MODERN PHYSICS

In Earlier days
Newton, Hamilton, & Lagrangian explained
motion of objects → observable → naked eye
(Macroscopic)

A/c to them → motion → position & momentum
(mv)

solved many problems
& Explained many theories

Such as

Motion of objects → The subject → Mechanics
poperities of heat → Thermodynamics
properities of sound → Accoustics

Mechanics + Thermodynamics + Accoustics
= Dynamics

Dynamics is a branch of physics which explains Mechanics, Thermodynamics and Accoustics.

After some years they want to know about light.

A/c Newton's Corpuscular theory
→ Light has particle nature
Young's Double slit experiment
→ Light has wave nature

Maxwell → Dual Nature
Electro magnetic waves

$\left.\begin{array}{l}\text{Electro}\\\text{Dynamics}\end{array}\right\}$ Electric field, Magnetic field
Electromagnet

The Combination of Dynamics and Electro dynamics is known as "classical mechanics

After the discovery of atom, e^-, proton, x-rays

* Classical Theory does not explain the microscopic (bodies) particles such as atom, e^-, proton etc
* It does not answer many question

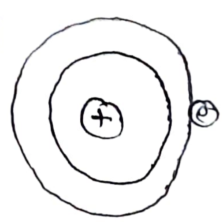
  Why do stars shine?
  Why does Copper Conduct electricity & glass not?
* It does not explain the stabilit of atom

<u>Failures of classical theory</u>:

* Classical theory fails to explain the stability of atom.

• A moving charged particle looses energy continuously

Let us consider an atom



If electron looses energy continuously, it comes closer to the nucleus and when it falls in nucleus atom collapse, but observed fact is atom is stable.

* It also fails to explain the Hydrogen Spectrum.

According to classical theory Energy Spectrum is Continuous i.e it emits radiations of all wave lengths. But it is observed that Our hydrogen Spectrum is Line Spectrum i.e discrete and emits only certain wavelengths only.

* It also fails to explain black body radiation, photo electric effect, Compton effect, Specific heats of Solids.

A New theory was developed to explain all failures of classical theory that is "Modern Physics".

Black body Radiation :

Radiation :

Hot body placed near a Cold body → temperature of hot body decreases

Reason : Exchange of energy

you place two bodies → different temp → vaccum → Exchange of energy

Exchange of energy does not need any medium

Exchange of energy → Conduction, Convection

* The body which is at a temperature emits energy → heat energy
(or) Radiant energy
(or) Thermal radiation

In earlier days (b → 1790)
Ice block → cold body → emits → cold radi
fire → hot body → emits → hot radiati
After Some years → Prevost (1972)

Cold body → Receives (or) absorbs Max radiatio
emits less rad (U stand near ice block)

Hot body → Emits more radiation & absorbs less radiat

According to Prevost
(i) All bodies emits radiations at all temperatures
(ii) Whenever temperature increases emission of energy also increases.

When the temperature of body increase it gives IR, V, UV

The body is at lower temperatures So it gives very less number of radiations (No sensation)
The body is at room temperature it emits → IR (Sensation)
The body is at a temperature greater than hundreds or thousands of °c then Colour of body changes
Red → orange → yellow → white → blue

1000°c or > 1000°c ⟶ Red or Orange

2000°c ⟶ yellow / white

Lavae ⟶ 1000°c to 1200°c

If temp is further increased ⟶ emits
⟶ UV radiations

To measure radiant energy we use
⟶ Thermopiles & bolometers

Black body : The body which absorbs all the radiations incident on it and emits all radiations when it is heated.

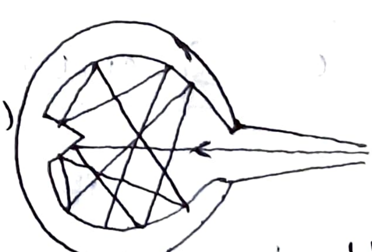
Eg : Lamp black, Platinum black absorb 98% of radiations incident on it

There is no perfect black body in our universe.

Name was first introduced by Kirchoff - in 1860

For scientific investigations

Spherical Cavity
(small hole to allow radiations)
Conical Projection



Inner surface of Spherical cavity is coated with platinum black or Lamp black

Conical projection is at opp to hole
Conical projection prevent the direct reflection of radiation.

Kirchoff proposed two laws about black body.

(i) Black body is a body which absorbs all the radiations incident on it and behaves as a perfect radiator when it is heated.

(ii) Emission of Energy depends up on temperature of the body we raised and independent of nature and shape of black body.

Eg; Chaina Cup

Emissive Power:

The energy radiated by a black body per unit surface area per unit time is known as "Emissive power"

Emissive power mainly depends on surface area.

SA $\rightarrow$ less $E_\lambda \rightarrow$ less

Energy distribution of Blackbody radiation (or) Spectrum of Blackbody radiation:

It was first studied by Lummer & pringsheim

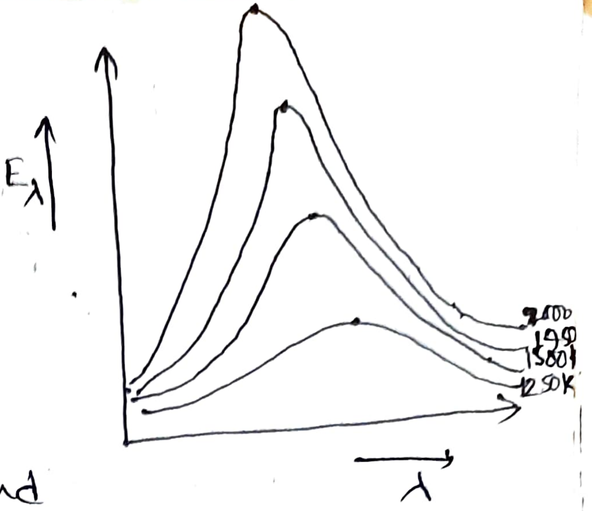
They Conduct so many experimen at different temperatures.

They draw graph between λ & E_λ

Observations:

① Energy distribution is not uniform

② ~~At~~ a particular temperature, as λ increases, E_λ increases to a max value and then decreases.



③ As temperature increases, the cure becomes sharp and curve shifts towards shorter wavelengths.

④ The total energy emitted by the body at a particular temperature is nothing but area under the curve at that temperature.

Laws of Blackbody Radiations:

1) Stefan's Law: The energy emitted by the blackbody per unit area per unit time is directly proportional to 4th power of absolute temperature

$$E_\lambda \propto T^4$$

$$E_\lambda = \underset{\text{stefan's constant}}{\sigma} T^4$$

$$E_\lambda = \sigma (T_1^4 - T_2^4)$$

It fails in some conditions

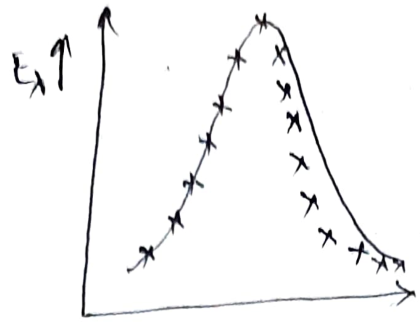
2) Wien's Law :-

~~Adiabatic~~ change ($\Delta H = 0$) $\longrightarrow$ Thermodynamics

(i) $\lambda T = \text{Const} \Rightarrow \lambda \propto 1/T$

(ii) $E_\lambda d\lambda = \alpha \lambda^{-5}$

It can't explain the black body radiations at longer wavelengths

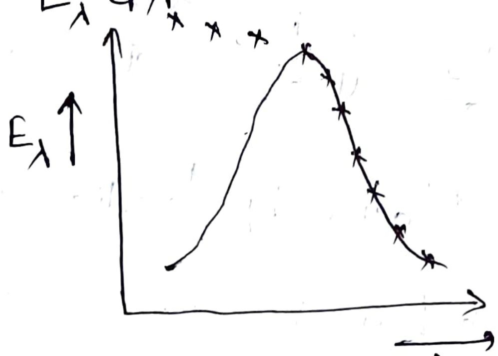


Thus wein's law fails to explain energy distribution.

