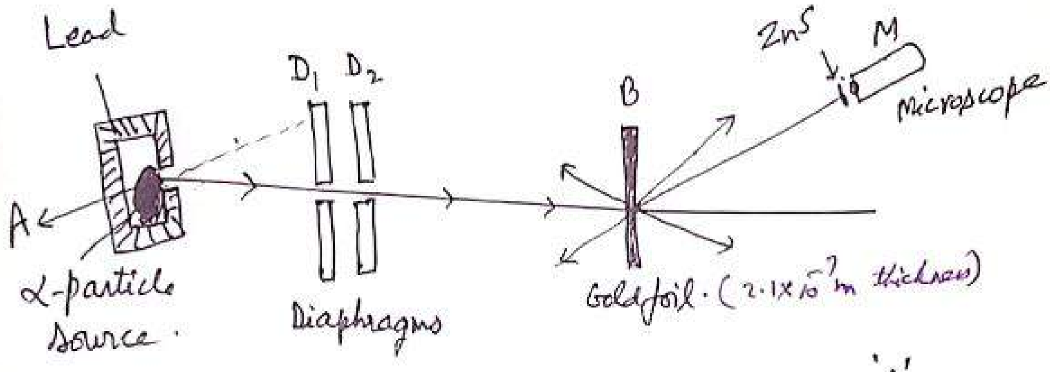
Rutherford's Atomic Model :- The scattering of α-particle was investigated by Rutherford and his co-workers.

The experimental arrangement is shown in below figure.



- α-particle is helium nucleus containing 2 proton and 2 neutron
- Only about 0.14% of incident α-particle scatter by more than 1°.
- About 1 in 8000 α-particle is reflected back.

An α particle is over 7000 times more massive than an electron.

- α-particle are emitted from a radio-active source 'A'.
- After passing through the diapharagms D_1, D_2 a narrow beam of α-particles is incident on the thin gold foil 'B'.
- Passing through the gold foil, the α-particles are scattered through different angles.
- When an α-particle is incident on zinc sulphide, it produces fluorescence and it is detected with the help of the microscope 'M'.

Rutherford came to the conclusion that

(1) At the centre of atom, there is nucleus of radius approximately 10^{-14}m, in which the entire positive charge and the entire mass of atom is concentrated.

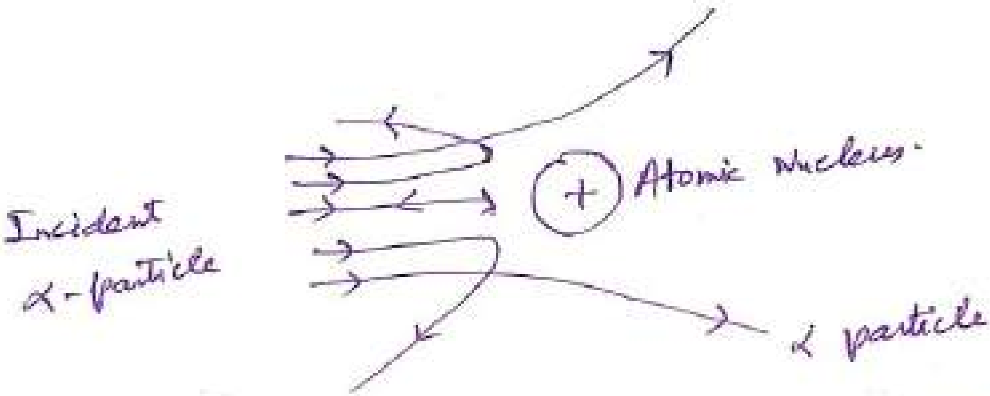
(2) The electrons (negatively charged) are distributed in a hollow sphere of radius nearly 10^{-10}m.

(3) The total negative charge of electrons is equal to the positive charge of the nucleus.

(4) The electrons do not reside stationary around the nucleus, otherwise the electrons due to attractive force of positive charge of nucleus will fall into the nucleus and the atom will no longer be stable. Rutherford assumed that the electrons revolve around the nucleus in circular orbits.

(5) The force acting on electrons due to nucleus provides the force required for revolving in the circular path around the nucleus.

The discovery of the nucleus of the atom is due to Rutherford!



