What is photo-electric effect?

When radiations such as x rays, γ rays, ultraviolet rays and even visible light falls on a good number of substances, chaiefly metals; electron are ejected from those substances. The phenomenon is called photo-electric effect.

Characteristics of Photo-electric effect:-

1. The electrons were emitted immediately.
2. Increasing the intensity of the light increased the number of photoelectrons but not maximum kinetic energy.
3. Weak violet light will eject only a few electrons.
4. When the intensity of incident light is kept fixed and frequency is increased, the photoelectric current remains same but the stopping potential increases. If the frequency decreases, the stopping potential decreases.
5. There is no time lag between the incidientce of light and emission of photoelectrons.
6. The threshold frequency is different for different metal.

Laws of Photo-electric effect / emission :-

(i) Photo electric effect is an instantaneous proce[ss]

(ii) Photoelectric current is directly proportional to the intensity of incident light and independent of frequency. or the number of electrons emitted per second is directly proportional to the intensity of radiation.

(iii) The emission of electrons stops below a certain minimum frequency known as threshold frequency. or, There is a minimum frequency which below no emission occurs called threshold frequency.

(iv) The stopping potential ~~hence~~ and hence the maximum velocity of the electrons depends upon the frequency of incident light and is independent of frequency.

(v) The maximum kinetic energy of the electrons emitted increases with the frequency of radiation

(vi) No. of ejected electrons increased in intensity is increased.

(vii) If $h\nu$ is equal to or higher than $h\nu_0$. then the electrons are free to eject.