Rayleigh jean's Law :-

Energy distribution is explained by degree's of freedom based on classical Theory.

$$E_\lambda d\lambda = b\lambda^{-4} d\lambda$$



This law obeys experimental values at longer wavelength and becomes infinite at shorter wavelengths which is abnormal thing. This is known as "Ultraviolet catastrophe".

Planck's radiation law :

Failures of weins & Rayleigh are easily solved by Max planck in 1910. He assumed that

1) The Black Body radiation chamber consists of infinite no of atoms

2) Each atom behaves as an oscillator. i.e each atom vibrates with it's own natural frequency.

3) Atoms or oscillators absorbs all the energy incident on it, but emits energy when it's energy is equal to integral multiples of $h\nu$

4) And It obeys maxwell boltzmann statistics

According to classical theory energy spectrum is continuous but according to plancks it is not continuous.

$N \longrightarrow$ Total No of oscillators in BBRC

$E \longrightarrow$ Total energy of N oscillators

Average energy $(\bar{E}) = \dfrac{E}{N} \longrightarrow (1)$

$N_0 \longrightarrow$ No of oscillators are vibrating with zero energy $(0h\nu)$

$N_1 \longrightarrow$ " $(1h\nu)$

$N_2 \longrightarrow$ " $(2h\nu)$

$N_n \longrightarrow$ " $(nh\nu)$

Total no of particles

$$N = N_0 + N_1 + N_2 + \cdots + N_n \quad -(2)$$

$$E = N_0(0h\nu) + N_1(1h\nu) + N_2(2h\nu) + \cdots + N_n(nh\nu) \quad -(3)$$

According to Boltzmann statistics

$$N_n = N_0 e^{-\frac{nh\nu}{KT}} \quad \text{——— (4)}$$

$$\left.\begin{aligned} N_0 &= N_0 e^{-\frac{0h\nu}{KT}} = N_0 \\ N_1 &= N_0 e^{-\frac{h\nu}{KT}} \\ N_2 &= N_0 e^{-\frac{2h\nu}{KT}} \\ N_n &= N_0 e^{-\frac{nh\nu}{KT}} \end{aligned}\right\} \text{——— (5)}$$

Expression for N

Substitute equation (5) in (2)

$$N = N_0 + N_0 e^{-h\nu/KT} + N_0 e^{-2h\nu/KT} + \cdots + N_0 e^{-nh\nu/KT}$$

$$\text{Let } e^{-h\nu/KT} = x$$

$$N = N_0(1+x+x^2+ \cdots + x^n)$$

$$\Rightarrow N = N_0 (1-x)^{-1} = \frac{N_0}{1-x}$$

$$\Rightarrow N = \frac{N_0}{1-x} \quad \text{——— (6)}$$

Expression for E

substitute equation (5) in (3)

$$E = N_0(0) + N_0 e^{-h\nu/KT}(h\nu) + N_0 e^{-2h\nu/KT}(2h\nu) + \cdots + N_0 e^{-nh\nu/KT}(nh\nu)$$

$$E = 0 + N_0 e^{-h\nu/KT}(h\nu) + N_0 e^{-2h\nu/KT}(2h\nu) + \cdots + N_0 e^{-nh\nu/KT}(nh\nu)$$

$$\text{Let } e^{-h\nu/KT} = x$$

$$E = h\nu(N_0 x + 2N_0 x^2 + 3N_0 x^3 + \cdots + nN_0 x^n)$$

$$E = N_0 h\nu x(1 + 2x + 3x^2 + \cdots + nx^n)$$

$$= (N_0)(h\nu)(x)(1-x)^{-2}$$

$$E = \frac{(N_0)(h\nu)(x)}{(1-x)^2} \quad \text{--- (7)}$$

Expression for Average Energy :

Substitute (6) & (7) in eq (1)

$$(\bar{E}) = \frac{E}{N} = \frac{\dfrac{(N_0)(h\nu)(x)}{(1-x)^2}}{\left(\dfrac{N_0}{1-x}\right)}$$

$$= \frac{(\cancel{N_0})(h\nu)(x)}{(1-x)^{\cancel{2}}} \times \frac{(\cancel{1-x})}{\cancel{N_0}}$$

$$= \frac{(h\nu)(x)}{(1-x)}$$

$$= (h\nu)\frac{1}{\left(\frac{1}{x}-1\right)}$$

$$= (h\nu)\frac{1}{(x^{-1}-1)}$$

$$= (h\nu)\frac{1}{\left(\left(e^{-h\nu/KT}\right)^{-1}-1\right)}$$

$$\boxed{\bar{E} = \frac{h\nu}{\left(e^{h\nu/KT}-1\right)}}$$

Energy of Each oscillator is given as this

According to Maxwell Boltzmann, the total no of oscillators in the frequency range ν & $\nu + d\nu$ are

$$\frac{8\pi\nu^2 d\nu}{c^3}$$

Total energy in the frequency range ν & $\nu + d\nu$

$E_\nu \, d\nu$ = (Average energy) x (Total no of oscill in the range (ν & $\nu+d\nu$))

$$E_\nu \, d\nu = \frac{h\nu}{e^{h\nu/KT} - 1} \left(\frac{8\pi \nu^2 d\nu}{c^3} \right)$$

$$\boxed{E_\nu \, d_\nu = \frac{8\pi h \nu^3}{c^3 \left(e^{h\nu/KT} - 1\right)} d\nu}$$

Which is known as plancks radiation law in terms of frequency.

$$c = \nu\lambda$$

$$\nu = c/\lambda$$

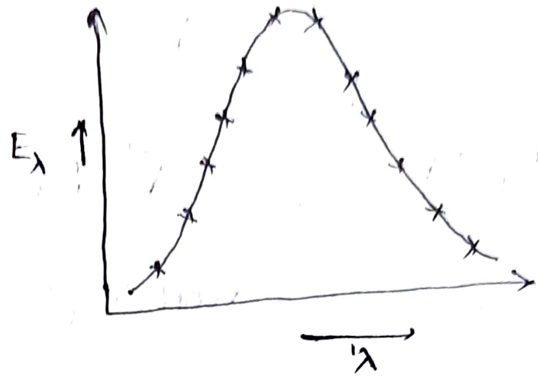
$$d\nu = -c/\lambda^2 \, d\lambda$$

$$|d\nu| = c/\lambda^2 \, d\lambda$$

$$E_\lambda \, d\lambda = \frac{8\pi h (c/\lambda)^3}{c^3 \left(e^{hc/\lambda KT} - 1\right)} \left(\frac{c}{\lambda^2}\right) d\lambda$$

$$\boxed{E_\lambda \, d\lambda = \frac{8\pi h c}{\lambda^5 \left(e^{\frac{hc}{\lambda KT}} - 1\right)} d\lambda}$$

which is known as plancks radiation law, in terms of wavelength.



According to plancks radiation law all the values agreed with experimental values. Thus plancks radiation law successfully explains the energy distribution of black body radiation.