An alpha particle tending to collide head on with the nucleus, slows down due to repulsive force of the nucleus, finally stops and is then repelled back. This α-particle, therefore retraces its path, scattering through 180°.

Drawbacks of Rutherford's model :- The two main drawbacks of Rutherford's model :-

(1) This model could not explain the stability of atom.
According to the theory of electrodynamics, each accelerated charged particle emit out energy continuously in form of e.m. wave.
According to Rutherford's model, since electron revolves around the nucleus in circular path, it has centripetal acceleration, so the electron revolving around the nucleus in an atom continuously emits energy in the form of e.m. waves due to which its energy decreases. Due to continuous decrease in energy of electron, the radius of circular path also decreases continuously. Thus the electron moving in a spiral path will ultimately fall into the nucleus and the atom will not remain stable.

(2) According to Rutherford's model, electrons can rotate in any orbit of any radius and thus it must emit electromagnetic radiations of all frequencies. This is also contrary to the experimental results.
Experimentally, it is found that atoms, like hydrogen atoms, emit line spectra of fixed frequencies only and not of all frequencies.

These difficulties were overcome in 1913 by the scientist Niel Bohr who propounded a model with the help of quantum theory and is known as Bohr's model of the atom.

Bohr's model of the atom :– Bohr in 1913 suggested a model of the atom for which he was awarded Nobel Prize in Physics in 1922.
Bohr applied the quantum theory of radiation as developed by Planck and Einstein to the Rutherford's model. His theory is mainly based on the following postulates.

(1) The atom consists of a positively charged nucleus at its centre.

(2) The negatively charged particles known as electrons move around the nucleus in various orbits known as stationary energy levels. The electrons cannot emit radiation when moving in their own stationary levels.

(3) The Coulombian and Newtonian forces are applicable in the domain of the atom.

(4) The electrons revolve round the nucleus in various circular orbits and the angular momentum about the nucleus is an integer multiple of $\frac{h}{2\pi}$ where h is Planck's constant. ($= 6.6 \times 10^{-34}$ J.s).

$$mvr = \frac{nh}{2\pi} \quad \text{where } n = 1, 2, 3, 4 \ldots$$

'n' gives the quantum number or principal quantum number.

(5) When an electron jumps from a higher energy level to a lower energy level, it gives out electromagnetic radiation of a particular frequency.

$$E_n - E_p = h\nu \qquad (n > p)$$

where E_n and E_p are the energies in the n^{th} and p^{th} orbit. ν is the frequency of the radiation.

Bohr's postulates are the combination of some of the ideas of the classical physics and quantum physics.
While in some ways they agree with classical physics, in other ways they are contradictory to it.

Bohr's model to derive expressions for the radius of n^{th} orbit, energy of electron in the n^{th} orbit, and the wavelength of wave emitted due to transition of electron from the n^{th} orbit to the p^{th} orbit.

Radius of n^{th} orbit :- Let an electron of mass 'm' and charge 'e' be revolving in n^{th} orbit of radius 'r' with velocity 'v' around the nucleus of charge Ze. Here 'Z' is the atomic number of the atom.

According to Bohr's model,

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

or

$$v = \frac{nh}{2\pi mr} \qquad \text{———— (1)}$$

When an electron revolves in a circular orbit, for the dynamic equilibrium, the force of attraction between the electron and the nucleus provides the necessary centripetal force for the motion in circular path i.e.,

$$\frac{mv^2}{r} = \frac{1}{4\pi\epsilon_0}\frac{Ze(e)}{r^2} \qquad \text{———— (2)}$$

where Ze = charge on nucleus
e = charge on electron

$$v^2 = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{mr} \qquad \text{———— (3)}$$

Using Eq^n (1) and (3), we get

Variation of velocity with 'n'

$$\left(\frac{nh}{2\pi mr}\right)^2 = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{mr}$$

or

$$\frac{n^2h^2}{4\pi^2m^2r^2} = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{mr}$$

or

$$r = \frac{4\pi\epsilon_0}{Ze^2}\cdot\frac{n^2h^2}{4\pi^2m} = \frac{\epsilon_0 n^2h^2}{\pi mZe^2}$$

$$\boxed{r_n = \frac{\epsilon_0 n^2 h^2}{\pi m Z e^2}} \quad \text{and} \quad v = \frac{e^2}{2\epsilon_0 nh}$$

From above eq^n, the radius of n^{th} orbit can be determined.
The radius of an orbit is directly proportional to the square of number of that orbit.
As n increases, the value of r also increases.