Experiment of photo-electric effect :-

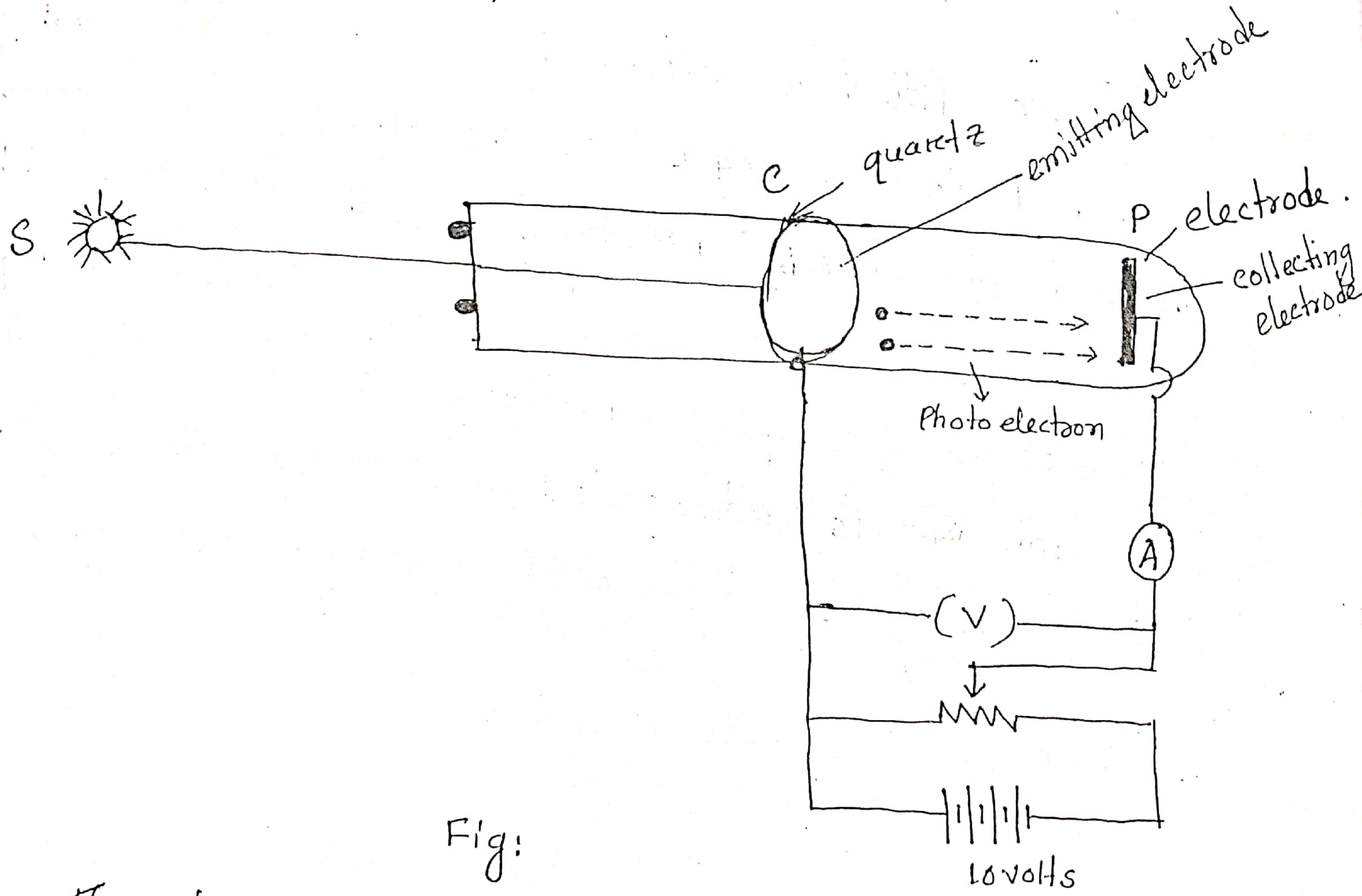
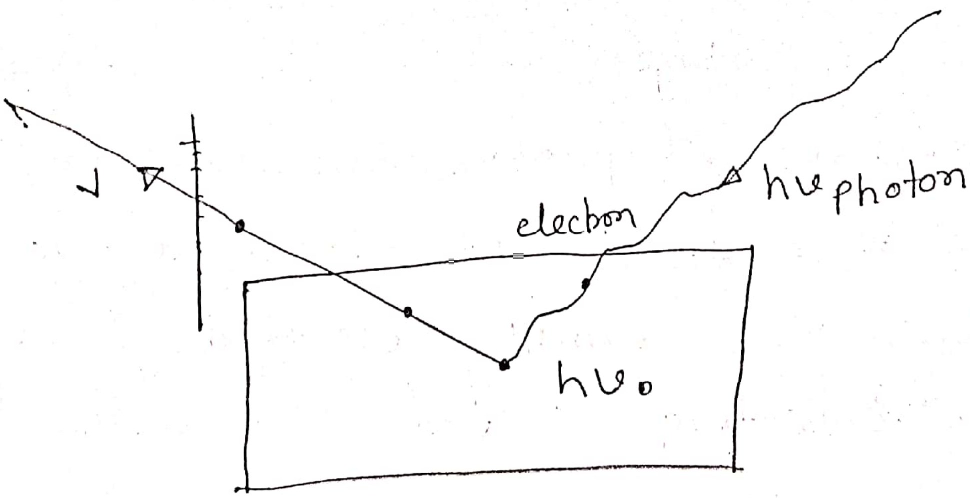


Fig:

The phenomenon of photo electric emission can be studied ~~w~~ in detail with the apparatus shown in Fig. There, C is emitting electrode of material P is the collecting electrode. S is the light source. If C fitted in negetive edge of the battery and P is in positive edge. Then the light coming from the source incident in C electrode the electron emitted from the electrode and P electrode attracted with electron as P is positive that's why the current flows the curcuit.

If we fitted e electrode in positive electrode edge and P is in negative. The the electron was incident in e electrode and emitted the electron instanteneously and that's why as e electrode is p in positive so the emitted electron is attracted in e electrode and that's why the flow of current decreases.

Einstein Photoelectron equation :-



The energy is subsequently imparted to one of the electrons of the atom. The energy is utilized for two purposes :-

(i) Partly for getting the electron free from the atom and away from the metal surface. this energy is known as photo-electric work function of metal and represented by ϕ or W_0.

(ii) the balanced of the photon energy is used up in imparting to the freed electron a kinetic energy of $\frac{1}{2}mv^2$

So, energy conservation law, we have,

$$h\nu = W_0 + \frac{1}{2}mv^2$$

$$\therefore \boxed{\frac{1}{2}mv^2 = h\nu - W_0}$$

This equation known as Photo-electric equation of Einstein.