Deduction of Weins Law from Plancks Radiation Law:

$$E_\lambda \, d\lambda = \frac{8\pi hc}{\lambda^5 \left[e^{\frac{hc}{\lambda KT}} - 1\right]} d\lambda$$

At shorter wavelengths λ is very small very small $\Rightarrow \lambda T$ also very small $\Rightarrow \frac{hc}{\lambda KT}$ is very big $\Rightarrow e^{\frac{hc}{\lambda KT}}$ is very very big $\Rightarrow e^{hc/\lambda KT} >> 1$, 1 can be neglected

$$E_\lambda \, d\lambda = \frac{8\pi hc}{\lambda^5 \left[e^{\frac{hc}{\lambda KT}} - 1\right]} d\lambda$$

$$E_\lambda \, d\lambda = \frac{8\pi hc}{\lambda^5 e^{hc/\lambda KT}} d\lambda$$

$$= \frac{a}{\lambda^5} d\lambda \quad \text{where } a = \frac{8\pi hc}{\lambda^5 e^{hc/\lambda KT}}$$

$$\Rightarrow \boxed{E_\lambda \, d\lambda = a \lambda^{-5} d\lambda}$$

which is nothing but weins law

Deduction of Rayleigh Jeans Law :

According to plancks Radiation law

$$E_\lambda d\lambda = \frac{8\pi hc}{\lambda^5 \left(e^{hc/\lambda KT} - 1\right)} d\lambda$$

At longer wavelengths λ is increasing, T is also increasing so λT is increasing $\Rightarrow \frac{hc}{\lambda KT}$ is a decreasing value or small $\Rightarrow$ $e^{\frac{hc}{\lambda KT}}$ is also very small

$$\Rightarrow e^{\frac{hc}{\lambda KT}} = 1 + \frac{hc}{\lambda KT} + \frac{1}{2}\left(\frac{hc}{\lambda KT}\right)^2 + \cdots$$

$\because \frac{hc}{\lambda KT}$ is very small we can neglect the higher order terms

$$\Rightarrow e^{\frac{hc}{\lambda KT}} = 1 + \frac{hc}{\lambda KT}$$

∴ The plancks Radiation law becomes

$$E_\lambda d\lambda = \frac{8\pi hc}{\lambda^5\left(\cancel{1}+\frac{hc}{\lambda KT}-\cancel{1}\right)} d\lambda$$

$$= \frac{8\pi hc}{\lambda^4\left(\frac{hc}{KT}\right)} d\lambda$$

$$= \frac{8\pi K.T}{\lambda^4} d\lambda$$

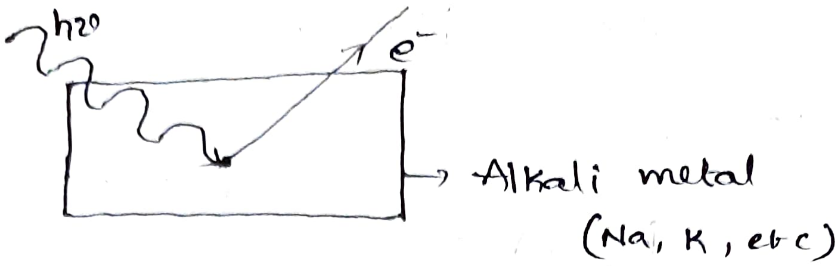
$$\boxed{E_\lambda d\lambda = b\,\lambda^{-4}\, d\lambda}$$

which is nothing but Raleigh jean's law.

Hence Planck's Radiation Law Successfully explains the Distribution of energy at all wavelengths.

Photoelectric Effect :

When a beam of radiation of certain frequency incident on an alkalimetal surface then electrons are emitted out of metal surface. This phenomenon is known as a "photo electric effect".



The electrons emitted out of metal surface. These electrons are known as "photo electrons".

This photo electric effect was first discovered by Hertz and experimentally proved by many scientists

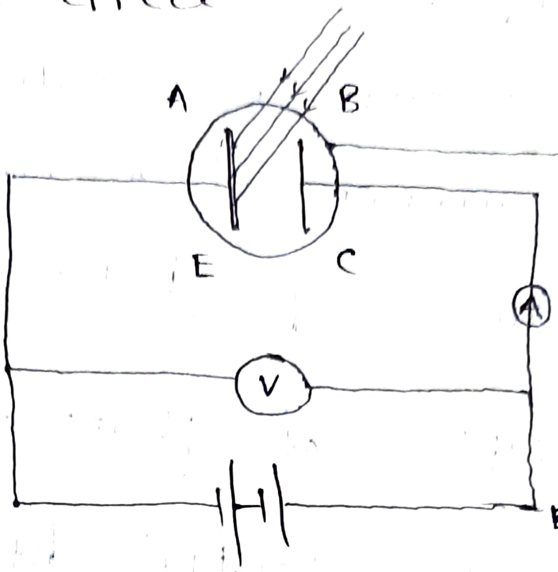
→ JJ Thompson, Millikan
↓
Noble prize → 1923

Hertz discovered this photo electric-effect by incidenting U.V rays on Zinc plate and observe electrons Coming out of metal surface.

Key points:

* 1 photon can interact with one electron only & after interaction, the total energy of photon disappears.

Small experiment proved the photo-electric effect



→ Evacuated Chamber
↓
There are two metal plates AE, BC
→ AE → -ve terminal of battery
BC → +ve terminal of battery
BC → collector

No light incident on A → No current in Ammeter

If we incident light on A → Deflection in Ammeter

i.e electrons are emitted out of metal surface.

The current in the circuit which gives deflection in Ammeter is known as "photo current".

This experiment proves that when light incident on the metal surface, electrons are emitted out of metal surface.

The no. of electrons emitted & Kinetic Energy of electrons depends up on the following factors.

1) potential difference between metal plates
2) Intensity of incident radiation
3) frequency of incident radiation
4) Nature of photometal used

Characteristics of photo electrons:

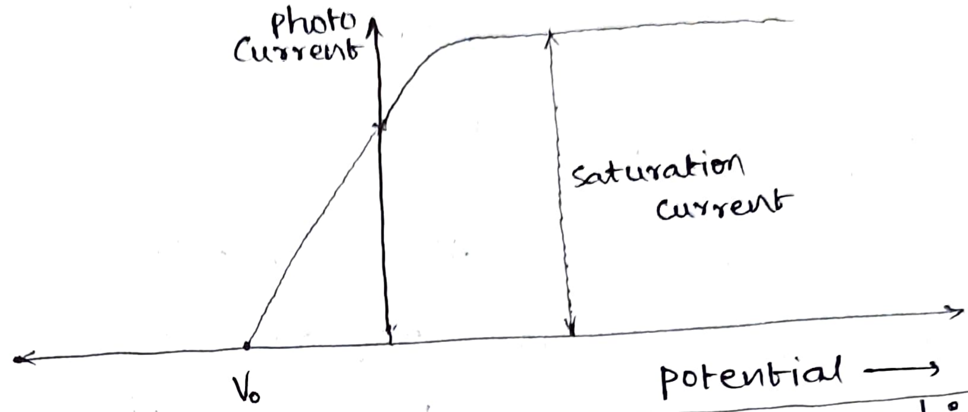
1) Effect of potential difference:

Intensity, frequency, photo metal are kept constant. When there is no potential difference, some current flows through the Ammeter. A is given to negative & B is given to positive.

When we increase the potential the photo current increases to a max value. If we increase the potential further then current becomes constant which is known as "saturation current".

Now by reversing +& - terminal & applying potential, at a particular value current = zero

The potential at which the value of current becomes zero is known as "stopping potential".



