CHAP-12 (ATOMS)

ALPHA PARTICLE SCATTERING EXPERIMENT :

Rutherford and his two associates H. Geiger and E. Marsden performed experiments on the scattering of α- particle from thin foils and obtained an important insight into the structure of the atom.

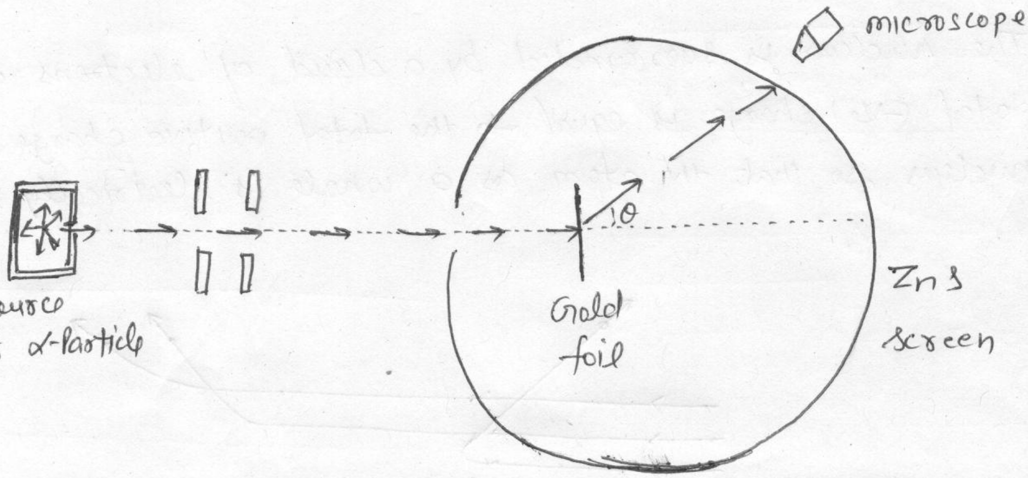
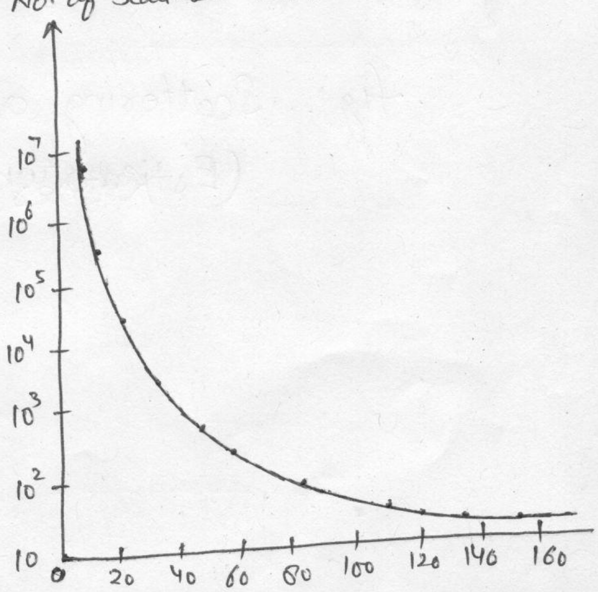


fig. Geiger & Marsden experiment

OBSERVATIONS :-

from the graph, it is clear that

1. most of the α- particle pass straight through gold foil
2. A few α- particles, about 1/8000, get deflected through 90° or more.
3. Occasionally, an α- particle gets rebounded from the gold foil, suffering a deflection of nearly 180°



Significance of the result :-

Rutherford concluded the following important facts about an atom

1. As most of the α- particle pass straight through the foil, so most of the space within atoms must be empty.

2. Most of the α- Particle scattered largly, so there must be a (+ve) charge particle whoes size is tiny and whole ~~mass~~ mass will be concentrated in to it.

3. The nucleus is surrounded by a cloud of electrons whose total (-ve) charge is equal to the total positive charge on the nucleus so that the atom as a whole is electrically neutral.

