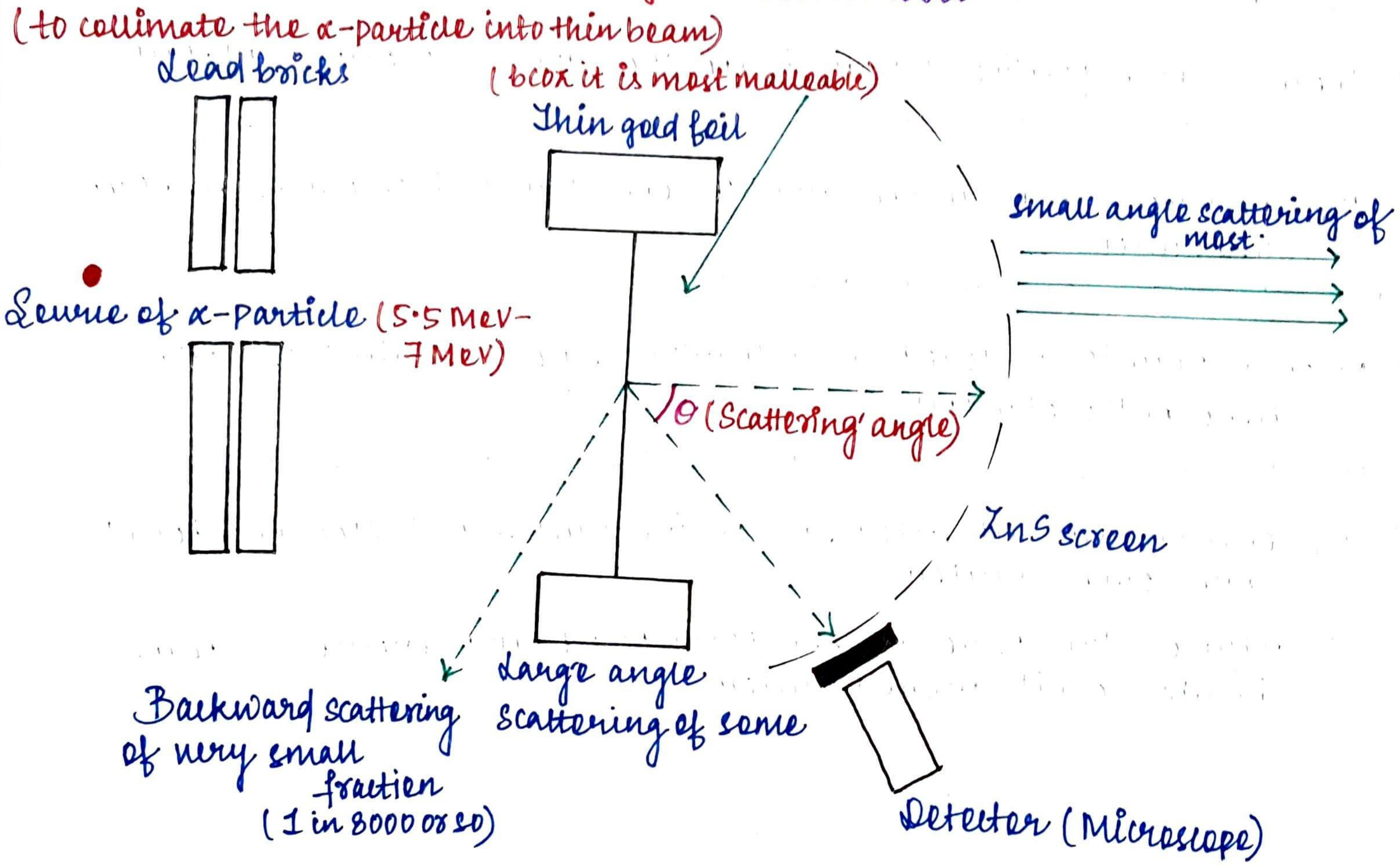
ATOMS :-

* All elements consist of very small invisible particles are called atoms.
* The first model of atom was proposed by JJ Thomson in 1898 called plum pudding model of the atom.