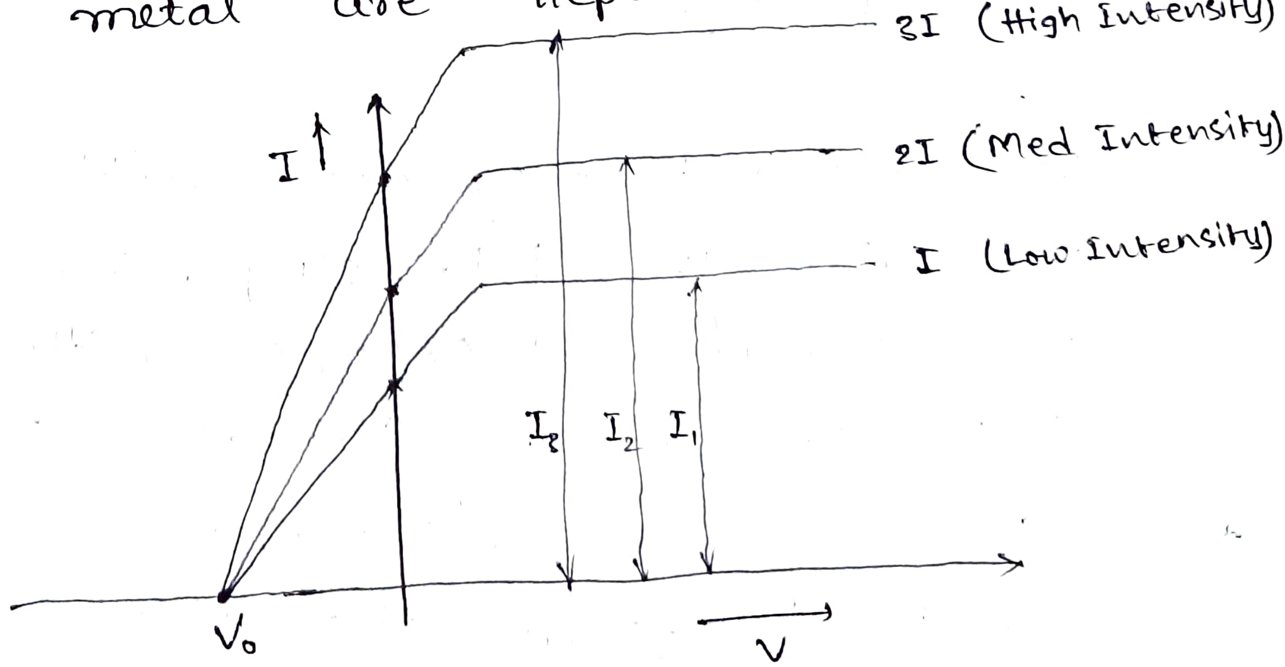
$\boxed{\text{K.E of electrons depens on applied potential between metal plates}}$

At stopping potential The Kinetic energy Max of electrons is equal to applied potential.

(KE Depends on potential)

2) <u>Intensity of incident radiation</u>:

frequency and photo-metal are kept constant.



At the intensity I we can measure the current by varying the potential. We get some saturation current (I_1) and some stopping potential

Now at the medium intensity 2I we can measure the photo current by varying potential. We get some saturation current $I_2 > I_1$ & some stopping potential V_0 same as for I.

At High Intensity 3I also we get a saturation current $I_3 > I_2$ & same stopping potential.

i.e current increases with increase in intensity. That is no. of electrons emitted out of metal surface increase.

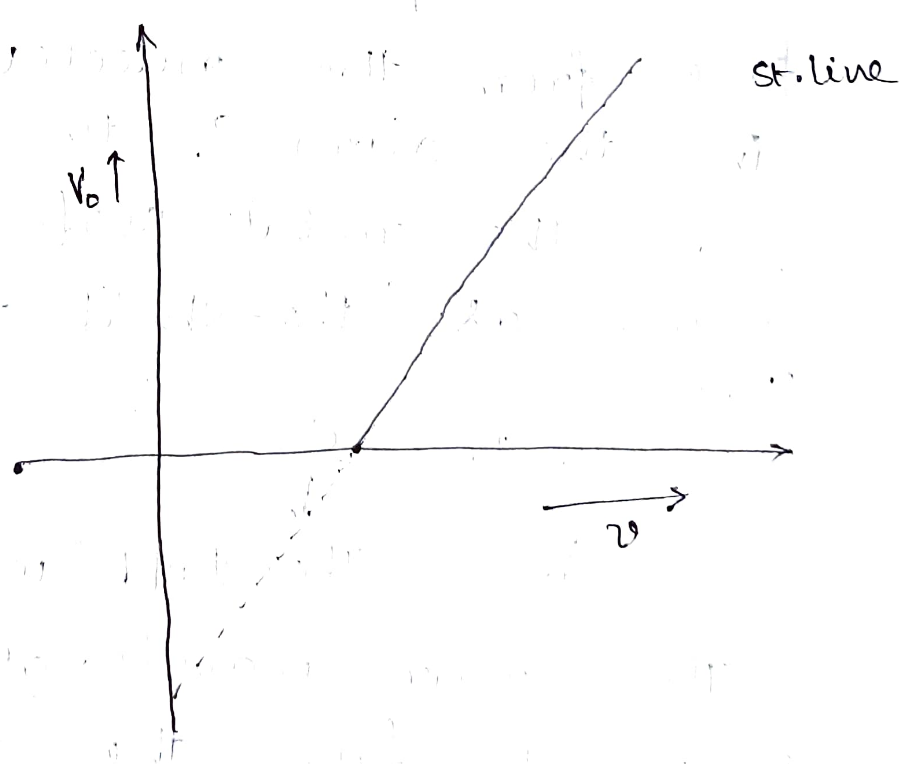
*** So no of electrons emitted from the metal surface depends up on intensity of incident radiation and stopping potential is independent of incident radiation.

*** so kinetic energy of electrons is independent of incident radiation.

3) Effect of frequency of incident radiation:

Keep intensity of incident radiation and photo metal constant

(ν varies → filters)



We can measure different stopping potentials for different frequencies of radiation.

The potential can not increase up to some frequency. That is no current flows up to some frequency. After getting a minimum value potential starts to increases with increase in the frequency.

This minimum frequency is known as "Threshold frequency"

The minimum frequency required for the electrons to free from the nucleus attraction in the atom & to free from the metal surface is known as "threshold frequency" (ν_0)

$$\nu_0 = \frac{c}{\lambda_0}$$

$\lambda_0 \longrightarrow$ Threshold wavelength

The max wavelength required from the electrons to free from metal surface is known as "Threshold wavelength" (λ_0)

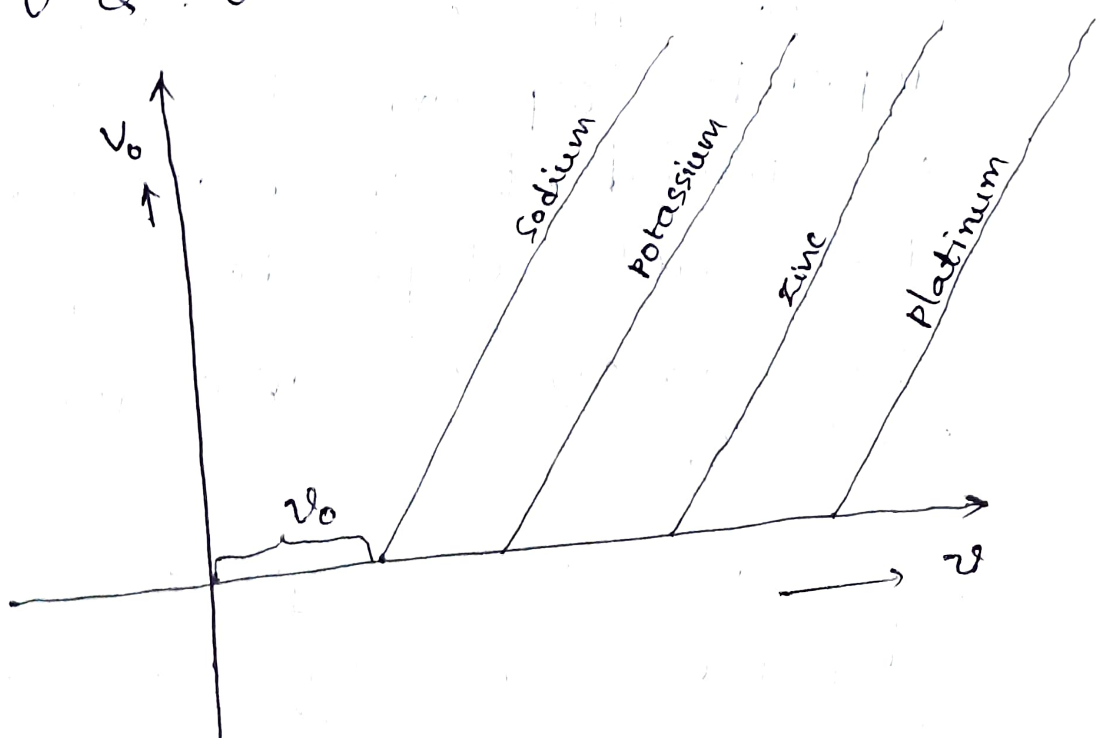
From first characteristic KE depends up on the potential difference applied between metal plates