Now, $\frac{1}{2}mv_s^2 = h\nu - h\nu_0$

$$\therefore \boxed{eV_s = h\nu - h\nu_0}$$

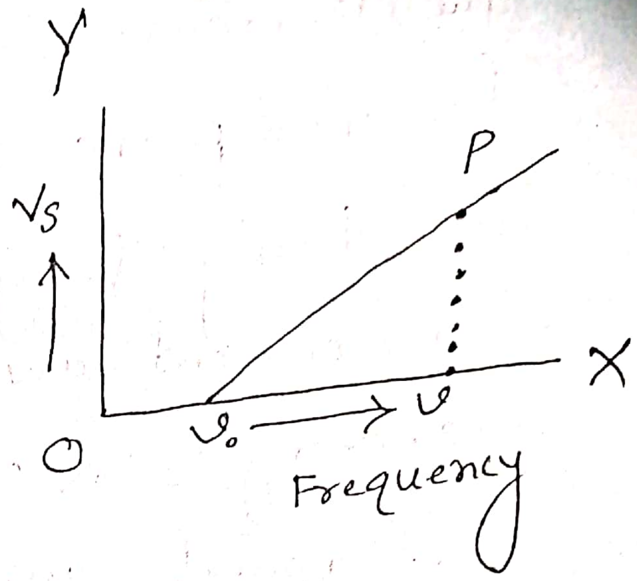
$\therefore W_0 = h\nu_0$

$\frac{m}{2} = V_s$

$m = 2V_s$

$eV_s = \frac{1}{2}mv_{mas}^2$

From Graph :-



Let,
stopping voltage $= V_s$
electron charge $= e$
$\therefore$ max. electron energy $= eV_s$

$\therefore$ emitted electron max. velocity $= V_m$
$\therefore$ max. energy $= \frac{1}{2} m V_m^2$

we get, $\frac{1}{2} m V_m^2 = eV_s$

weget From graph,

$$\tan\theta = \frac{eV_s}{\nu - \nu_0}$$

$\because \tan\theta =$ slope $= h.$

$$\Rightarrow h = \frac{eV_s}{\nu - \nu_0}$$

$$\Rightarrow eV_s = h\nu - h\nu_0$$

$$\Rightarrow \frac{1}{2} m V_m^2 = h\nu - h\nu_0$$

$$\therefore \boxed{\frac{1}{2} m V_m^2 = h\nu - h\nu_0}$$

$$\therefore \boxed{\frac{1}{2} m V_m^2 = h\nu - W_0}$$ $\longrightarrow$ Einstein photo electric equation.

Threshold Frequency :-

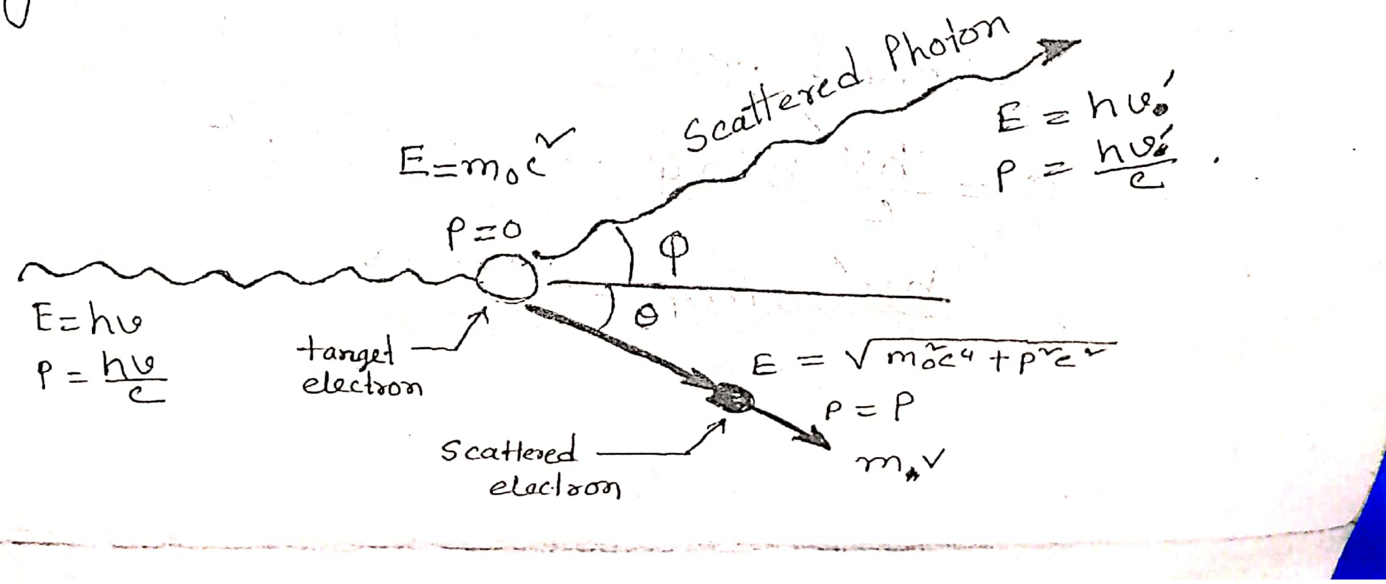
Threshold frequency defines as the minimum frequency which can cause photo-electron emission. or, the emission of electron stop below a certain minimum frequency is called threshold frequency. Represented by ν_0.