α-particle scattering expt :-

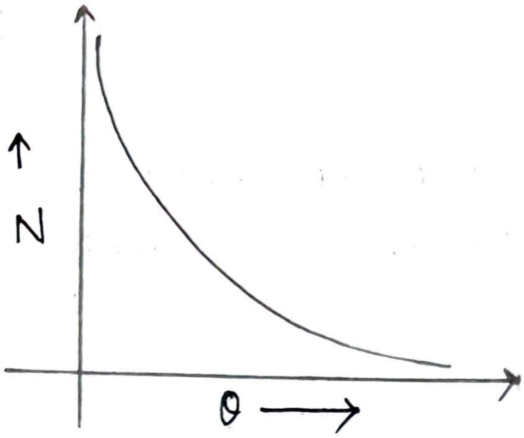
* In 1911, Geiger and Marsden performed α-particle scattering expt. on the suggestion of Rutherford.

Schematic arrangement of Geiger-Marsden expt :-



OBSERVATIONS :-

1. Most of the α-particle (99·86%) went undeviated. i.e they didnot suffer any collision. i.e they went straight.
2. About 0·14% of α-particle deviate more than 0°
3. 1 in 8000 of the α-particle deviate more than 90°
4. 1 in 10^6 of the α-particle return back i.e (deviate through an angle of 180°)



N = no. of α-particles deviated

θ = Scattering angle

No of α-particle, deviated at an angle θ,

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

Z = atomic no. of foil

RESULTS/CONCLUSIONS:-

① Most part of the atom is empty space (hollow)

Reason:- 99.86% α-particles passes undeviated.

② There is some positive charge inside the atom in a very small space.

Reason:- 0.14% α-particle deflect more than 1°.

③ The positive charge inside atom is conc. to an extremely small space called nucleus.

Reason:- 1 in 10^6 α-particle deviate through 180°.

④ No. of α-particle scattered at particular angle 'θ' is different for different metal foils.

Reason:- Different metals have different +ve charge on their nucleus.

⑤ The electron are attracted by positive nucleus but electron donot move toward nucleus.

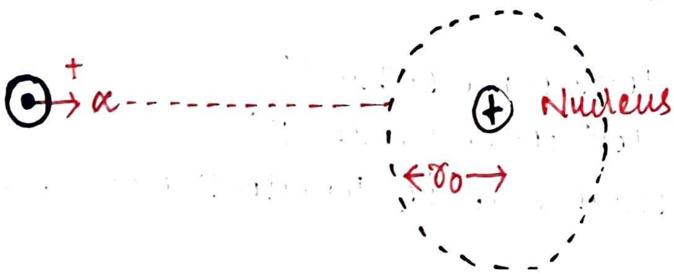
e^- utilises this force as centripetal force and revolves in any circular orbit around nucleus.

$$F_e = F_c$$

⇒ electrostatic force = centripetal force.

DISTANCE OF CLOSEST APPROACH:- (r_0)

It is the minimum distance between which the α-particle passes through the central line of nucleus and centre of atom.



∴ If r_0 is the distance of closest approach, then $KE = PE$

$$\Rightarrow KE = \frac{1}{4\pi\epsilon_0} \frac{2e \cdot Ze}{r_0}$$

$$\Rightarrow KE = \frac{1}{4\pi\epsilon_0} \frac{2Ze^2}{r_0}$$

$$\Rightarrow KE \cdot 4\pi\epsilon_0 \cdot r_0 = 2Ze^2$$

$$\Rightarrow r_0 = \frac{2Ze^2}{4\pi\epsilon_0 \cdot KE}$$

$$\Rightarrow r_0 = \frac{1}{4\pi\epsilon_0} \frac{2Ze^2}{KE}$$

$$\Rightarrow \boxed{r_0 = \frac{2KZe^2}{KE}}$$ (If K.E is max then r_0 is min)