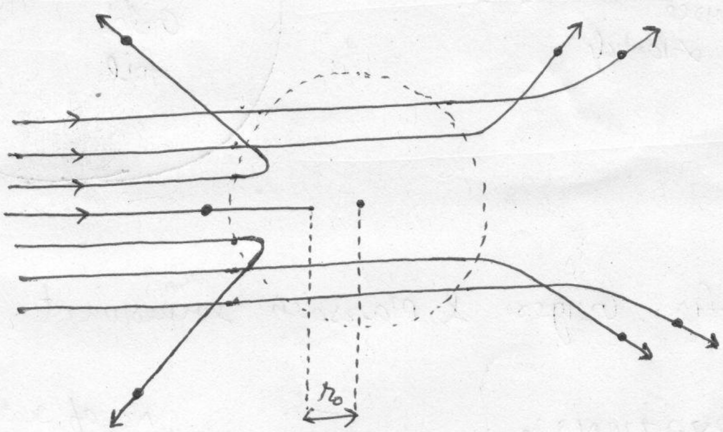


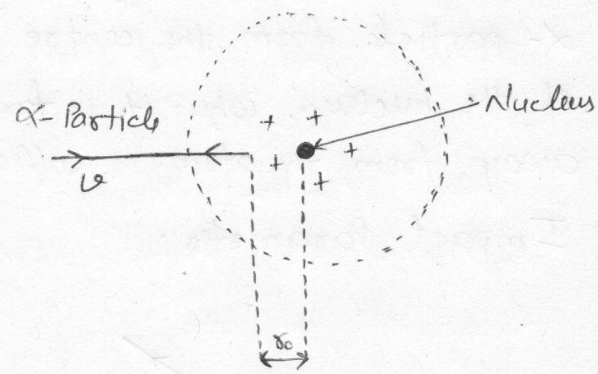
fig: Scattering of 'α- Particles' on the Rutherford model

DISTANCE OF CLOSEST APPROACH :

(ESTIMATION OF NUCEAR SIZE)

Charge on nucleus $q_1 = +Ze$

Charge on α-Particle $q_2 = +2e$



∵ The minimum distance where the Kinetic energy convert in Potential energy is called closest approach.

$$K.E = \text{Potential energy}$$

$$\frac{1}{2} m v^2 = k \frac{Ze\,2e}{r_0} \qquad \left(\because U = k \frac{q_1 q_2}{r_{12}}\right)$$

$$\boxed{r_0 = \frac{2kZe^2}{K_\alpha}}$$

$$\boxed{r_0 = \frac{4kZe^2}{mv^2}} \Rightarrow \boxed{r_0 = 4 \times \frac{1}{4\pi\varepsilon_0} \cdot \frac{Ze^2}{mv^2} = \frac{Ze^2}{\pi\varepsilon_0 m v^2}}$$

or $k = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \ Nm^2/C^2$

If $K_\alpha = 5.5\ MeV$ (from Rutherford Experiment)

$= 5.5 \times 1.6 \times 10^{-13}\ J$ (for Gold $Z = 79$)

$$r_0 = \frac{2kZe^2}{K_\alpha} = \frac{2 \times 9 \times 10^9 \times 79 \times (1.6 \times 10^{-19})^2}{5.5 \times 1.6 \times 10^{-13}}$$

$$r_0 = 4.13 \times 10^{-14}\ m = 41.3 \times 10^{-15}\ m$$

$$\boxed{r_0 = 41.3\ fm}$$

IMPACT PARAMETER

The perpendicular distance of the velocity vector of the α- particle from the centre of the nucleus, when it is far away from the atom is called Impact Parameter.

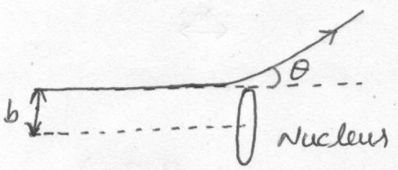


fig: Parameter b and scattering angle θ.