Stopping Potential or Voltage :-

The stopping Potential is defined as the potential necessary to stop any electron from reaching the other side.

Compton effect :-

Compton effect defines as an increase in wavelength of x-rays or gamma rays that occurs when they are scattered.



loss of photon energy = gain in electron energy

$$h\nu - h\nu' = mc^2 - m_0c^2$$

$$\Rightarrow h\nu = h\nu' + \frac{m_0c^2}{\sqrt{1-v^2/c^2}} - m_0c^2$$

$$\therefore h\nu = h\nu' + m_0c^2\left[\frac{1}{\sqrt{1-v^2/c^2}} - 1\right] \quad \text{——— (1)}$$

X-direction,

Initial momentum = final momentum

$$\frac{h\nu}{c} + 0 = \frac{h\nu'}{c}\cos\varphi + \frac{m_0v}{\sqrt{1-v^2/c^2}}\cos\theta$$

$$\Rightarrow \frac{h\nu}{c} = \frac{h\nu'}{c}\cos\varphi + \frac{m_0v}{\sqrt{1-v^2/c^2}}\cos\theta \quad \text{——— (ii)}$$

Y-direction,

Initial momentum = Final momentum

$$0 = \frac{h\nu'}{c}\sin\varphi - mv\sin\theta$$

$$\Rightarrow \frac{h\nu'}{c}\sin\varphi = \frac{m_0v}{\sqrt{1-v^2/c^2}}\sin\theta \quad \text{——— (iii)}$$

we know, $\lambda = \frac{c}{\nu}$ and $\lambda' = \frac{c}{\nu'}$

$\nu = \frac{c}{\lambda}$ and $\nu' = \frac{c}{\lambda'}$

Now, equ (i), (ii) & (iii) we get,

$$\frac{hc}{\lambda} = \frac{hc}{\lambda'} + m_0 c^2 \left[\frac{1}{\sqrt{1-v^2/c^2}} - 1\right]$$

$$\Rightarrow \frac{h}{\lambda} - \frac{h}{\lambda'} + m_0 c = \frac{m_0 c}{\sqrt{1-v^2/c^2}} \quad \text{——— (iv)}$$

again,

$$\frac{h}{\lambda} - \frac{h}{\lambda'} \cos\phi = \frac{m_0 v}{\sqrt{1-v^2/c^2}} \cos\theta \quad \text{——— (v)}$$

and,

$$\frac{h}{\lambda'} \sin\phi = \frac{m_0 v}{\sqrt{1-v^2/c^2}} \sin\theta \quad \text{——— (vi)}$$