Max value of $KE = 7.7\ MeV$, $Z = 79$

$$r_0 = \frac{2 \times 9 \times 10^9 \times 79 \times (1.6 \times 10^{-19})^2}{7.7 \times 10^6 \times 1.6 \times 10^{-19}}$$

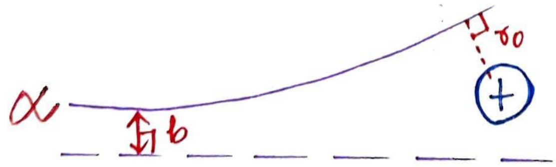
$$= 30 \times 10^{-15}\ m$$

$$r_0 = 30\ fm$$

* Actual gold size of nucleus is 6 fm.

IMPACT PARAMETER (b)

It is the perpendicular distance of the initial velocity vector of the α-particle from the central line of nucleus.



$$\boxed{b = \frac{1}{4\pi\epsilon_0} \cdot \frac{Ze^2 \cot \theta/2}{KE}}$$

Where, b = impact parameter
θ = Scattering angle
KE = kinetic energy of α-particle

when $b \to 0$, $\theta = \pi$
$b \to \infty$, $\theta = 0$ ($b >> r_0$)

ELECTRON ORBITS :-

Centripetal force required by the electron is provided by the electrostatic force of attraction between the nucleus and electron.

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

$$\Rightarrow \frac{mv^2}{r} = \frac{Ke^2}{r^2}$$

$$\Rightarrow mv^2 r = Ke^2$$

$$\Rightarrow \boxed{r = \frac{Ke^2}{mv^2} = \frac{e^2}{4\pi\varepsilon_0 mv^2}}$$

This is the expression for radius.

GOLDEN KEY POINTS :-

- * Size of Nucleus – 10^{-15} m
- * Size of Atom – 10^{-10} m
- * α-particle :- He^{++} = Helium nucleus (2p 2n)
  Charge = +2e
  Mass = 4 amu.

Kinetic energy,

$$K.E = \frac{1}{2}mv^2$$

$$= \frac{1}{2} \times \frac{Ke^2}{r}$$

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

$$\boxed{K.E = \frac{e^2}{8\pi\varepsilon_0 r}}$$

Potential energy,

$$PE = \frac{Kq_1 q_2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{-e \cdot e}{r} = \frac{-2e^2}{8\pi\varepsilon_0 r}$$

Total energy,

$$T.E = K.E + PE = \frac{e^2}{8\pi\varepsilon_0 r} - \frac{2e^2}{8\pi\varepsilon_0 r}$$

$$\Rightarrow \boxed{T.E = \frac{-e^2}{8\pi\varepsilon_0 r}}$$

–ve sign indicates that electron is bound to the nucleus. i.e energy is required to free the electron from nucleus.

DRAWBACK'S OF RUTHERFORD'S MODEL:-

Rutherford's model suffers two major drawbacks:-

① He cannot explain stability of atom.

According to electromagnetic theory, an accelerated charged particle emit energy in the form of electromagnetic radiation. So, electron comes closer to the nucleus and the entire model is collapsed.

② He cannot explain discrete spectrum of atoms.

BOHR'S MODEL OF HYDROGEN ATOM:-

These three postulates are as follows:-

i) Bohr's first postulate:- electron can revolve only in certain stable orbits. These orbits have fixed energy and these are called as energy levels or stationary state. These were named K L M N
1 2 3 4

* electron have same energy as that of the orbit in which it is revolving.
* while revolving in a particular energy level (orbit) electron donot emit any radiation.
* If an electron absorb or emit energy, it must move to different energy level.