Special features:-

1. The large impact parameter, the weak repulsive force. and θ is almost zero
2. The small impact parameter, the large repulsive force and θ will be large.
3. for a head-on collision, the impact parameter is zero.

Hence, the shape of the trajectory of the scattered α- Particles depends on the impact parameter. and nature of potential field.

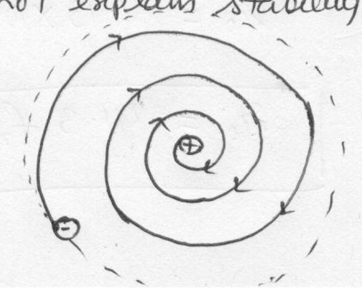
Rutherford found relation b/w impact parameter (b) and the scattering angle.

$$\boxed{b = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2Ze^2 \cot \theta/_2}{K}}$$

where $K = \frac{1}{2}mv^2$ = Kinetic Energy of α- Particle.

LIMITATIONS OF RUTHERFORD ATOMIC MODEL:

1. Stability of atom: According to Rutherford electrons revolves around the nucleus in circular orbit. Since, circular motion is an accelerated motion, and accelerated charge particle radiate energy. So, during Circular motion electron should release the energy and move in orbits of gradually decreasing radii. The electron should follow spiral path and finally it should collapse into the nucleus. Hence Rutherford's model Cannot explain stability of atom.



BOHR'S ATOMIC MODEL :-

Bohr's gave following postulate regarding motion of electron around the nucleus. It is also called Planetary model of atom.

1. Nuclear Concept :- Every atom consists small and massive central core, called nucleus around which electrons revolve. The essential centripetal force required for their rotation is provided by the electrostatic attraction between the electrons and the nucleus.

2. Quantum Condition :- Electrons can revolve only those orbit in which their's angular momentum is multiple integer of $\frac{h}{2\pi}$, where h is planck's constant.

angular momentum (L)

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

where $n = 1, 2, 3$ ------

n is called principal quantum number and this above equation is called Bohr's quantum Condition.

3. Stationary or Stable orbits :

The orbit in which angular momentum of electrons is $\frac{nh}{2\pi}$, is called stable or stationary orbit. In these stable orbit, electrons does not radiate energy.

4. Frequency Condition.

When atom acquire some extra energy from out side, then its any electron goes to Corresponding higher energy level. But stays there only for 10^{-8} sec and during return back, it radiates energy in form of electromagnetic wave.

If Energy in lower and higher energy level is E_1 and E_2 respectively then, radiating energy by electron

$$\Delta E = E_2 - E_1$$

but $\Delta E = h\nu$

$$\boxed{h\nu = E_2 - E_1}$$

where ν = frequency of electromagnetic wave or photon.

EXPLAINATION OF BOHR'S QUANTISATION CONDITION BY de-Broglie:-

According to de-Broglie, the electron is also associated with wave character. Hence a circular orbit can be taken to be a stationary energy state only if it contains an integral number of de-Broglie wave length, i.e.,

$$2\pi r = n\lambda \quad \text{——— (1)}$$

where $n = 1, 2, 3 \ldots$ and r = radius of circular orbit

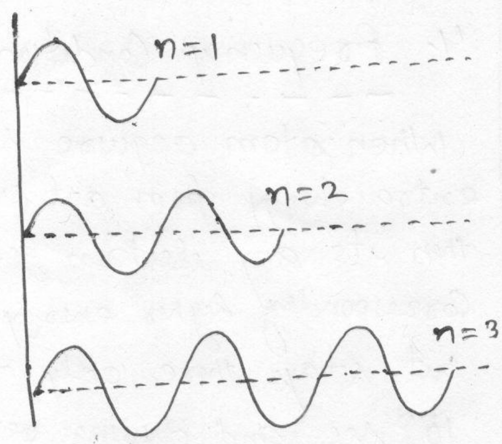


fig. (a)