Radius of 1^{st} orbit of hydrogen atom :- In hydrogen atom $Z=1$, for the first orbit, $n=1$.

The radius is given by expression

$$r_n = \frac{\epsilon_0 n^2 h^2}{\pi m Z e^2} = \frac{4\pi\epsilon_0 n^2 h^2}{4\pi^2 m Z e^2}$$

For 1^{st} orbit

$$r_1 = (4\pi\epsilon_0)\frac{n^2 h^2}{4\pi^2 m Z e^2}$$

$$= \frac{1}{9\times10^9} \times \frac{(6.6\times10^{-34})^2}{4\times(3.14)^2\times(9.0\times10^{-31})\times(1.6\times10^{-19})^2}$$

$$= 0.53\times10^{-10}\,m$$

$$\boxed{r_1 = 0.53\,\mathring{A}}$$

radius of second orbit will be

$$r_2 = (2)^2 r_1 = 4r_1 = 2.12\,\mathring{A}$$

radius of third orbit will be

$$r_3 = (3)^2 r_1 = 9r_1 = 4.57\,\mathring{A}$$

The Variation of radius (r) of stationary orbit of hydrogen atom with the principal quantum number is shown in figure

Energy of electron in n^{th} orbit :- Let an electron of mass 'm' and charge, '$-e$' be revolving in n^{th} orbit of radius 'r' with velocity 'v' around the nucleus of charge ze. Here Z is the atomic number of the atom.

Energy of electron in the n^{th} orbit = K.E. + electrostatic P.E.

or $$E_n = \frac{1}{2}mv^2 + \frac{1}{4\pi\epsilon_0}\frac{ze(-e)}{r}$$

But according to bohr's model..

$$\frac{mv^2}{r} = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{r^2}$$

or $$\frac{1}{2}mv^2 = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{2r}$$

$\therefore$ $$E_n = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{2r} - \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{r}$$

$$= -\frac{1}{4\pi\epsilon_0}\frac{Ze^2}{2r}$$

Substituting the value of 'r' = $\frac{4\pi\epsilon_0 n^2h^2}{4\pi^2 m Ze^2}$, we get

$$E_n = -\frac{1}{4\pi\epsilon_0} Ze^2 \cdot \frac{1 \cdot 4\pi^2 m Ze^2}{2(4\pi\epsilon_0)n^2h^2}$$

$$= -\frac{1}{2}\cdot Z^2e^4 \cdot \frac{4\pi^2 m}{(4\pi\epsilon_0)^2 n^2h^2}$$

$$= \frac{-2\pi^2 m Z^2 e^4}{(4\pi\epsilon_0)^2 n^2h^2}$$

$$\boxed{E_n = \frac{-mZ^2e^4}{8\epsilon_0^2 n^2h^2}}$$ or $E_n = -\frac{Rch}{n^2}$ joule where $R = \frac{2\pi^2 me^4}{(4\pi\epsilon_0)^2 ch^3}$ ($Z=1$)

The value of $R = 1.1\times10^7\ m^{-1}$.

Above eqn gives the energy of electron in the n^{th} orbit. The $-ve$ sign in this expression implies that as 'n' increases, the energy E also increases i.e. the electron in the upper orbit has more energy and the electron in the lower orbit has less energy.

- As n increases, the K.E. of electron of electron decreases, but its potential energy increases.

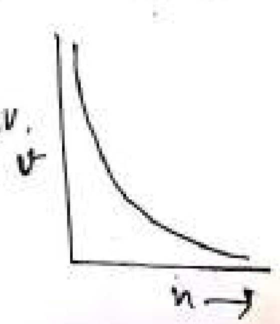
In first orbit ($n=1$) of hydrogen atom ($Z=1$), the energy of e^- is

$$E_1 = -\frac{2\pi^2 me^4}{(4\pi\epsilon_0)^2h^2}$$

$$= -21.7\times10^{-19} \text{ joule} = -13.6\,eV.$$

$$E_2 = -\frac{Rch}{4} = -3.4\,eV$$

$$E_3 = -\frac{Rch}{9} \text{ joule or } -1.5\,eV.$$



Wavelength of radiation corresponding to the transition of electron from the n^{th} orbit to the p^{th} orbit :-

