CHAPTER III

ATOMIC STRUCTURE

Introduction

Niel Bohr was the first to give a satisfactory atomic model of Hydrogen atom which could explain successfully the stability of the atom, origin of spectral lines in Hydrogen atom and also gave a model for all other atoms.

Bohr's model of the atom is just an attempt to extend the application of Planck's quantum principle to Rutherford's atom model. Bohr's atom model may be summarized in the following assumptions (Bohr's postulates)

1. *An atom consists of a +vely charged nucleus responsible for almost the entire mass of the atom.*
2. *Electrons revolve round the nucleus in certain permitted circular orbits of definite radii. These allowed orbits are called stationary orbits.*

The necessary centripetal force to keep the electron moving in stationary circular orbit is supplied by the Coulomb'selectrostatic force of attraction between the electron and the nucleus.

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

m = mass of electron, v=velocity of electron

r = radius of stationary orbit

z = atomic number and for hydrogen z =1

ze= charge on nucleus

(-e)= charge on electron

When an electron revolves in a stationary orbit, it does not radiate energy.

3. *The stationary orbits are those in which the angular momentum of the moving electron is an integral multiple of* $\frac{h}{2\pi}$

ie $$\boxed{L = mvr = n\frac{h}{2\pi}}$$

constant, n→ principle quantum number, ien=1,2,3……..

This equation is called Bohr'squantum condition.

According to this condition the number of allowed orbits of moving electrons is discrete.

4. *The energy is radiated only when an electron jumps from one stationary orbit to another stationary orbit*

ie, $\boxed{h\,\vartheta = E_i - E_f}$

E_i = *energy in initial state*
E_f = *Energy in final state and* $E_i > E_f$

This is known as Bohr's frequency condition or radiation condition.

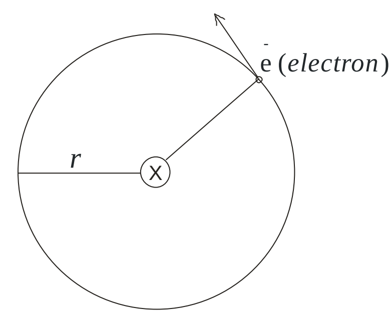
The Bohr atom (Bohr's theory of hydrogen atom)

I. Expression for the radius of the electron in the n^th orbit

1^st method: Hydrogen atom consists of a +vely charged nucleus of charge Ze.

A single electron of charge –e is revolving around the nucleus in circular orbit

Ze
Z=1 for hydrogen



Electrostatic attraction between the electron and

The nucleus $F = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2}$

This force provides the centripetal force.

$$\therefore \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2} = \frac{mv^2}{r}$$

$$r = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{mv^2} \ldots\ldots\ldots\ldots\ldots\ldots.(1)$$

By Bohr's quantum condition

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

$$\mathrm{v} = \frac{nh}{2\pi mr} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Put (2) in (1)

$$r = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{\frac{m.n^2h^2}{4\pi^2m^2r^2}}$$

$$r = \frac{n^2h^2\varepsilon_0}{\pi mze^2}$$

∴radius of the n^{th} stationary orbit for hydrogen,

$$r_n = \frac{n^2 h^2 \varepsilon_0}{\pi m e^2} \dots\dots\dots\dots\dots\dots\dots\dots (3) \qquad z = 1, \ \ for\ hydrogen$$

Bohr's radius a_o:

The radius of the innermost orbit in hydrogen atom is called Bohr's radius.

$$\boldsymbol{a_0} = r_1 = \frac{h^2 \varepsilon_0}{\pi m e^2} = 5.292 \times 10^{-11} m \dots\dots\dots\dots\dots 3(a)$$

II^{nd}method:

The Bohr atom (Bohr's theory of hydrogen atom by de Broglie's hypothesis):

Consider the hydrogen atom,the +ve charge on its nucleus=Ze, where Z=1 .Let an electron of charge '-e' move round the nucleus in an orbit of radius r with velocity v.

According to de Broglie, a moving electron shows wave like behavior.

∴ deBroglie wave length of this electron ,when it moves round the nucleus is $\lambda = h/_{mv}$.

When the electron moves along the circular orbit, centripetal force is provided by electrostatic force of attraction between the nucleus and the electron.

ie, $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2}$put Z=1

∴ Electron velocity $v = \frac{e}{\sqrt{4\pi\varepsilon_0 m r}} \dots\dots\dots\dots\dots\dots\dots (1)$

But orbital electron wavelength

$$\lambda = \frac{h}{mv} = \frac{h}{m\frac{e}{\sqrt{4\pi\varepsilon_0 m r}}}$$

$$\lambda = \frac{h}{e}\sqrt{\frac{4\pi\varepsilon_0 r}{m}} \dots\dots\dots\dots\dots\dots (2)$$

Put $r = 5.3 \times 10^{-11} m = Bohr' radius$,we get,

$\lambda = 33 \times 10^{-11} m$ This wavelength is exactly the same as the circumference of the electron orbit.

ie, $2\pi r = 33 \times 10^{-11} m$.