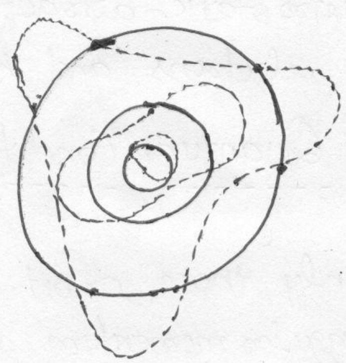


fig. (b)

but According to de-Broglie

$$\lambda = \frac{h}{mv}$$

puting in eqn (1)

$$2\pi r = n\frac{h}{mv}$$

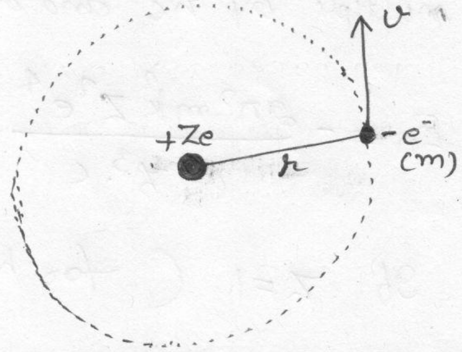
$$\boxed{mvr = n\frac{h}{2\pi}}$$

This is Bohr's quantisation condition for angular momentum.

BOHR'S MODEL OF HYDROGEN ATOM

$\because q_1 = Ze, \quad q_2 = e$

$F = k\frac{q_1 q_2}{r^2} = k\frac{Ze \cdot e}{r^2}$



from I^st postulate of Bohr's

Centripetal force = electrostatic force

$$\frac{mv^2}{r} = k\frac{Ze \cdot e}{r^2}$$

$$mv^2 = \frac{kZe^2}{r} \quad \text{------} \quad (1)$$

$$r = \frac{kZe^2}{mv^2} \quad \text{------} \quad (2)$$

from second postulate

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

$$r = n\frac{h}{2\pi mv} \quad \text{------} \quad (3)$$

from eqⁿ (2) and (3)

$$\frac{kZe^2}{mv^2} = \frac{nh}{2\pi mv}$$

$$\boxed{v = \frac{2\pi kZe^2}{nh}} \quad \text{---} \quad (4)$$

multiple and divide by c

$$v = \left(\frac{2\pi kZe^2}{ch}\right)\frac{c}{n}$$

but $\frac{2\pi kZe^2}{ch}$ = constant

its value comes $\left(\frac{1}{137}\right)$ where $Z=1$

so, speed of electron

$$\boxed{v = \frac{1}{137} \cdot \frac{c}{n}}$$

Bohr's radius :-

Puting $v = \frac{2\pi kZe^2}{nh}$ in equation (3)

$$r = \frac{nh}{2\pi m \frac{2\pi kZe^2}{nh}}$$

$$r = \frac{n^2h^2}{4\pi^2 k m Ze^2}$$

$$r = \frac{n^2}{Z}\left(\frac{h^2}{4\pi^2 kme^2}\right)$$

where $\frac{h^2}{4\pi^2 kme^2}$ = constant

its value comes 0·53 A°

$$r = \frac{n^2}{Z}(0{\cdot}53\,A^\circ)$$

for hydrogen $Z=1$

If $n = 1$

$$\boxed{r_0 = 0.53 A^\circ}$$

This is called Bohr's radius.

Energy of electron:-

Kinetic energy

$$K = \frac{1}{2}mv^2 = \frac{1}{2} \cdot k\frac{Ze^2}{r}$$

(from equation 1)