(8)

If there is transition of electron of hydrogen atom from the n^{th} orbit to the p^{th} orbit, then according to the Bohr's model, the frequency of Electromagnetic wave emitted is given as:

$$\nu = \frac{E_n - E_p}{h} \quad \text{——(1)}$$

The energy of electron in n^{th} orbit is $E_n = -\frac{Rch}{n^2}$ ——(2)

and energy of electron in p^{th} orbit is $E_p = -\frac{Rch}{p^2}$ ——(3)

where R is the Rydberg's constant.

Substituting Eq^n (2) & (3) in Eq^n (1), we get

$$\nu = \frac{1}{h}\left[-\frac{Rch}{n^2} - \left(-\frac{Rch}{p^2}\right)\right] = Rc\left(\frac{1}{p^2} - \frac{1}{n^2}\right)$$

We know $c = \nu\lambda$ or $\frac{1}{\lambda} = \frac{\nu}{c}$ where 'c' is the speed of light.

Hence

$$\frac{1}{\lambda} = R\left(\frac{1}{p^2} - \frac{1}{n^2}\right)$$

The quantity $\frac{1}{\lambda}$ is called the wave number and it is denoted by the symbol $\bar{\nu}$.

$$\boxed{\bar{\nu} = R\left(\frac{1}{p^2} - \frac{1}{n^2}\right)}$$

Short-Coming of Bohr's Atomic Model :-

(1) Bohr's theory could explain the different spectral series and different spectral lines in each series in the spectrum of hydrogen atom, but it could not explain the fine structure of each spectral line. when seen by the high resolution Spectroscope. Each spectral line is comprised of several close spectral lines, for example, the H_α line of Balmer series is a group of 5 fine spectral lines.

(2) Bohr's theory could not explain the different intensities of different spectral lines of an atom.

(3) This theory only explain the spectrum of single electron atoms (such as hydrogen, ionised helium etc.), but it could not explain the spectrum of atoms having more than one electron.

(4) This theory could not explain the zeeman effect.

(5) Bohr's model does not give the idea of distribution and arrangement of electrons in the orbits.

(6) Bohr's model is based on two theories which are contradictory to each other.

(7) They proposed the concept of only circular orbit but electron orbits are elliptical also. The theory could not explain the existence of these orbits.

(8) The theory treated electron as a particle only so it could not explain wave nature of electron.

Spectral Series of Hydrogen atom :-

Experimentally, it is observed that in the emission spectrum of hydrogen atom apart from the visible region, in the invisible region (i.e. u-v and infrared regions). also have some spectral lines are obtained. These lines have been classified in different series namely

(1) Lyman series :- If $p = 1$ and $n = 2, 3, 4, \ldots$, then

$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right) \text{ where } n = 2, 3, 4, \ldots$$

In this series, the longest wavelength (for $n = 2$) is nearly 1215 °A and the shortest wavelength or the limit of this series (for $n = \infty$) is nearly 910 °A.
This series is obtained in the ultraviolet region.

(2) Balmer series :- If $p = 2$ and $n = 3, 4, 5, \ldots$; then

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \text{ where } n = 3, 4, 5, \ldots$$

In this series the longest wavelength (for $n = 3$) is nearly 6563 Å and the shortest wavelength or the limit of this series (for $n = \infty$) is nearly 3646 °A.
This series is obtained in the visible region.
In the Balmer series, the four prominent lines are H_α (red), H_β (green), H_γ (blue) and H_δ (violet) which are obtained due to transition of electron respectively from third, fourth, fifth and sixth orbit to the second orbit.

$$H_\alpha = 6563 \text{ Å}$$

$$H_\beta = 4861 \text{ °A} \qquad H_\infty = 3646 \text{ °A}$$

$$H_\gamma = 4340 \text{ °A}$$

$$H_\delta = 4102 \text{ °A}$$

(3) Paschen Series :- If $p = 3$ and $n = 4, 5, 6, 7, \ldots$ then,

$$\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right) \text{ where } n = 4, 5, 6, 7 \ldots$$

In this series, the wavelength of first member for $n = 4$ is 18751 °A and the wavelength of series limit (for $n = \infty$) is nearly 8107 °A.
This series is obtained in infrared region.

