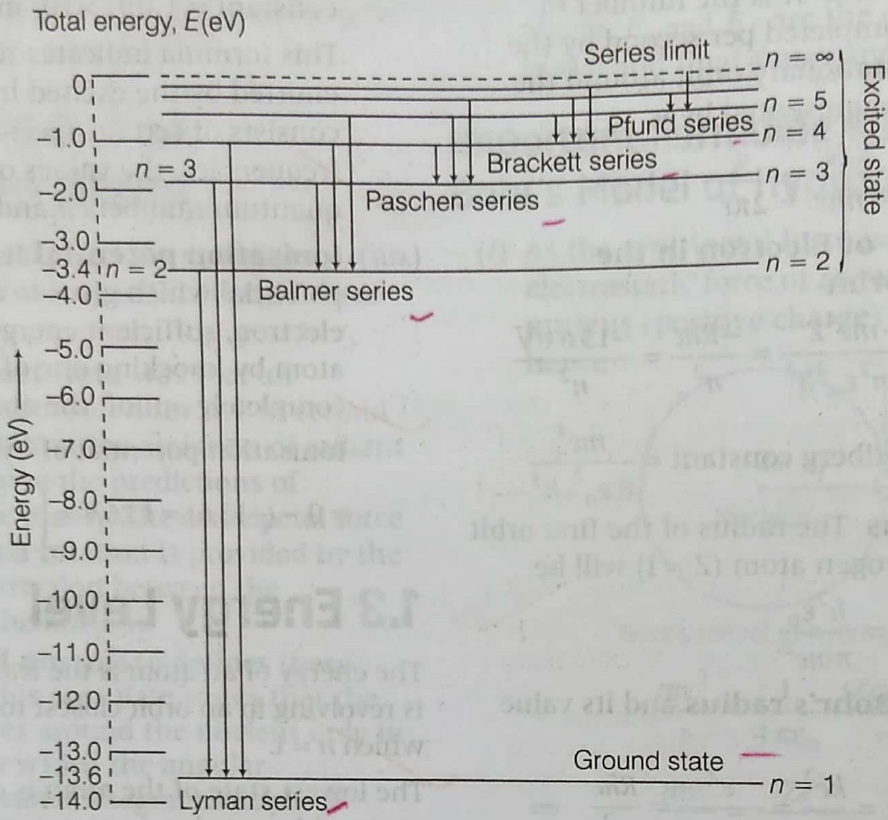
Energy Level Diagram

It is a diagram in which the energies of the different stationary states of an atom are represented by parallel horizontal lines, drawn according to some suitable energy scale. Such a diagram illustrates more clearly the known facts about the stationary states and the emission or absorption of various spectral lines.



Emission of a spectral line by a hydrogen atom

The atomic hydrogen emits a **line spectrum** consisting of various series.



The frequency of any line in a series can be expressed as

(*i*) Lyman series, $\nu = Rc\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$; $n = 2, 3, 4$ ... belong to the ultraviolet region of the electromagnetic spectrum.

(*ii*) Balmer series, $\nu = Rc\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$; $n = 3, 4, 5$ ... lies in the visible region and is called *Balmer series.*

(*iii*) Paschen series, $\nu = Rc\left(\frac{1}{3^2} - \frac{1}{n^2}\right)$; $n = 4, 5, 6$ ... a spectral series in the infrared regions is called Paschen series.

(*iv*) Brackett series, $\nu = Rc\left(\frac{1}{4^2} - \frac{1}{n^2}\right)$; $n = 5, 6, 7$ ... a spectral series in the infrared region is called Brackett series.

(*v*) Pfund series, $\nu = Rc\left(\frac{1}{5^2} - \frac{1}{n^2}\right)$; $n_2 = 6, 7, 8$ ... a spectral series in the infrared region is called Pfund series.

Limitations of Bohr's Model

(*i*) Applicable only for hydrogen like atom.

(*ii*) Does not explain the fine structure of spectral lines in H-atom.

(*iii*) Does not explain about shape of orbit.

If n is the quantum number of the highest energy level, involved in transitions, then total number of spectral line emitted, $N = \frac{n(n-1)}{2}$.