Potential energy

$$U = k\frac{q_1 q_2}{r} = \frac{kZe(-e)}{r}$$

$$U = -k\frac{Ze^2}{r}$$

Total kinetic energy

$$E_n = K + U$$

$$= \frac{kZe^2}{2r} - k\frac{Ze^2}{r}$$

$$= k\frac{Ze^2}{r}\left(\frac{1}{2} - 1\right)$$

$$\boxed{E_n = -\frac{kZe^2}{2r}}$$

Puting $r = \frac{n^2 h^2}{4\pi^2 mkZe^2}$

$$E_n = -\frac{kZe^2}{2r} \cdot \frac{4\pi^2 mkZe^2}{n^2 h^2}$$

$$E_n = -\frac{2\pi^2 mk^2 Z^2 e^4}{n^2 h^2}$$

multiple by hc and divide also

$$E_n = -\frac{2\pi^2 mk^2 Z^2 e^4}{n^2 h^3 \cdot c} \cdot hc$$

If $Z = 1$ (for hydrogen)

then $\frac{2\pi^2 mk^2 e^4}{h^3 \cdot c} = R$ (Constant)

R is called Rydberg constant and its value comes

$$R = 1.0973 \times 10^7 \ m^{-1}$$

Hence,

$$\boxed{E_n = -\frac{Rhc}{n^2}}$$

Puting $R = 1.0973 \times 10^7 \ m^{-1}$

$h = 6.64 \times 10^{-34}$ J·s

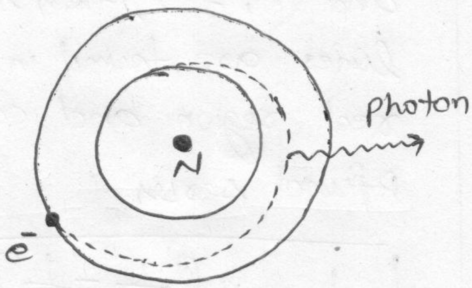
$c = 3 \times 10^8$ m/s

$$\boxed{E_n = -\frac{13.6}{n^2} eV}$$

(−ve) sign indicate that electron is bound to nucleus by attractive force and work is required to be done to pull it away from the nucleus.

SPECTRAL SERIES OF HYDROGEN ATOM

According to Bohr's frequency condition, when electron makes a transition from a higher energy level (n_2) to a lower energy level n_1, then the



difference of energy appears in the form of a photon. The frequency ν of the emitted photon is given by $h\nu = E_{n_2} - E_{n_1}$

but $E_{n_1} = -\dfrac{Rhc}{n_1^2}$

and $E_{n_2} = -\dfrac{Rhc}{n_2^2}$

so,

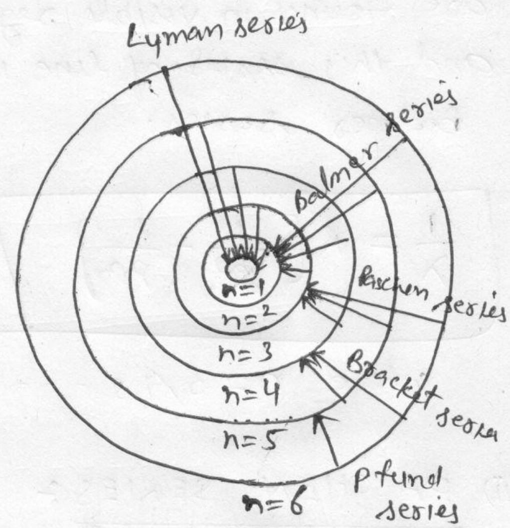
$$h\nu = -\frac{Rhc}{n_2^2} - \left(-\frac{Rhc}{n_1^2}\right)$$

$$\frac{hc}{\lambda} = -\frac{Rhc}{n_2^2} + \frac{Rhc}{n_1^2}$$

$$\frac{hc}{\lambda} = Rhc\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$$\boxed{\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]}$$

$\frac{1}{\lambda}$ is called wave number.