(4) Brackett Series :- If $p=4$ and $n=5,6,7,\ldots$ then

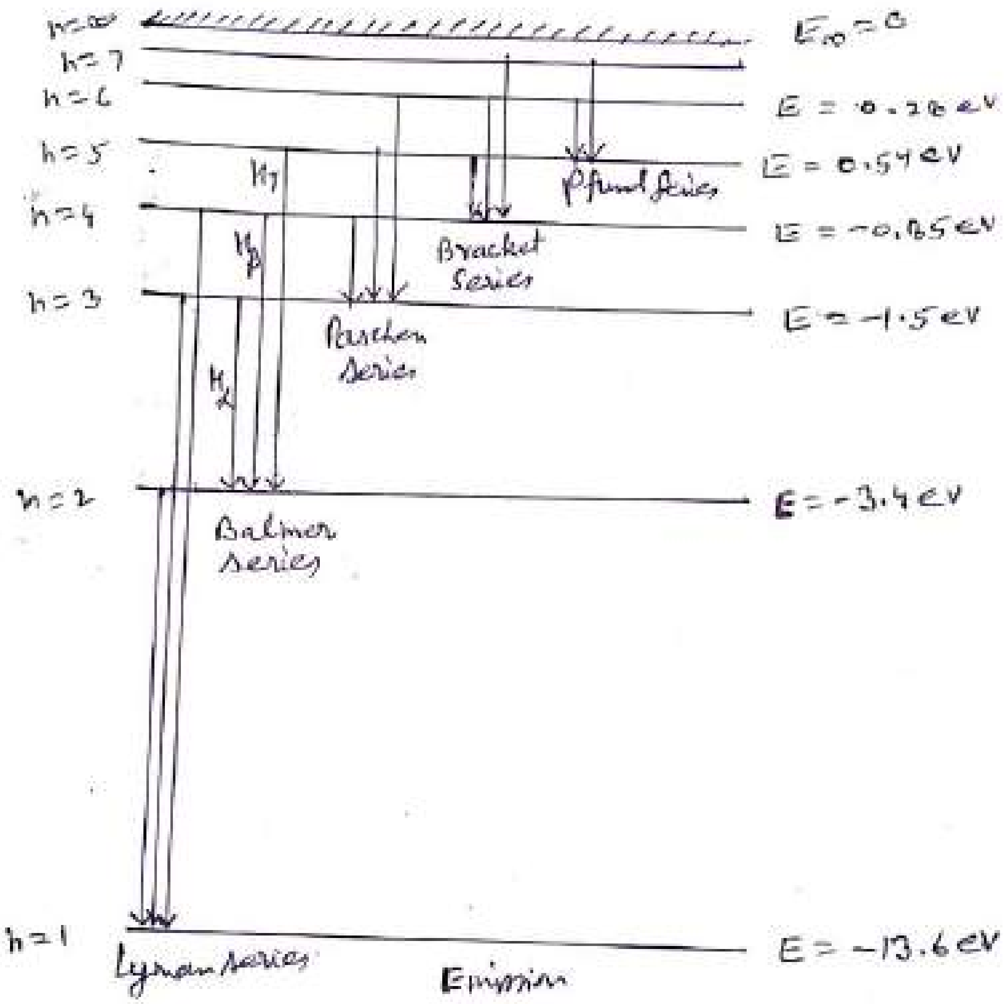
$$\frac{1}{\lambda}=R\left(\frac{1}{4^2}-\frac{1}{n^2}\right) \text{ where } n=5,6,7,\ldots$$

In this series, the first member wavelength for $n=5$ is 40500 Å and the wavelength of series limit $(n=\infty)$ is nearly 14516 Å. This series is obtained in the far infrared region.

(5) Pfund Series :- If $p=5$ and $n=6,7,8,\ldots$ then

$$\frac{1}{\lambda}=R\left(\frac{1}{5^2}-\frac{1}{n^2}\right) \text{ where } n=6,7,8,\ldots$$

In this series the first member wavelength for $n=6$ is 74000 Å and the series limit wavelength $(n=\infty)$ is nearly 22700 Å. This series is obtained in far-far infrared region.



Spectral lines on Energy level diagram in the Spectrum of Hydrogen.