From Third one potential depends up on frequency.

From these two the kinetic energy of emitted electrons depends on frequency of incident radiation.

4) Effect of photo metal:

Keep the intensity of incident radiation constant. By drawing graph between ν & V_0



By using different photo metals we get different intercepts on ν- axis i.e Threshold frequency is different for different photo metals.

i.e Threshold frequency depends on the nature of photo metal used

Time lag :

* The time difference between emission of e^- and incident light is 10^{-8} sec.

Laws of photo electric effect:

1) The no of electrons depends up on the intensity of incident radiation, & does not depends up on frequency of incident radiation

2) Kinetic Energy of electron depends on frequency of incident radiation and

does not depends on intensity of radiation.

3) The minimum frequency required to emit electrons out of metal surface is known as "Threshold frequency". Before this frequency no electrons emit out of metal surface.

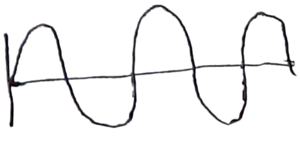
4) There is no time lag between emission of e^- and incident light (10^{-8} sec)

Failures of classical Theory for photoelectric effect:

According to photo electric effect

1) Energy is continuous and Energy absorbed by the electron depends up on Intensity of incident radiation.

i.e $E \propto I \propto A^2$



i.e $KE \propto I$

(which is contradiction to 2nd law)

2) The time of emission of e^- depends up on Intensity of incident radiation

i.e Low I

violet of low I → sodium → for one e^- ↓ 1½ year

i.e ~~[illegible]~~ Contradiction to the fourth law of photo electric effect.

photo electric effect fails to explain the 2nd law and 4th law of photo electric effect but it explains successfully the interference, polarisation, diffraction etc by considering the wave nature of Light.

Eienstein's Explanation :-

As photo electric effect was not explained by ~~[illegible]~~ classical theory.

Einstein explained the photo electric effect using Quantum Theory by considering the particle nature of light in 1905.

He assumed that

1) The Energy is discontinuous

2) The energy can be divided into small energy packets called Quanta or photon

$E = nh\nu$

3) The photon has less energy when frequency is less $(E = h\nu)$

4) The photon has high energy when frequency is high

5) One photon can interact with only when electron. That is when we incident the photon on electron, the energy of photon is Completely absorbed by the electron.

According to Einstein

The energy of photon when incident on electron.

The energy absorbed by electron can be utilised in two ways.

i) Some of it's energy is used to free from metal surface

ii) remaining energy is converted to kinetic energy.

$$h\nu = \underbrace{W_0}_{\text{work function}} + \frac{1}{2}mv^2$$

$$W_0 = h\nu_0$$

It is the minimum energy required to emit electron out of the metal surface.

We know that At Current = 0

$$eV_0 = \frac{1}{2}mv^2_{max}$$

V_0 is stopping potential

$$h\nu = h\nu_0 + eV_0$$

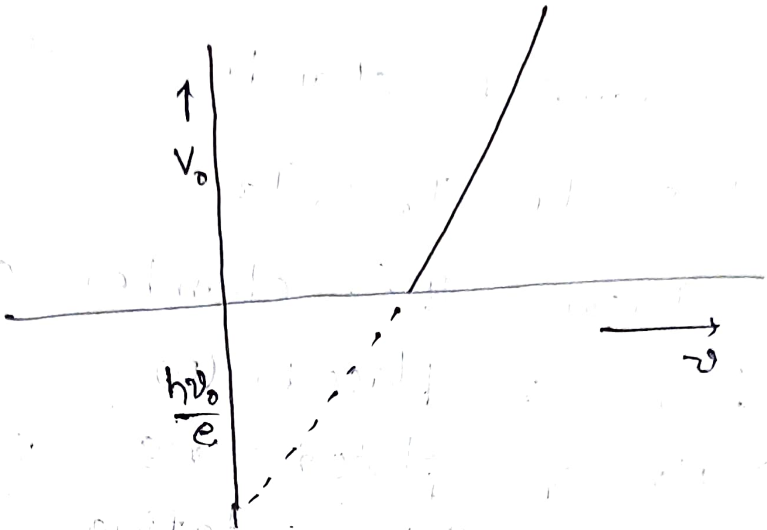
$$h(\nu - \nu_0) = eV_0$$

$$V_0 = \left(\frac{h}{e}\right)\nu - \left(\frac{h}{e}\right)\nu_0$$

which is of the form

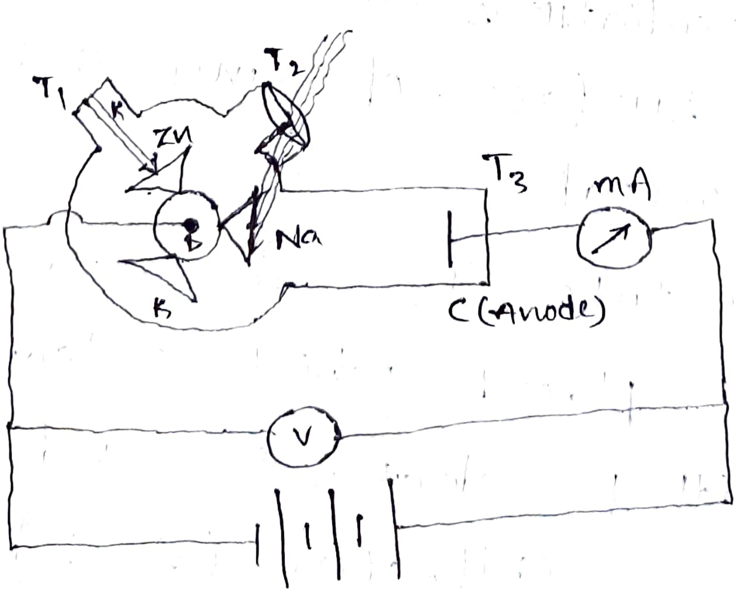
$$y = mx + c$$

Slope $m = h/e$, intercept $c = \frac{-h\nu_0}{e}$



$h \rightarrow$ planck constant which was introduced by Mullikon.

Verification of Einstein's photo electric effect by Mullikan :- & Determination of plancks const



The Einsteins photo electric effect was first verified by Mullikan.

He observed diff frequencies for different photo metals by different stopping potentials.

Construction :-

1) Evacuated chamber with side tubes T_1, T_2 & T_3

2) Inside the chamber a rotati drum is placed. (D)

3) No of photometals are attac to this rotating drum (D

4) An adjustable knife edge is placed at side tube T_1 which cleans the surface of metal

(If any oxidation takes place, it removes them from metal)

5) Side tube T_2 acts as a window to allow the radiatio of different frequencies.