ii) Bohr's second postulate:- electron can revolve only in those circular orbits for which the orbital angular momentum of electron is an integral multiple of $h/2\pi$ (Defining stable orbits)

$$L = \frac{nh}{2\pi} \quad , n = \text{any +ve integer } 1, 2, 3, \ldots$$

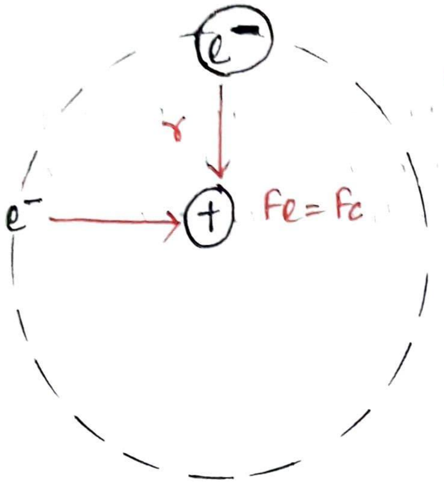
$$\Rightarrow \boxed{mvr = \frac{nh}{2\pi}} \quad \text{(Bohr's quantisation cond}^n\text{)}.$$

iii) Bohr's third postulate:- While revolving in a higher energy level an electron may emit energy radiation (photon) of a specific wavelength and falls (de-excites) to a lower energy level. The energy of such photon is always equal to the difference in two energy levels.

$$\boxed{E = E_{n_2} - E_{n_1}}$$

$$\Rightarrow \frac{hc}{\lambda} = E_{n_2} - E_{n_1}$$

BOHR'S THEORY OF HYDROGEN LIKE ATOMS :-



So, the necessary centripetal force of electron is provided by the electrostatics force of attraction.

$$F_e = F_c$$

$$\Rightarrow \frac{Kq_1q_2}{r^2} = \frac{mv^2}{r}$$

$$\Rightarrow \frac{Ke\cdot Ze}{r^2} = \frac{mv^2}{r}$$

$$\Rightarrow \frac{K\cdot e\cdot Ze}{r} = mv^2 \quad \text{—— (I)}$$

According to Bohr's postulate,

$$mvr = \frac{nh}{2\pi} \quad \text{—— (II)}$$

$eq^n(II)^2 \div eq^n(I)$

$$\frac{m^2v^2r^2}{mv^2} = \frac{n^2h^2}{4\pi^2} \times \frac{r}{KZe^2}$$

$$\Rightarrow mr = \frac{n^2h^2}{4\pi^2} \times \frac{4\pi\varepsilon_0}{Ze^2}$$

$$\Rightarrow mr = \frac{n^2h^2}{\pi} \times \frac{\varepsilon_0}{Ze^2}$$

$$\Rightarrow \boxed{r = \frac{n^2h^2\varepsilon_0}{m\pi Ze^2}} \quad \text{—— (III)}$$

Radius for n^{th} orbit,

$$\boxed{r = \frac{n^2h^2\varepsilon_0}{\pi m Ze^2}}$$

if $Z = 1, n = 1$

$$r = \frac{h^2\varepsilon_0}{\pi m e^2} = 0.53 \times 10^{-10}\,m = \boxed{0.53\,\mathring{A}}$$

(It is called as Bohr's radius)

N.B:- (1) $r \propto \frac{n^2}{Z}$

$$\Rightarrow \frac{r_1}{r_2} = \frac{n_1^2}{n_2^2} \times \frac{Z_2}{Z_1}$$

(2) $\boxed{r_n = 0.53 \frac{n^2}{Z} A^\circ}$

Velocity of electron in stationary orbits:-

Putting the value of r in eqn (II)

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

$$\Rightarrow m \times v \times \frac{n^2h^2\epsilon_0}{\pi m Z e^2} = \frac{nh}{2\pi}$$