Squaring (v) and (vi) and adding them,

$$\frac{h^2}{\lambda^2} - \frac{2hh}{\lambda\lambda'}\cos\phi + \frac{h^2}{\lambda'^2}\cos^2\phi + \frac{h^2}{\lambda'^2}\sin^2\phi =$$

$$\frac{m_0^2 v^2}{(1-v^2/c^2)}\cos^2\theta + \frac{m_0^2 v^2}{(1-v^2/c^2)}\sin^2\theta .$$

$$\Rightarrow \frac{h^2}{\lambda^2} + \frac{h^2}{\lambda'^2} - \frac{2h^2\cos\phi}{\lambda\lambda'} = \frac{m_0^2 v^2}{(1-v^2/c^2)}$$

$$\Rightarrow \frac{h^2}{\lambda^2} + \frac{h^2}{\lambda'^2} - \frac{2h^2\cos\phi}{\lambda\lambda'} = \frac{m_0^2 c^2}{(1-v^2/c^2)} - m_0^2 c^2 \quad \text{— (VII)}$$

Squaring equ (iv) we get,

$$\frac{h^2}{\lambda^2} + \frac{h^2}{\lambda'^2} + m_0^2 c^2 - \frac{2h^2}{\lambda\lambda'} - \frac{2hm_0c}{\lambda'} + \frac{2hm_0c}{\lambda} = \frac{m_0^2 c^2}{(1-v^2/c^2)}$$

$$\Rightarrow \frac{h^2}{\lambda^2} + \frac{h^2}{\lambda'^2} - \frac{2h^2}{\lambda\lambda'} + 2m_0ch\left(\frac{1}{\lambda} - \frac{1}{\lambda'}\right) + m_0^2 c^2 = \frac{m_0^2 c^2}{\sqrt{(1-v^2/c^2)}} \quad \text{— (VIII)}$$

subtracting (VII) from (VIII),

$$\frac{2h^2}{\lambda\lambda'}(\cos\phi - 1) + 2m_0ch\left(\frac{1}{\lambda} - \frac{1}{\lambda'}\right) = 0$$

$$\Rightarrow 2m_0ch\left(\frac{1}{\lambda} - \frac{1}{\lambda'}\right) = -\frac{2h^2}{\lambda\lambda'}(\cos\phi - 1)$$

$$\Rightarrow 2m_0ch\left(\frac{1}{\lambda} - \frac{1}{\lambda'}\right) = \frac{2h^2}{\lambda\lambda'}(1 - \cos\phi)$$

$$\Rightarrow m_0c\left(\frac{1}{\lambda} - \frac{1}{\lambda'}\right)\lambda\lambda' = h(1-\cos\phi)$$

$$\Rightarrow \lambda' - \lambda = \frac{h}{m_0 c}(1 - \cos\varphi)$$

$$\therefore \boxed{\Delta\lambda = \lambda' - \lambda = \frac{h}{m_0 c}(1 - \cos\varphi)}$$

Postulates of Bohr Atom Model :-

1. Electrons revolve around the nucleas in a circular path which are known as orbits or energy level or shells.
2. Each shell or orbit corresponding to a definate energy. Those energy are known as energy levels or energy shells.
3. While in those specific orbits, an electron does not radiate (or lose) energy.
4. The angular momentum (mvr) of an electron orbiting around the nucleus is an integral multiple of plank constant divided by 2π. ($mvr = \frac{nh}{2\pi}$)
5. An electron can move from one energy level to another by quantam or photon jumps. If an electron jump from one lower energy level to higher energy level, it absorbs a definate amount of energy.

If an electron jump from higher energy level to lower energy level, it radiates a definate amount of energy.

Limitations of Bohr's Model :-

1. The Bohr model can only explain the line spectrum of hydrogen. (an atom with one electron adequately)
2. It cannot explain Zemaan effect perfectly.
3. Scientists eventually concluded that Bohr's model didnot fully describe the structure of an atom.

Radii of Permitted Path or Orbits :-

Electrostatic Force, E.F $= \frac{1}{4\pi\epsilon_0} \cdot \frac{Ze^2}{r^2}$

Centrifugal force, C.F $= \frac{mv^2}{r}$

The system will be stable if,

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

$$\Rightarrow v^2 = \frac{Ze^2 r}{4\pi\epsilon_0 m r^2} \quad \text{------ (1)}$$

According to Bohr postulates,

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

$$\Rightarrow v = \frac{nh}{2m\pi r}$$

Put the value in (i),

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

$$\Rightarrow \frac{n^2h^2}{\pi mr} = \frac{Ze^2r}{\epsilon_0}$$

$$\therefore \boxed{r = \frac{n^2h^2\epsilon_0}{Ze^2\pi m}}$$

This is the radii of permitted orbitals.