These radiations are incident on clean surface of any one of the metal

6) In side tube T_3, a metal plate is placed which collect the emitted electrons and acts as a collector (Anode)

7) A milli Ammeter which reads the current.

8) We maintain Anode at +ve and -ve potentials w.r.t rotating drum (Cathode)

Working :-

1) Now we incident light of certain frequency on one of the metal, then electrons are emitted out of the metal surface and milli Ammeter shows deflection.

2) Now we increase the potential which implies photo current to increase

3) Apply -ve potential to Anode For a small negative potential slow electrons are pulled back & if we increase negative potential fast electrons are also pulled back. and current starts to decrease slowly

4) At a particular value of potential photo current becomes zero which is known as stopping potential.

Now this potential is nothing but which controls the Kinetic Energy of electrons.

5) Let $V_0 \longrightarrow$ stopping potential

$V_{max} \longrightarrow$ Max velocity of e

$$\frac{1}{2} m V_{max}^2 = eV_0 \longrightarrow (1)$$

Now According to Einsteins photo electric equation :

$$h\nu = W + \frac{1}{2} m V_{max}^2$$

$W \longrightarrow$ work function

$$h\nu = h\nu_0 + \frac{1}{2} m V_{max}^2$$

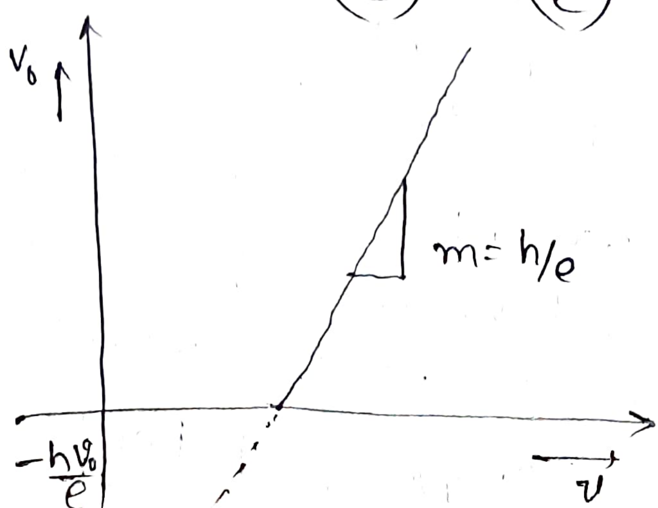
$$\Rightarrow \frac{1}{2} m V_{max}^2 = h\nu - h\nu_0$$

$$= h(\nu - \nu_0) \quad \text{---} (2)$$

from (1) & (2)

$$eV_0 = h\nu - h\nu_0$$

$$V_0 = \left(\frac{h}{e}\right)\nu - \left(\frac{h}{e}\right)\nu_0$$



The values are agreed with the Mullikan.

Hence photo electric equation of Einstein is verified.

Determination of plancks constant:

By the graph of mullikan we can find the slope of graph m.

But $m = h/e$

$\Rightarrow$ planck's constant $h = m \times e$

$= \text{slope} \times \text{charge of } e^-$

In this way we can determine the planck's constant

Compton Effect:

When a radiation of high frequency or low wavelength (x-rays or γ-rays) is incident on some matter, then the scattered radiation consists of two components.

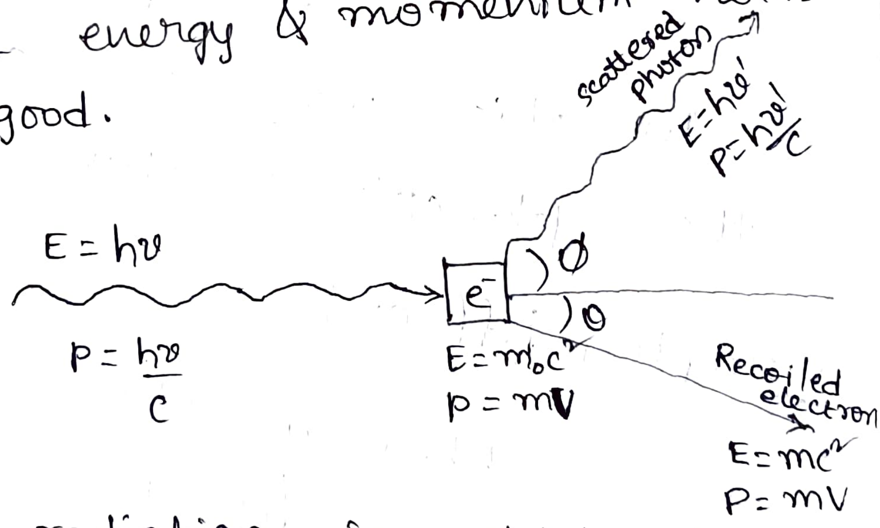
1st one is the radiation which consists of same frequency as incident radiation

2nd one is the radiation which consists of less frequency than incident radiation.

prof A. H. Compton.

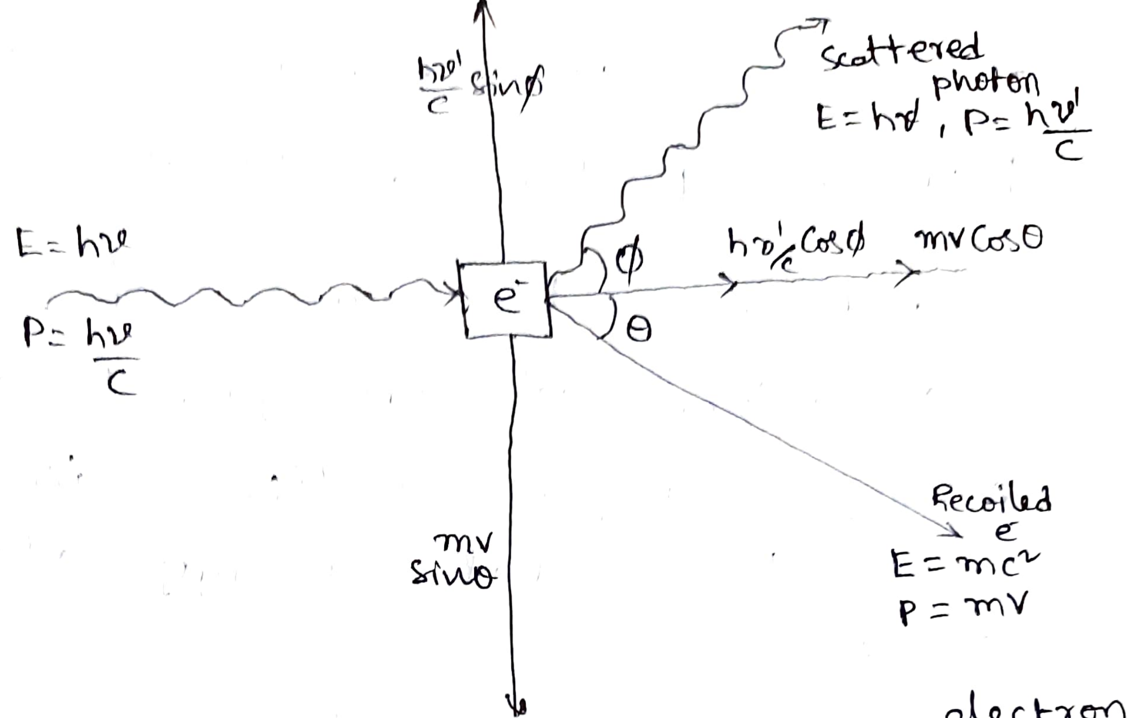
Quantum theory → The radiation consists of system of particles called photons of energy $h\nu$

→ The interaction between photon & electron can be considered as elastic collision i.e Law of conservation of energy & momentum holds good.