The orbit of the electron in a hydrogen atom corresponds to one complete electron wave joined on it. According to de Broglie the stationary orbits are those in which the orbital circumference $(= 2\pi r)$ is an integral multiple of de Broglie wavelengthλ.

$$\therefore\ 2\pi r_n = n\lambda, \quad \text{where}, n = 1,2,3 \ldots\ldots\ldots\ldots$$

Put (2) in the above equation

$2\pi r_n = n\frac{h}{e}\sqrt{\frac{4\pi\varepsilon_0 r_n}{m}}$ r_n= radius of the orbit that contains n wavelength.

∴ The possible electron orbits are those, whose radii are given by,

Orbital radii in Bohr atom $\boxed{r_n = \frac{n^2h^2\varepsilon_0}{\pi me^2}}$ ……………(3)

Eqn (3) is called Bohr formula for the radii of the stationary orbits for hydrogen atom.

Bohr's radius a_o:

The radius of the innermost orbit in hydrogen atom is called Bohr's radius.

∴ Bohr's radius $\boldsymbol{a_0} = r_1 = \frac{h^2\varepsilon_0}{\pi me^2} = 5.292 \times 10^{-11} m \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3(a)$

The other radii are given in terms of Bohr's radius by the formula $r_n = n^2 a_0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$

II. Energy levels and spectra

1. Expression for total energy:

The total energy E of the electron in a hydrogen atom,

$E = K.E + P.E$

K.E= $^1/_2\, mv^2$

E=$^1/_2\, mv^2 - \frac{e^2}{4\pi\varepsilon_0 r}$

P.E = $\frac{-e^2}{4\pi\varepsilon_0 r}$

=$^1/_2\, m\frac{e^2}{4\pi\varepsilon_0 mr} - \frac{e^2}{4\pi\varepsilon_0 r}$

V= $\frac{e}{\sqrt{4\pi\varepsilon_0 mr}}$ …………(1)

=$\frac{1}{8}\frac{e^2}{\pi\varepsilon_0 r} - \frac{e^2}{4\pi\varepsilon_0 r} = \frac{-e^2}{8\pi\varepsilon_0 r}$

ie, total energy E_n in terms of the orbital radius r_n is

$E_n = \frac{-e^2}{8\pi\varepsilon_0 r_n} \dots\dots\dots\dots\dots\dots\dots .(5) r_n = \frac{n^2h^2\varepsilon_0}{\pi me^2} \dots\dots\dots\dots (3)$

$= \frac{-e^2}{8\pi\varepsilon_0 \frac{n^2h^2\varepsilon_0}{\pi me^2}} = \frac{-me^4}{8\varepsilon_0^2h^2}\left(\frac{1}{n^2}\right), \quad n = 1,2,3, \dots ..$

ie, Total energy of the electron in the nth orbit,

$$\boxed{\boldsymbol{E_n = \frac{-me^4}{8\varepsilon_0^2h^2}\left(\frac{1}{n^2}\right)}} \dots .(6)$$

This is the expression for energy of the electron in the nth orbit.

When,

n=1,

$E_1 = \frac{-me^4}{8\varepsilon o^2h^2}$ …………….. 6(a)

$$E_1 = -2.18 \times 10^{-18} J = -13.6\, eV$$

Also $\boldsymbol{E_n} = \frac{\boldsymbol{E_1}}{\boldsymbol{n^2}} \dots\dots\dots\dots\dots .. 6(b)$

$i.e, \quad E_n \propto \frac{1}{n^2}$ or, $\boldsymbol{E_n = \frac{-13.6}{n^2}}$………. 6 (c)

ie, total energy E of the electron in an orbit varies inversely as the square of n.

Note:-

1. *The energies specified by eqn (6) are called the energy levels of the hydrogen atom. Energy levels are all negative, which signifies that electron does not have enough energy to escape from the nucleus.*
2. *The lowest energy level E_1 is called ground state of the atom and the higher levels E_2, E_3, E_4…….are called excited states.*
3. *The work needed to remove an electron from an atom in its ground state is called its ionization energy. The ionization energy is accordingly equal to $-E_1$. In the case of hydrogen the ionization energy is 13. 6 e V. Since ground state energy of the hydrogen atom is-13.6 e V.*
4. *From eqn (6) and (3), we see that in Bohr model of the atom both the energy of the electron and the radii of its orbits are quantized.*

Energy quantization:

We have $\boldsymbol{E_n} = \frac{-\boldsymbol{me^4}}{\boldsymbol{8\varepsilon_0{}^2h^2}}\left(\frac{\boldsymbol{1}}{\boldsymbol{n^2}}\right)$**..............(6)**

For n=1, $E_1 = \frac{-me^4}{8\varepsilon_0{}^2h^2}\left(\frac{1}{1^2}\right)$

For n=2, $E_2 = \frac{-me^4}{8\varepsilon_0{}^2h^2}\left(\frac{1}{2^2}\right)$

For n=3, $E_3 = \frac{-me^4}{8\varepsilon_0{}^2h^2}\left(\frac{1}{3^2}\right)$

In other words, electron can have only definite values of energy and not any value of energy. It is called energy quantization.

2. *Origin of line spectra: (Bohr's interpretation of hydrogen spectrum)*

According to Bohr's radiation condition, radiation of energy takes place only when an electron jumps from one stationary orbit into another.

If n_i and n_f are the quantum numbers of initial and final states and E_i and E_f are their respective energies.

$$E_i - E_f = h\vartheta$$

but

$$E_n = \frac{E_1}{n^2} \dots\dots\dots\dots 6(b)$$

$$or \vartheta = \frac{E_i - E_F}{h} \therefore E_i = \frac{E_1}{n_i{}^2}$$

$$= \frac{\frac{E_1}{n_i{}^2} - \frac{E_1}{n_f{}^2}}{h}$$

$$E_f = \frac{E_1}{n_f{}^2}$$

$$= \frac{-E_1}{h}\left[\frac{1}{n_f{}^2} - \frac{1}{n_i{}^2}\right]$$

$\therefore$frequency of the emitted radiation,

$$\vartheta = \frac{-E_1}{h}\left[\frac{1}{{n_f}^2} - \frac{1}{{n_i}^2}\right] \ldots\ldots\ldots\ldots\ldots (7)$$

Note :

But c = $\vartheta\lambda or \frac{1}{\lambda} = \frac{\vartheta}{c}$ E_1= - quantity

$-E_1$=+ve quantity

The Quantity $1/_\lambda$ is the number of waves in unit length. It is called wave number $\bar{\vartheta}$.

∴ Wave number of the emitted radiations.

$$\bar{\vartheta} = \frac{1}{\lambda} = \frac{\vartheta}{c} = \frac{-E_1}{ch}\left[\frac{1}{{n_f}^2} - \frac{1}{{n_i}^2}\right]$$

$$\boxed{\bar{\vartheta} = -\frac{E_1}{ch}\left[\frac{1}{{n_f}^2} - \frac{1}{{n_i}^2}\right] \ldots\ldots\ldots..(8)}$$

Or $\bar{\vartheta} = -\frac{(-me^4)}{8{\varepsilon_0}^2h^2hc}\left[\frac{1}{{n_f}^2} - \frac{1}{{n_i}^2}\right] E_1 = \frac{-me^4}{8{\varepsilon_0}^2h^2} \ldots\ldots\ldots.6(a)$

$$\bar{\vartheta} = \frac{1}{\lambda} = \frac{me^4}{8{\varepsilon_0}^2h^3c}\left[\frac{1}{{n_f}^2} - \frac{1}{{n_i}^2}\right] \ldots\ldots\ldots.(9)$$

But, $\frac{me^4}{8{\varepsilon_0}^2h^3c} = R$ and is known as Rydberg's constant

R =1.09737 x $10^7 m^{-1}$ for hydrogen atom

$$\therefore \bar{\vartheta} = \frac{1}{\lambda} = R\left[\frac{1}{{n_f}^2} - \frac{1}{{n_i}^2}\right] \ldots\ldots\ldots\ldots 9(a)$$

This equation states that the radiation emitted by excited hydrogen atom should contain certain discrete wave lengths only. These wave lengths, furthermore, fall into definite sequences (series) that depend on quantum number n_f of the final energy level of the electron.

a) Spectral series of hydrogen atom

We have $\bar{\vartheta} = \frac{1}{\lambda} = -\frac{E_1}{ch}\left[\frac{1}{{n_f}^2} - \frac{1}{{n_i}^2}\right] \ldots\ldots\ldots(8)$.This equation explains successfully the origin of various lines in the spectrum of hydrogen atom.Series of lines are obtained due to the transition of electrons from various outer orbits (n_i) to a fixed inner orbit (n_f).