1. LYMAN SERIES :-

If electron jumps from any higher energy level $n_2 = 2, 3, 4 ----$ to lower energy level $n_1 = 1$, then spectral lines are found in ultraviolet region of the electromagnetic spectrum and these lines are called Lyman series.

$$\frac{1}{\lambda} = R\left[\frac{1}{1^2} - \frac{1}{n_2^2}\right]$$

where $n_2 = 2, 3, 4 ----$

(ii) BALMER SERIES :-

When electron jumps from any higher energy level $n_2 = 3, 4, 5$ ---- to second energy level $n_1 = 2$, then spectrum line are found in visible region and this series of line is called Balmer series.

$$\boxed{\frac{1}{\lambda} = R\left[\frac{1}{2^2} - \frac{1}{n^2}\right]}$$

where $n = 3, 4, 5$ ---

(iii) PASCHEN SERIES :-

If electron jumps from $n_2 = 4, 5, 6$ --- and $n_1 = 3$ then spectral line are found in infrared region which is called Paschen series.

$$\boxed{\frac{1}{\lambda} = R\left[\frac{1}{3^2} - \frac{1}{n^2}\right]}$$

$n = 4, 5, 6$ ----

(iv) BRACKETT SERIES :-

If $n_2 = 5, 6, 7$ --- and $n_1 = 4$ then spectral lines are found in infrared region and called Bracket series.

$$\boxed{\frac{1}{\lambda} = R\left[\frac{1}{4^2} - \frac{1}{n^2}\right]}$$

where $n = 5, 6, 7$ ----

(v) PFUND SERIES :-

If $n_2 = 6, 7, 8$ -----

and $n_1 = 5$, then spectral lines are found in infra reed region and called Pfund series

$$\boxed{\frac{1}{\lambda} = R\left[\frac{1}{5^2} - \frac{1}{n^2}\right]}$$

where $n = 6, 7, 8$ ---

Special note :-

$n_2 = n_1 + 1$ is called H_α line (minimum frequency or maximum wavelength

$n_2 = n_1 + 2$ called H_β line or second line

$n_2 = n_1 + 3$ called H_γ line or third line

$n_2 = \infty$ is called series limit or, maximum frequency or, minimum wavelength.

ENERGY LEVEL DIAGRAM

The diagram in which the energies of the different stable states of an atom are represented by parallel horizontal lines, drawn according to some suitable energy scale is called energy level diagram.