The radiation in which change in frequency is known as "modified radiation" & The radiation in which no change in the frequency is known as "un modified radiation"

The compton effect gave modified radiations, un modified radiations and recoiled electron.



		Photon	electron
Before Collision.			m_0c^2
	1) Energy	$h\nu$	0
	2) Momentum x-axis	$\frac{h\nu}{c}$	0
	y-axis	0	
After Collision			
	1) Energy	$h\nu'$	mc^2
	2) Momentum x-axis	$\frac{h\nu'}{c}\cos\phi$	$mv\cos\theta$
	y-axis	$\frac{h\nu'}{c}\sin\phi$	$mv\sin\theta$

Total Energy before Collision $= h\nu + m_0c^2$

Total Momentum before Collision $= h\nu/c$ (x-axis)

(y-axis) $= 0$

Total Energy after collision $= h\nu' + mc^2$

Total Momentum after collision along x-axis $= \frac{h\nu'}{c}\cos\phi + mv\cos\theta$

along y-axis $= \frac{h\nu'}{c}\sin\phi - mv\sin\theta$

Here scattering obeys law of Conservation of energy & Momentum as it is an elastic collision between photon & electron.

According to Law of Conservation of energy, total energy before collision is equal to total energy after collision

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

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

$$\Rightarrow mc^2 = h(\nu - \nu') + m_0c^2 \longrightarrow (1)$$

According to law of Conservation of momentum, total momentum before collision and after collision are equal.

so along x-axis

$$\frac{h\nu}{c} = \frac{h\nu'}{c}\cos\phi + mv\cos\theta$$

$$\Rightarrow h\nu = h\nu'\cos\phi + mvc\cos\theta$$

$$\Rightarrow mvc\cos\theta = h\nu - h\nu'\cos\phi \quad (2)$$

Now along y-axis

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

$$\Rightarrow \quad mvc\sin\theta = h\nu'\sin\phi \quad \longrightarrow (3)$$

Squaring and adding equations (2) & (3)

$$m^2v^2c^2(\sin^2\theta + \cos^2\theta) = (h\nu'\sin\phi)^2 + (h\nu - h\nu'\cos\phi)^2$$

$$\Rightarrow \quad m^2v^2c^2 = h^2(\nu')^2\sin^2\phi + h^2\nu^2 + h^2(\nu')^2\cos^2\phi - 2h^2\nu\nu'\cos\phi$$

$$\Rightarrow \quad m^2v^2c^2 = h^2(\nu')^2(\sin^2\phi + \cos^2\phi') + h^2\nu^2 - 2h^2\nu\nu'\cos\phi$$

$$\Rightarrow \quad m^2v^2c^2 = h^2\nu^2 + h^2\nu_1^2 - 2h^2\nu\nu'\cos\phi \quad \longrightarrow (4)$$

$$\Rightarrow \quad m^2v^2c^2 = h^2(\nu^2 + \nu_1^2 - 2\nu\nu'\cos\phi)$$

$$\Rightarrow \quad m^2v^2c^2 = h^2\nu^2 + h^2\nu_1^2 - 2h^2\nu\nu'\cos\phi \quad \longrightarrow (4)$$

from equation (1)

$$mc^2 = h(\nu - \nu') + m_0c^2$$

Squaring equation (1)

$$m^2c^4 = [h(\nu - \nu')]^2 + m_0c^2 + 2h(\nu - \nu')m_0c^2$$

$$\Rightarrow \quad m^2c^4 = h^2(\nu^2 + \nu'^2 - 2\nu\nu') + m_0^2c^4 + 2h(\nu - \nu')m_0c^2$$

$$\Rightarrow \quad m^2c^4 = h^2\nu^2 + h^2\nu'^2 - 2h^2\nu\nu' + m_0^2c^4 + 2h(\nu - \nu')m_0c^2 \quad \longrightarrow (5)$$

equation (5) − equation (4)

$$m^2c^4 = h^2\nu^2 + h^2\nu'^2 - 2h^2\nu\nu' + m_0^2c^4 + 2h(\nu-\nu')$$

$$-\ m^2v^2c^2 = h^2\nu^2 + h^2\nu'^2 - 2h^2\nu\nu'\cos\phi$$

$$m^2c^4 - m^2v^2c^2 = -2h^2\nu\nu' + m_0^2c^4 + 2h(\nu-\nu')m_0c^2 + 2h^2\nu\nu'\cos\phi$$

$$= 2h^2\nu\nu'(\cos\phi - 1) + m_0^2c^4 + 2h(\nu-\nu')m_0c^2 \longrightarrow (6)$$

$$\Rightarrow m^2c^4 - m^2v^2c^2 = m^2c^4\left(1 - \frac{v^2}{c^2}\right)$$

According to Einsteins special theory of relativity

$$m = \frac{m_0}{\sqrt{1 - v^2/c^2}}$$

$$\Rightarrow \left(m\sqrt{1 - v^2/c^2}\right) = m_0$$

$$\Rightarrow m^2\left(1 - v^2/c^2\right) = m_0^2 \quad \text{--- } (7)$$

Substitute equation (7) in LHS of (6)

$$\Rightarrow m_0^2c^4 = 2h^2\nu\nu'(\cos\phi - 1) + m_0^2c^4 + 2h(\nu-\nu')m_0c^2$$

$$\Rightarrow 2h^2\nu\nu'(\cos\phi - 1) + 2h(\nu-\nu')m_0c^2 = 0$$

$$\Rightarrow \cancel{2}h^{\cancel{2}}\nu\nu'(1-\cos\phi) = \cancel{2}\cancel{h}(\nu-\nu')m_0c^2$$

$$\Rightarrow (\nu-\nu')m_0c^2 = h\nu\nu'(1-\cos\phi)$$

$$\Rightarrow \frac{\nu - \nu'}{\nu\nu'} = \frac{h}{m_0 c^2} 2\sin^2\frac{\phi}{2}$$

$$\Rightarrow \frac{1}{\nu'} - \frac{1}{\nu} = \frac{2h}{m_0 c^2} \sin^2\frac{\phi}{2}$$

$$\Rightarrow \boxed{\underset{(200)}{\frac{1}{\nu'}} = \underset{(150)}{\frac{1}{\nu}} + \underset{(50)}{\frac{2h}{m_0 c^2} \sin^2\frac{\phi}{2}}}$$

$$\Rightarrow \frac{1}{\nu'} > \frac{1}{\nu}$$

$$\Rightarrow \boxed{\nu' < \nu}$$

$\nu = c/\lambda$ & $\nu' = c/\lambda'$

$$\Rightarrow \frac{\lambda'}{c} = \frac{\lambda}{c} + \frac{2h}{m_0 c^2} \sin^2\frac{\phi}{2}$$

$$\Rightarrow \lambda' = \lambda + \frac{2h}{m_0 c} \sin^2\frac{\phi}{2}$$

$$\Rightarrow \boxed{\lambda' > \lambda}$$

$$\boxed{\lambda' - \lambda = \frac{2h}{m_0 c} \sin^2\frac{\phi}{2}}$$

∴ i.e The difference in wavelengths is known as "Compton shift", represented by $\Delta\lambda$

$$\boxed{\Delta\lambda = \lambda' - \lambda}$$

∴ The change in wavelength, i.e Compton shift depends up on

Scattering angle of photon.