(Explanation:-

Whenever electron in a hydrogen atom jumps from higher energy level to the lower energy level, the difference of energies of the two levels is emitted as a radiation of particular wavelength. It is called a spectral line. As the wavelength of the spectral line depends upon the two orbits (ie, n_i and n_f) between which the transition of electron takes place, various spectral lines are obtained. These spectral lines are found to fall into a number of spectral series**)**

1. Lymann series:

This series is produced when an electron jumps from higher orbits to first orbit (ien_f=1). Thus for this series $\bar{\vartheta} = \frac{1}{\lambda} = -\frac{E_1}{ch}\left[\frac{1}{1^2} - \frac{1}{n^2}\right]$Where, n=$n_i$=2,3,4……..

This series is found in u-v region of the spectrum.

2. Balmer series:

This series is produced when electron jumps from higher orbits (or energy levels) to second stationary orbits) (ie, n_f=2)

ie, $\bar{\vartheta} = \frac{1}{\lambda} = -\frac{E_1}{hc}\left[\frac{1}{2^2} - \frac{1}{n^2}\right]$n=$n_i$=3,4,5…………

This series is found in the visible region of the spectrum. ***The first, second, third lines of this series are called $H_\propto$, H_β and H_γ lines respectively.***

For $H_\propto$, $n_f = 2,\ n_i = 3$

For H_β , $n_f = 2,\ n_i = 4$

For H_γ, $n_f = 2,\ n_i = 5$

3. Paschen series:

This series is produced when electron jumps from higher stationary states to third stationary orbit (n_f=3)

$\bar{\vartheta} = \frac{1}{\lambda} = -\frac{E_1}{ch}\left[\frac{1}{3^2} - \frac{1}{n^2}\right]$n= n_i =4,5,6.........

This series is found in near infrared region of the spectrum.

4. ***Bracket series:***

This series is produced when electron jumps from higher stationary orbits to fourth stationary orbits. (n_f=4)

$\bar{\vartheta} = \frac{1}{\lambda} = -\frac{E_1}{ch}\left[\frac{1}{4^2} - \frac{1}{n^2}\right]$n=$n_i$=5,6,7.........

This series is found in mid-infrared region of e.m spectrum

5. **Pfund series:**

This series is produced when electron jumps from higher stationary states to 5^{th} stationary state (n_f= 5). Thus for this series,

$\bar{\vartheta} = \frac{1}{\lambda} = -\frac{E_1}{ch}\left[\frac{1}{5^2} - \frac{1}{n^2}\right]$n=$n_i$=6,7,8.........

$This\ series\ is\ found\ in\ far\ infraed\ \ region.$

b) ***Energy level diagram of hydrogen atom:***

We have, $\boldsymbol{E_n} = \frac{-\mathbf{13.6}}{\boldsymbol{n^2}}$ $\boldsymbol{E_n} = \frac{\boldsymbol{E_1}}{\boldsymbol{n^2}} \ldots\ldots\ldots\ldots 6(b)$

$E_1 = -13.6\ eV$

When n=1,

$$E_1 = \frac{13.6}{1^2} = -13.6\ eV \to ground\ state$$

$$n = 2, \qquad E_2 = \frac{13.6}{2^2} = -3.4\ eV \to 1^{st}\ excited\ \ state$$

$$n = 3, \qquad E_3 = \frac{13.6}{3^2} = -1.51 eV \to 2^{nd}\ excited\ \ state$$

....

....