We know that energy in n^{th} orbit

$$E_n = -\frac{13.6}{n^2}$$

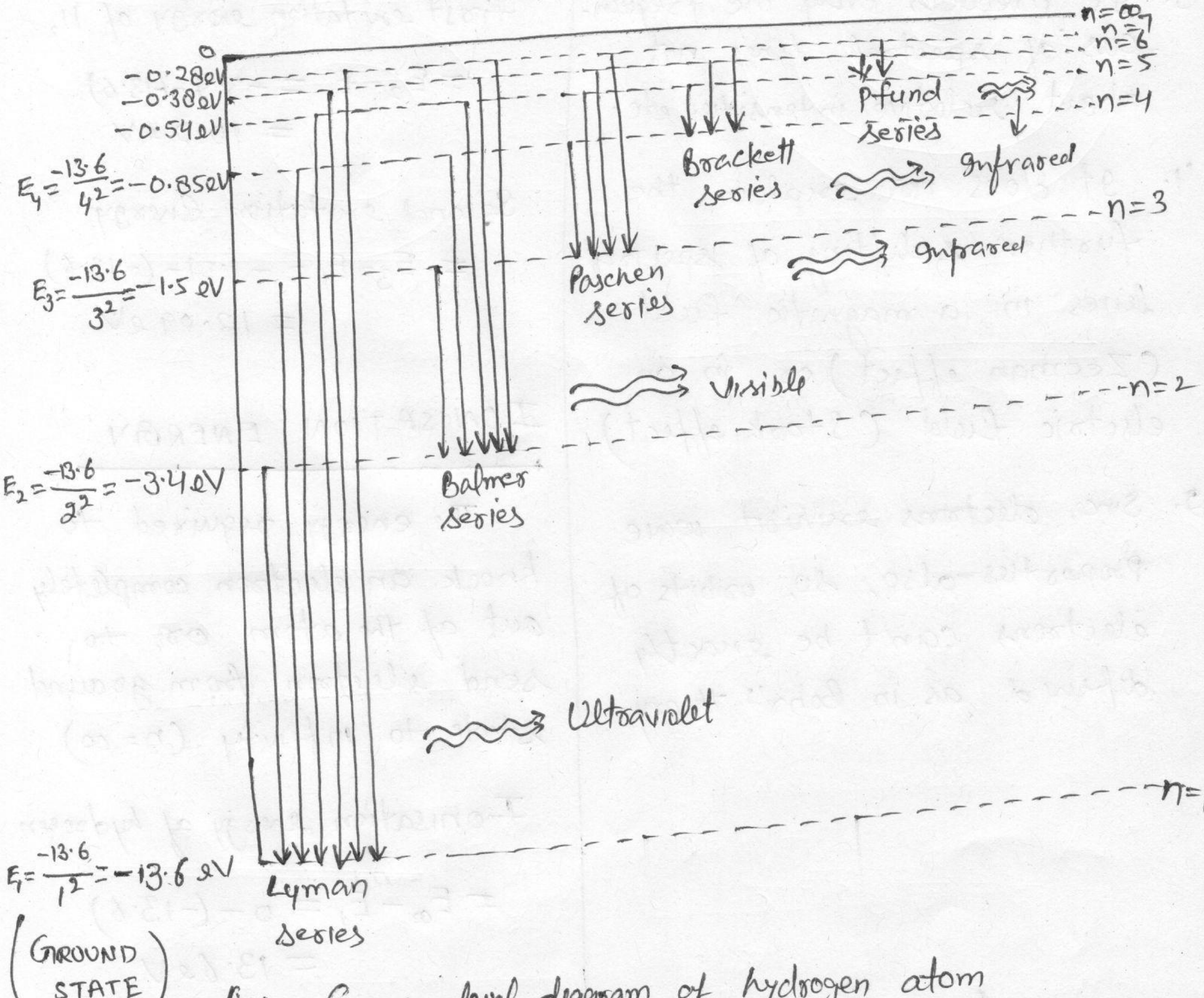


fig:- Energy level diagram of hydrogen atom

LIMITATIONS OF BOHR'S THEORY

1. It is applicable only to hydrogen like single electron atoms i.e. Li^{++} etc.
2. It does not explain why only circular orbits should be chosen when eleptical orbits are also possible.
3. It predicts only the frequencies of spectral lines not about relative intensities etc.
4. It does not explain the further splitting of spectral lines in a magnetic field (Zeeman effect) or in an electric field (Stark effect)
5. Since, electrons exihibit wave properties also, so, orbits of electrons can't be exactly defined as in Bohr's theory.

EXCITATION AND IONISATION POTENTIALS AND ENERGY

Excitation energy :- The energy required by its electron to jump from the ground state to any one of the excited states is called excitation energy.

first exitation energy of H_2.

$$= E_2 - E_1 = -3.4 - (-13.6)$$
$$= 10.2\,eV$$

Second exitation Energy

$$= E_3 - E_1 = -1.51 - (-13.6)$$
$$= 12.09\,eV$$

IONISATION ENERGY

The energy required to knock an electron completely out of the atom or, to send electron from ground state to infinity ($n = \infty$)

Ionisation energy of hydrogen

$$= E_\infty - E_1 = 0 - (-13.6)$$
$$= 13.6\,eV$$

EXCITATION POTENTIAL:

The accelerating potential which gives to a bombarding electron, sufficient energy to excite the atom by raising one of its electrons from an inner to an outer orbit is called excitation potential

First excitation potential of H_2

$$= -3.4 - (13.6) = 10.2\ V$$

IONISATION POTENTIAL:-

The accelerating potential which gives to a bombarding electron, sufficient energy to ionise the atom by knocking one of its electrons compeletly out of the atom.