For hydrozen, $Z = 1$

Radius of the nth Pertmitted orbit of hydrogen,

$$\boxed{r_n = \frac{n^2h^2\epsilon_0}{\pi me^2}}$$

The Radius of the first orbit $(n=1)$ for hydrogen atom,

$$r = \frac{1^2 \times (6.624\times10^{-34})^2 \times 8.854\times10^{-12}}{\pi\times(1.6\times10^{-19})^2 \times 9.1\times10^{-31}}$$

$= 5.29 \times 10^{-11}\ m$

$= 0.529\ A.U.$

The Radius of the first orbit for hydrogen atom is called Bohr Radius.

Orbital velocity of electron:-

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

$$\Rightarrow v^2 = \frac{Ze^2}{4\pi\epsilon_0 m r}$$

$$\Rightarrow v^2 = \frac{Ze^2 \times \cancel{\pi} Ze^2 \cancel{m}}{4\cancel{\pi}\epsilon_0 \cancel{m} \cdot n^2h^2\epsilon_0} \qquad \left[\because r = \frac{n^2h^2\epsilon_0}{\pi m Ze^2}\right.$$

$$\Rightarrow v^2 = \frac{Z^2e^4}{4n^2h^2\epsilon_0^2}$$

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

If, $Z = 1$, then

$$v = \frac{(1.6 \times 10^{-19})^2}{2 \times 8.854 \times 10^{-12} \times 1 \times 6.624 \times 10^{-34}}$$

$$= 2.2 \times 10^{8}\ ms^{-1}.$$

Orbital Energy of the Electron :-

$$P.E = \int_{\alpha}^{r} \frac{Ze^2}{4\pi\epsilon_0} \cdot \frac{dr}{r^2}$$

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

$$K.E = \frac{1}{2} mv^2 = \frac{1}{2} \times \cancel{m} \times \frac{Ze^2}{4\pi\epsilon_0 \cancel{m} r}$$

$$= \frac{Ze^2}{8\pi\epsilon_0 r}$$

$\therefore$ Total energy of the electron in the nth orbit,

$$E_n = P.E + K.E$$

$$= -\frac{Ze^2}{4\pi\epsilon_0 r} + \frac{Ze^2}{8\pi\epsilon_0 r}$$

$$= \frac{-2Ze^2 + Ze^2}{8\pi\epsilon_0 r}$$

$$= -\frac{Ze^2}{8\pi\epsilon_0 r}$$

$$= -\frac{Ze^2 \cdot \pi m Ze^2}{8\pi\epsilon_0 n^2 h^2 \epsilon_0} \qquad \left[\because r = \frac{n^2 h^2 \epsilon_0}{\pi m e Z^2}\right.$$

$$\therefore \boxed{E_n = -\frac{m Z^2 e^4}{8\epsilon_0^2 n^2 h^2}}$$

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substidating the numerical values, (for hydrogen)

$$E_n = -\frac{(9.11\times10^{-31})\times(1.6\times10^{-19})^4}{8\times8.854\times10^{-12}\times6.62\times10^{-34}\times n^2} \text{ Jolues}$$

$$= -\frac{9.11\times10^{-31}\times(1.6\times10^{-19})^4}{n^2\times8\times8.854\times10^{-12}\times6.62\times10^{-34}\times1.6\times10^{-19}} \text{ eV}$$

$$\therefore \boxed{E_n = -\frac{13.6}{n^2} \text{ ev}}$$ $[\because 1eV = 1.6\times10^{-19} J]$.

Lymen Sercies :-

In physics and chemistry, the lymen series is an hydrogen Spectraml series of transitions and resulting ultra-violet emission lines of the hydrogen atom as an electron goes from $n \geq 2$ to $n = 1$ (where n is the principal quantam number) the lowest energy level of the electron.