$$\Rightarrow \frac{nh\epsilon_0 v}{Ze^2} = \frac{1}{2}$$

$$\Rightarrow 2nh\epsilon_0 v = Ze^2$$

$$\Rightarrow \boxed{v = \frac{Ze^2}{2nh\epsilon_0}}$$

velocity of electron in the nth energy level:-

$$\boxed{v = \frac{Ze^2}{2nh\epsilon_0}}$$

for 1st orbit of hydrogen atom,

$$Z=1, n=1$$

$$v = \frac{e^2}{2h\epsilon_0} = \boxed{2.2 \times 10^6 m/s}$$

N.B:- (1) $v \propto \frac{Z}{n}$

$$\Rightarrow \frac{v_1}{v_2} = \frac{Z_1}{Z_2} \times \frac{n_2}{n_1}$$

(2) $\boxed{v_n = 2.2 \times 10^6 \frac{Z}{n} m/s}$

Energy of electron in stationary orbits:-

Electron has two type of energy:-

① $K\cdot E = \frac{1}{2} m v^2$

$= \frac{1}{2} \times m \times \left(\frac{Ze^2}{2nh\varepsilon_0} \right)^2$

$= \frac{1}{2} \times m \times \frac{Z^2 e^4}{4n^2h^2\varepsilon_0^2}$

$$\boxed{K\cdot E = \frac{mZ^2e^4}{8n^2h^2\varepsilon_0^2}}$$

② $PE = \frac{K q_1 q_2}{r} = \frac{K\cdot(-e)\cdot Ze}{\frac{n^2h^2\varepsilon_0}{\pi m Z e^2}}$

$= \frac{(-e)\cdot Ze \cdot Ze^2 \pi m}{4\pi\varepsilon_0 n^2h^2\varepsilon_0}$

$= \frac{-Z^2e^4m}{4\varepsilon_0 n^2h^2\varepsilon_0}$

$$\boxed{P\cdot E = \frac{-2Z^2e^4m}{8n^2h^2\varepsilon_0^2}}$$

Total energy = $K\cdot E + P\cdot E$

$= \frac{mZ^2e^4}{8n^2h^2\varepsilon_0^2} - \frac{2Z^2e^4m}{8n^2h^2\varepsilon_0^2}$

$$\boxed{T\cdot E = \frac{-mZ^2e^4}{8n^2h^2\varepsilon_0^2}}$$

Total energy is -ve. i.e electron is bound to the nucleus.

N.B:- ① $PE = 2TE = -2KE$

② $T\cdot E = -13.6 \frac{Z^2}{n^2}$ eV = energy of n^{th} orbit.

$T\cdot E = -13.6 \frac{Z^2}{n^2}$ eV

for H atom, $Z = 1$, $n = 1$

$T\cdot E = \boxed{-13.6\ eV}$ (ground state) (1^{st} orbit)

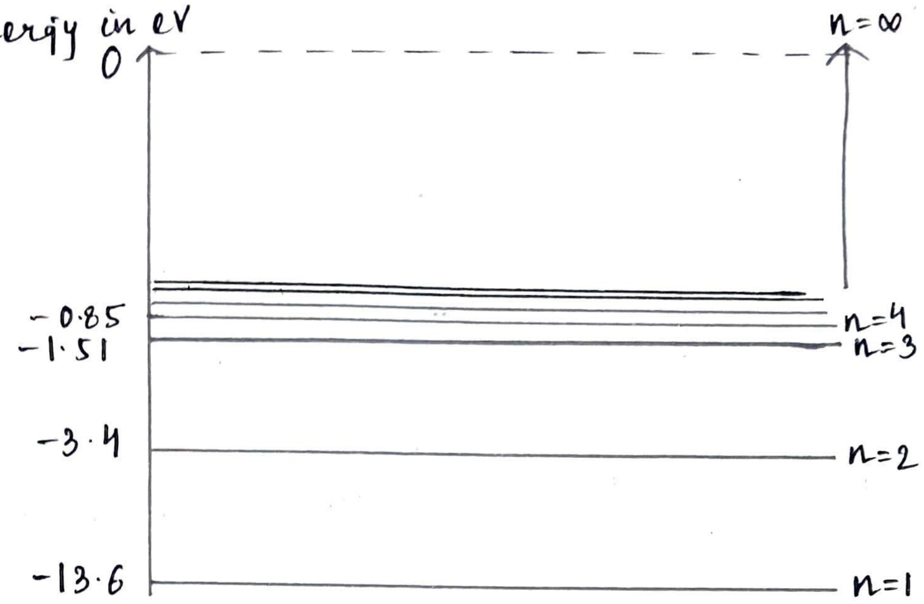
$T\cdot E = -13.6 \times \frac{1}{4} = \boxed{-3.4\ eV}$ (2^{nd} orbit) (1^{st} excited state)