Ionisation potential of H_2

$$= 0 - (-13.6)$$

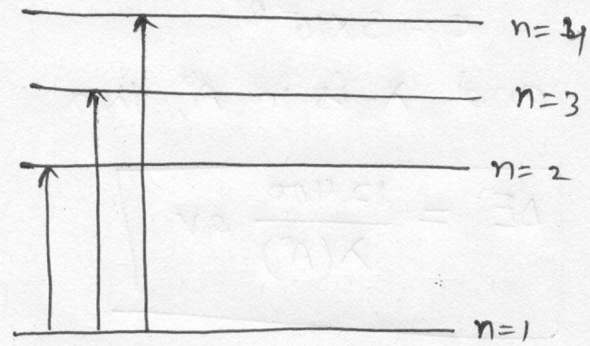
$$= 13.6\ V$$

(Ionisation Potential) of any atom

$$= \frac{-13.6\, Z^2}{n^2}\ \text{Volt}$$

ABSORPTION SPECTRUM:-

When electron reaches from ground state to higher energy level then spectral lines are called absorption spectrum i.e. for transition from n=1 to n=4

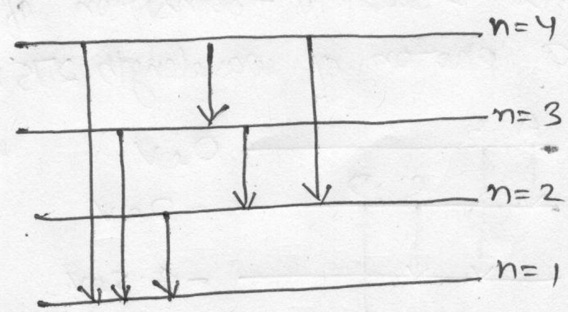


no. of spectral line = 3

EMISSION SPECTRUM:-

When electro transist from higher to lower energy level then no. of spectral lines are called emission spectrum. i.e. for n=4 to n=1

no. of line = 6



no. of speral line $= \frac{n(n-1)}{2}$

n = higher energy level

Very important formula:

Energy of photon $\Delta E = h\nu$

$$\Delta E = \frac{hc}{\lambda} \text{ joule}$$

If $h = 6.64 \times 10^{-34}$ J-s

$c = 3 \times 10^{8}$

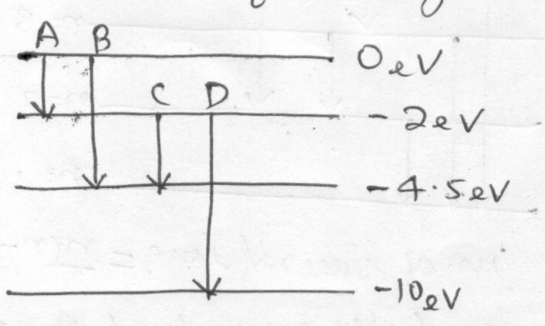
and λ is in A°, then

$$\boxed{\Delta E = \frac{12400}{\lambda(A^\circ)} \text{ eV}}$$

similarly,

$$\boxed{\lambda = \frac{12400}{\Delta E(\text{eV})} A^\circ}$$

Example :- (a) The energy levels of an atom are as shown below. Which of them will result in transition of a photon of wavelength 275 nm.



(b) which transition corresponds to emission of radiation of (i) maximum (ii) minimum wavelength

Solution: (a) for $\lambda = 275$ nm

$$\lambda = 275 \times 10^{-9} m$$
$$= 2750 \times 10^{-10} m$$
$$= 2750 A^\circ$$

Energy radiates

$$\Delta E = \frac{12400}{\lambda(A^\circ)} \text{ eV}$$
$$= \frac{12400}{2750} \text{ eV}$$
$$= 4.5 \text{ eV}$$

This energy corresponds to the transition B for which the energy change

$$= 0 - (-4.5) = 4.5 \text{eV}$$

(b) $\because \lambda_{min} \propto \frac{1}{(\Delta E)_{max}}$

so, transition A, Energy difference (emission) is minimum, corresponds to emission of maximum λ.

$$\therefore \lambda_{max} \propto \frac{1}{(\Delta E)_{max}}$$

So, transition D, for which (ΔE) is maximum, corresponds to minimum wavelength