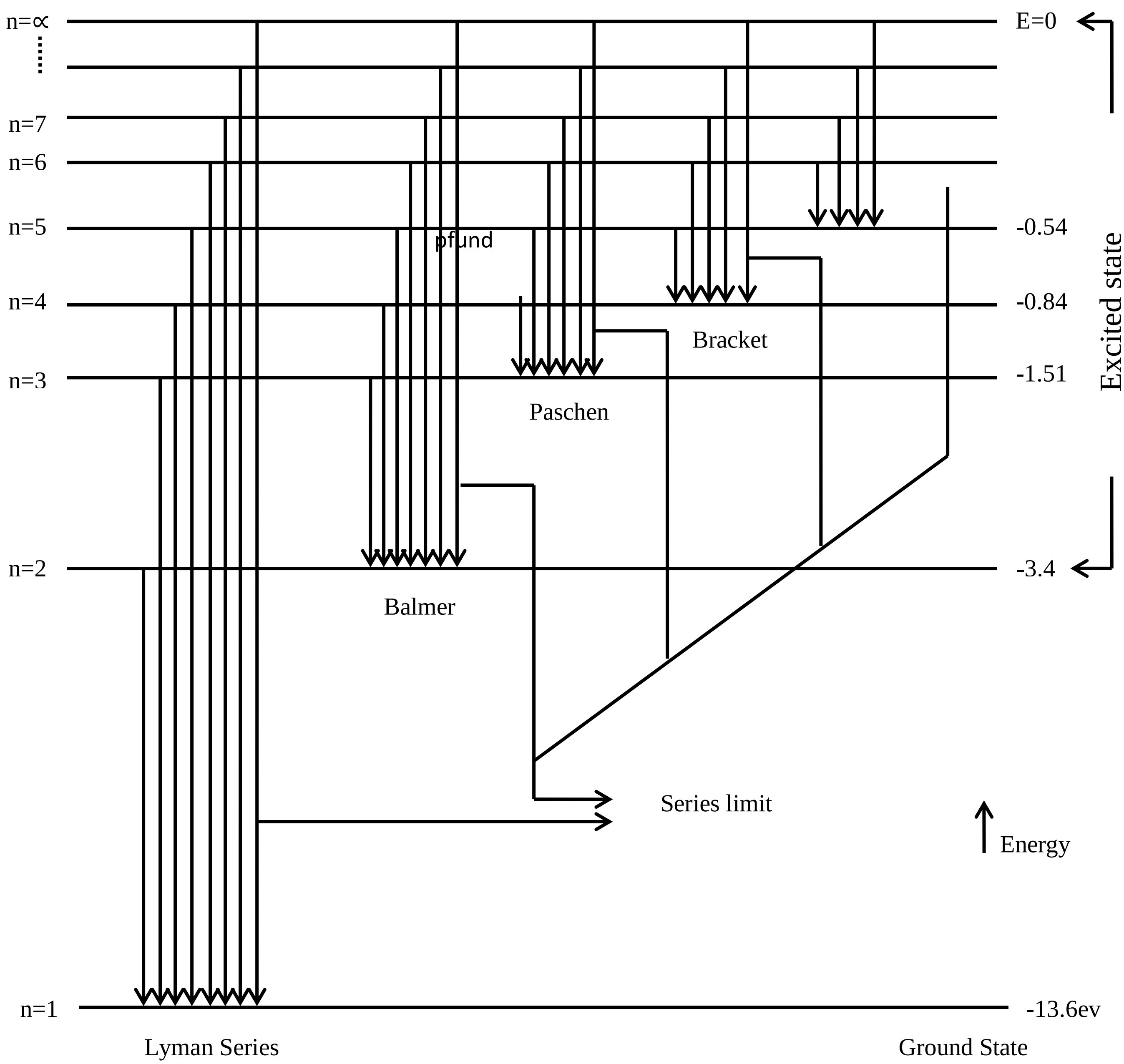
n $= \propto, \quad E_\propto = 0$

The equation $\boldsymbol{E_n} = \frac{-\boldsymbol{me^4}}{\boldsymbol{8\varepsilon_0{}^2h^2}}\left(\frac{\mathbf{1}}{\boldsymbol{n^2}}\right) = \frac{E_1}{n^2} \ldots\ldots\ldots\ldots 6(b)$,can be diagrammatically represented. ***Then it is called the energy level diagram***.

The lowest energy level E_1 is called the normal or the ground state of the atom and the higher energy levels, E_2, E_3…….are called the excited states. If n $=\propto$, $E_{\propto} = 0$,the electron is free. In all other orbits the energy is '-'ve. Due to this reason electron is bound to the nucleus. In the energy level diagram, the discrete energy states are represented by horizontal lines and the electronic jump between these states by vertical lines.

Note:-

$\frac{-E_1}{ch} = \frac{me^4}{8\varepsilon_0{}^2h^3c} = R = 1.097 \times 10^7 m^{-1,}$, R = Rydberg's Constant ie, Bohr's model of hydrogen atom is in accordance with spectral data.



Correspondence Principle:

Bohr's correspondence principles states that for large quantum numbers,quantum physics gives the same results as those of classical physics.

Proof:-

According to classical e.m theory, an electron moving in a circular orbit radiates e.m waves having a frequency equal to the frequency of the revolution including harmonics which are integral multiples of that frequency. Velocity of an electron of mass m revolving round the nucleus in an orbit of radius r is

$$v = \frac{e}{\sqrt{4\pi\varepsilon_o mr}} \qquad \text{Refer page (3),eqn (1)}$$

Classical frequency of revolution f of the electron

$$f = \frac{electronspeed}{orbitcircumference} = \frac{v}{2\pi r} = \frac{e}{2\pi\sqrt{4\pi\varepsilon_0 mr^3}}$$

$$f = \frac{1}{2\pi}\frac{e}{(4\pi\varepsilon_o m)^{1/2} r^{3/2}} \ldots\ldots\ldots. (1)$$

But orbital radii in Bohr atom,

$$r_n = \frac{n^2h^2\varepsilon_0}{\pi me^2} \ldots\ldots\ldots\ldots\ldots.. (2)\text{Ref.page (3), eqn(3)}$$

Put (2) in (1)

$$f = \frac{1}{2\pi}\frac{e}{(4\pi\varepsilon_0 m)^{1/2}\left(\frac{n^2h^2\varepsilon_0}{\pi me^2}\right)^{3/2}}$$

$$f = \frac{me^4}{4\boldsymbol{\varepsilon_0}^{\mathbf{2}}h^2}\frac{1}{n^3}$$

Or orbital frequency $f = \frac{me^4}{8\boldsymbol{\varepsilon_0}^{\mathbf{2}}h^2}\frac{2}{n^3} \ldots\ldots\ldots\ldots\ldots (3)$

This is the frequency which must be radiated by the moving electron classically.