$T\cdot E = -13.6 \times \frac{1}{9} = \boxed{-1.51\ eV}$ (3^{rd} orbit) (2^{nd} excited state)

$T\cdot E = -13.6 \times \frac{1}{16} = \boxed{-0.85\ eV}$ (4^{th} orbit) (3^{rd} excited state)

$T\cdot E = -13.6 \times \frac{1}{25} = \boxed{-0.54\ eV}$ (5^{th} orbit) (4^{th} excited state)

ENERGY LEVEL DIAGRAM:-



* While revolving in a lower energy level an e^- may absorb a radiation (photon) of a specific wavelength and jumps (excites) to a higher energy level.

The energy of such photon is always equal to the diff in 2 energy level.

$$E = E_{n_2} - E_{n_1}$$

$$\Rightarrow \boxed{\frac{hc}{\lambda} = E_{n_2} - E_{n_1}}$$

SHORTCUT FORMULA FOR FINDING λ OF EMITTED PHOTON:-

$$\boxed{\frac{1}{\lambda} = RZ^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)}$$

where, R = Rydberg constant

$R = 1.097 \times 10^7\ m^{-1}$

$\frac{1}{R} \approx 911\ A^\circ$.

N.B:- $\boxed{\underset{(\text{in } A^\circ)}{\lambda} = \frac{12375}{E(eV)}}$

Longest wavelength ⟶ Small transition

Shortest wavelength ⟶ larger transition.

- (i) For Lyman series

$$\boxed{\frac{1}{\lambda}=R\left(\frac{1}{1^2}-\frac{1}{n^2}\right),\ n=2,3,4,}$$ (UV region)

(ii) For Balmer series

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

(iii) For Paschen series

$$\boxed{\frac{1}{\lambda}=R\left(\frac{1}{3^2}-\frac{1}{n^2}\right),\ n=4,5,6,\ldots}$$ (low infrared region)

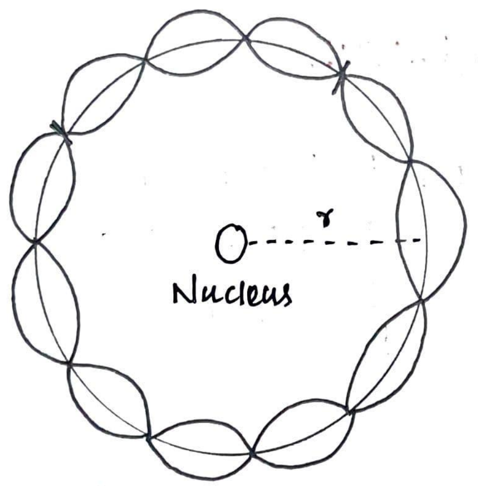
(iv) For Brackett series

$$\boxed{\frac{1}{\lambda}=R\left(\frac{1}{4^2}-\frac{1}{n^2}\right),\ n=5,6,7,\ldots}$$ (low infrared region)

(v) For Pfund series:-

$$\boxed{\frac{1}{\lambda}=R\left(\frac{1}{5^2}-\frac{1}{n^2}\right),\ n=6,7,8,\ldots}$$ (High infrared region)

DE-BROGLIE'S COMMENT ON BOHR'S SECOND POSTULATE:-



According to de-Broglie wavelength,

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

$$\therefore\ 2\pi r=\frac{nh}{mv}$$

$$\Rightarrow mvr=\frac{nh}{2\pi}=n(h/2\pi)$$

LIMITATIONS OF BOHR'S MODEL:-

① It stands true for only H-atom and H like atom (single e^- species)
② It cannot explain spectrum of multi e^- species.
③ It doesnot take into account the wave nature of e^- violating de-broglie hypothesis.
④ It violates heisenberg's uncertainity principle.
⑤ He cannot explain splitting of spectra lines in electricfield (Stark effect) and magnetic field (Zeeman effect)