Now the frequency radiated on the basis of quantum theory is given by (or Bohr's theory of hydrogen atom)

$$\vartheta = \frac{E_i - F_f}{h} = \frac{-E_1}{h}\left(\frac{1}{{n_f}^2} - \frac{1}{{n_i}^2}\right)$$ Refer eqn (7) Page No (4)

But $E_1 = \frac{-me^4}{8\boldsymbol{\varepsilon_0}^2 h^2}$ Refer, Page(5) eqn 6(a)

$$\therefore \vartheta = \frac{- \times -me^4}{8\boldsymbol{\varepsilon_0}^2 h^2 h}\left[\frac{1}{{n_f}^2} - \frac{1}{{n_i}^2}\right]$$

$$\vartheta = \frac{me^4}{8\boldsymbol{\varepsilon_0}^2 h^3}\left[\frac{1}{{n_f}^2} - \frac{1}{{n_i}^2}\right] \ldots\ldots\ldots\ldots(4)$$

When the quantum numbers involved are large ie n_f=n and n_i=n+1, where n>>1,

$$\vartheta = \frac{me^4}{8\boldsymbol{\varepsilon_0}^2 h^3}\left[\frac{1}{n^2} - \frac{1}{(n+1)^2}\right]$$

$$\vartheta = \frac{me^4}{8\boldsymbol{\varepsilon_0}^2 h^3}\left[\frac{(n+1)^2 - n^2}{n^2(n+1)^2}\right] = \frac{me^4}{\boldsymbol{8\varepsilon_0}^2 h^3}\left[\frac{n^2 + 2n + 1 - n^2}{n^2(n+1)^2}\right]$$

As n>>> 1, so neglecting 1,as compared to n and 2n, we get,

$$\vartheta = \frac{me^4}{8{\varepsilon_0}^2 h^3}\frac{2n}{n^2 n^2}$$

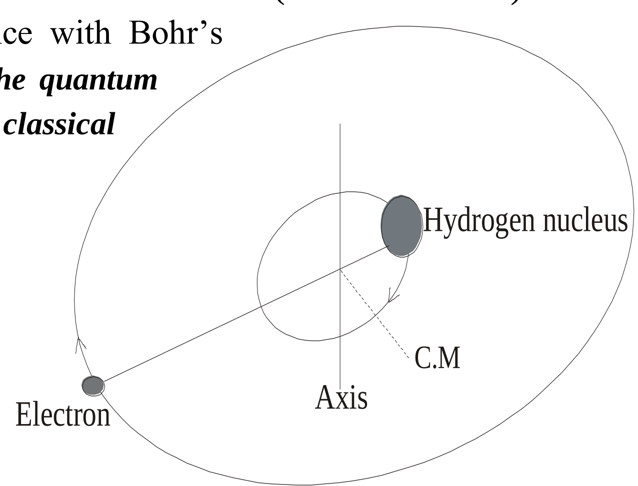
$\therefore$Bohr frequency $\vartheta = \frac{me^4}{8\boldsymbol{\varepsilon_0}^2 h^3}\frac{2}{n^3} \ldots\ldots\ldots(5)$

Compare eqn (3) and (5) we get,

Orbital frequency = Bohr frequency

Thus for very large quantum number n, the quantum theory frequency $\boldsymbol{\vartheta}$ of the radiation is identical with the classical frequency **f** of the revolution (or its harmonics) of the electron in the orbit. This is in accordance with Bohr's correspondence principle. In fact,"***The greater the quantum number, the closer quantum physics approaches classical physics".***

Nuclear motion:



While deriving Bohr's formula, we have assumed that the nucleus remains stationary. But actually both the nucleus as well as the election revolves around their common centre of mass, which is very close to the nucleus because the mass of the nucleus is greater than that of the electron. A system of this kind is equivalent to a single particle of mass m that revolves around the position of the heavier particle.

This two body problem isequivalent to a single body problem,if we consider the reduced mass m' which revolves around C.M

ie, reduced mass$m' = \frac{mM}{m+M}$ | m= mass of electron

M= Mass of nucleus (nucleus mass)

The quantity m' is called reduced mass of the electron because its value is less than m. We know, energy of the electron in the nth orbit,

$$E_n = \frac{-me^4}{8\varepsilon_0{}^2h^2}\left(\frac{1}{n^2}\right) = \frac{\mathrm{E}_1}{\mathrm{n}^2}$$

If nuclear motion is taken into account then mass of electron m is to be replaced by m'

$\therefore energylevelscorrectedfornuclearmass,$

$$\boldsymbol{E_n}' = \frac{-m'e^4}{8\varepsilon_0{}^2h^2}\left(\frac{1}{n^2}\right) = \frac{-mM}{m+M}\frac{e^4}{8\varepsilon_0{}^2h^2}\left(\frac{1}{n^2}\right)$$

$$= \frac{M}{m+M} \times \frac{E_1}{n^2}$$ but ,$\frac{m'}{m} = \frac{M}{m+M}$

$$\boldsymbol{E_n}' = \left(\frac{m'}{m}\right)\frac{E_1}{n^2}$$

ie, due to the motion of the nucleus all the energy levels of hydrogen are changed by the fraction,

$$\frac{m'}{m} = \frac{M}{M+m} = 0.9945$$

Atomic Excitation:

When electron in an atom is raised from its ground state to a higher energy state, the atom is said to be in the excited state. An atom can remain in an excited state only for a very short interval of time (10^{-8}sec). Then the atom returns to its ground state by a single quantum jump (electron jump) or by a series of such jumps between intermediate levels, emitting the absorbed energy in the form of e m radiations.

The minimum energy required to raise an atom from one energy level to another is called ***excitation energy***. When excitation energy is expressed in electron volt (eV), it is termed as ***excitation or resonance or radiation potential***.

Note:***If an electron is removed completely free from the influence of the nucleus of an atom, then that atom is said to be ionized***. The energy required to ionize an atom is termed as ***ionization energy***. When ionizationenergy is expressed in electron volt (eV), it is called as ***ionization potential***)

The excitation of an atom can be brought about by supplying energy. There are two main ways by which an atom can be excited.

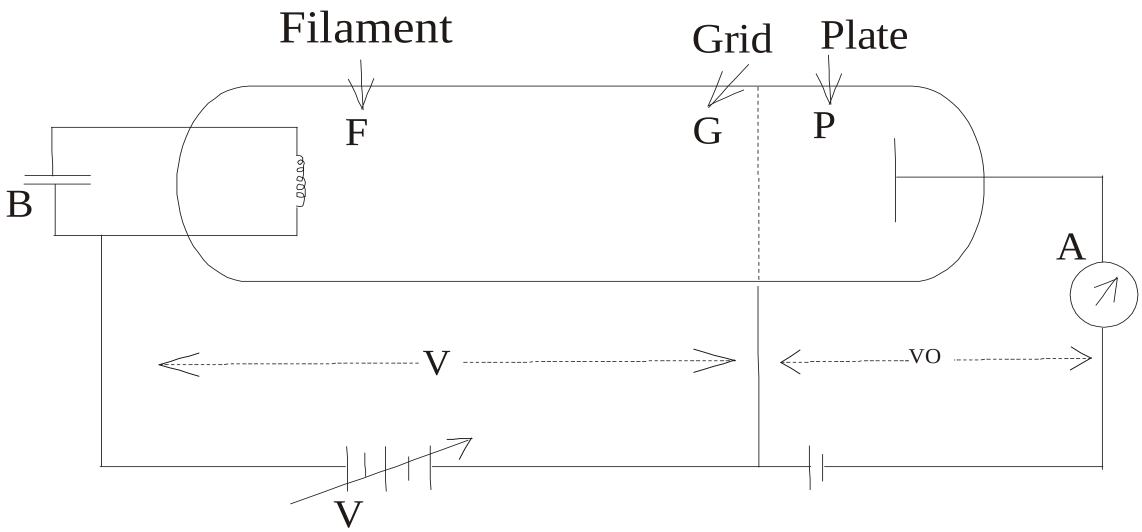
1. **Excitation by collision:** One method of exciting the atom is to bombard it with electrons having enough K.E. The electron gives up all or part of its K.E in exciting the atom. The atom then emits a photon in returning to its ground state. Neon signs and mercury vapor lamps are familiar examples of how a strong electric field applied between electrodes in a gas filled tube leads to the emission of the characteristic spectral radiation of that gas. We get reddish light in the case of neon and bluish light in the case of mercury vapor.
2. ***Irradiation of atoms with while light:***

   Atoms can be excited by energy supplied in the form of light. An atom absorbs a photon of light whose energy is just the right amount to raise the atom to a higher energy level. This process explains the ***origin of absorption spectra***.

   Frank- Hertz experiment:

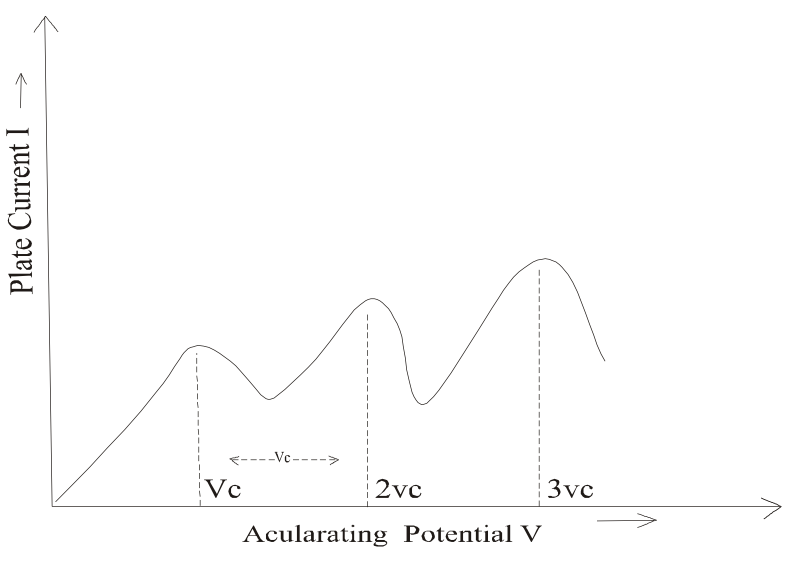
   According to Bohr's atomic model, the atomic energy levels are quantized. Frank - Hertz experiment provides a direct evidence for the existence of discrete energy states within an atom.

a) ***Experimental arrangement***



It consists of a glass tube T in which are mounted a filament F, the grid G and a plate P. The gas of the element whose atoms are to be studied is filled in the glass tube T. Electrons are produced by heating the filament F by a L.T (low tension) battery B. These electrons are accelerated towards a grid G by the P.d 'V' between F and G.'V' can be varied by a potentiometer arrangement. The accelerated electrons are retarded by applying a small retarding potential V_0 (=.5V) between the grid G and the collecting plate P. Thus, only those electrons from G can go to P which has kinetic energies greater than this p.d V_o. The electrons collected by the plate P give rise to a current which is measured by a millimeter A.

Keeping V_o constant, V is gradually increased in small steps from zero upward and plate current is measured in each case. The current is plotted against the accelerating potential V. The curve obtained shows a series of regularly spaced peaks.



Explanation of the graph

Electrons are emitted from F with a range of small energies. In the beginning they acquire a small additional energy eV on reaching G. Those electrons whose energy is now greater than eV_o reach pand a current is obtained. On increasing the acceleration potential V,the plate current increases. Between F and G the electrons collide with the gas atoms. But since the electron energies are not enough to excite the atoms, the electrons do not lose energy in these elastic collisions.

When the accelerating potential V becomes equal to the first excitation potential V_c of the gas atoms, the electron energy at G is eV_c. The electrons can now suffer inelastic collisions with gas atoms near G and excite them to an energy level above their ground state.The electrons lose their energy and are unable to reach p against the retarding potential. Hence the current drops sharply. Thus the position of the first peak gives the excitation potential V_c of the gas atoms.

As the accelerating potential V is increased further, electrons acquire enough energy to reach the plate P. When V becomes equal to $2V_c$, a second inelastic collision occurs near the grid G and the current drops again. Thus the second peak gives $2V_c$. This process repeats as V is further increased.

The true excitation potential V_C is obtained by measuring the distance between two successive peaks.

c) Demonstration of the existence of discrete energy levels:

Each time there is an inelastic collision, the atom will be excited and return to the ground state by the emission of photons.

$E = h\vartheta = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3x10^{8}J}{2536\times10^{-10}}$ $= 4.9eV$

λ is taken as2536^0A = Wavelength of radiation coming from the tube

Thus this experiment shows that the energy lost by the electron in its inelastic collision with the atom reappears as a quantum of energy of wavelength,

$$\lambda = \frac{hc}{E}$$

The experiment shows that electrons transfer energy to the atoms in discrete amounts and that they cannot excite the atoms if their energy is less than eV_C. Franck- Hertz demonstrated it directly by observing the spectrum of the gas during electron collisions. They showed that particular spectral line does not appear until the electron energy reaches a threshold value. For example, in the case of mercury vapor, they found that minimum electron energy of 4.9eV was required to obtain 2536^0 A line of Hg, and a photon of 2536^0A light has an energy of just 4.9eV. This shows that discrete energy levels do exist in atoms and the electrons of the atom can exist only in these levels.