Case (i)

$$\phi = 0$$

$$\Delta\lambda = \lambda' - \lambda = 0$$

Case (ii)

$$\phi = 90$$

$$\Delta\lambda = \frac{2h}{m_0 c}\left(\frac{1}{\sqrt{2}}\right)^2 = \frac{h}{m_0 c}$$

$$\boxed{\Delta\lambda = \frac{h}{m_0 c}} \longrightarrow \text{Compton wavelen}$$

0.02426

Case (iii) $\phi = 180$

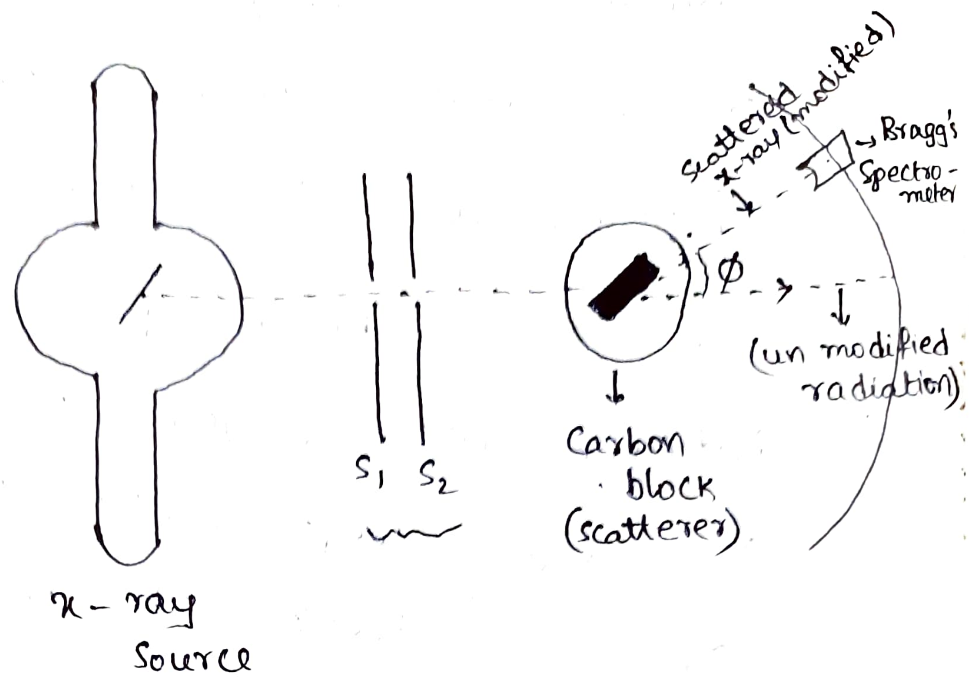
$$\Delta\lambda = \frac{2h}{m_0 c}(1)^2$$

$$\boxed{\Delta\lambda = \frac{2h}{m_0 c}}$$

0.04852

From this we can observe that, as scattering angle increases, Compton shift increase

Experimental Verification of Compton effect :



* The figure shows experimental set up for the verification of Compton effect

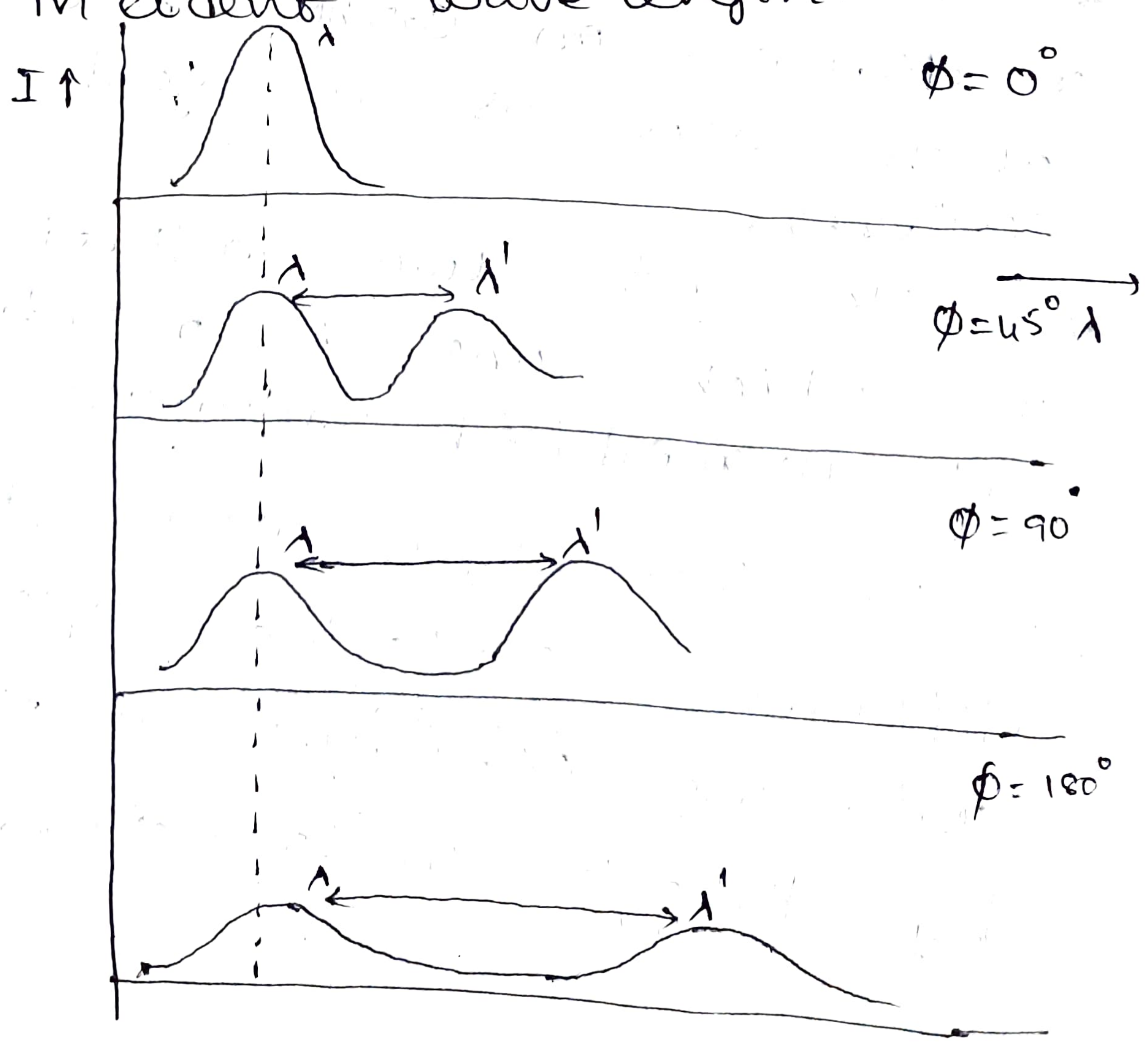
* Here we incident High energy radiations on Carbon block which acts as a good scatterer.

* We get two radiations in which one is modified and unmodified radiation.

* The intensity & wavelength at different scattering angles of scattering radiations (X - rays) are studied by Bragg's Spectrometer.

* Now a graph drawn between wavelength and intensity for different scattering angles.

We get two peaks of intensities & for two wavelength. One peak represents wavelength say as that of incident radiation (un modified), another peak represent wave length of scattered radiation, which is greater than that of incident wave length.



From Graph as Scattering angle increases Compton shift increases.

The Difference between two peaks give the "Compton shift"

* For $\phi = 90^\circ$ we get Compton wavelength.

Thus Compton effect is verified experimentally

De-Broglie concept of Matter waves:

Light or radiation has dual nature i.e particle nature & wave nature

when it interacts with matter it behaves as particle and when it travells through medium it behaves as wave.

In Newton time. Light & Matter have particle nature

After discovery of Interference, Diffraction & polarisation — They proved that light has wave nature.

In 20th century photo electric effect & Compton effect are discovered.

From this they proved that the light has particle nature.

Finally they concluded that the light has dual nature but it can't exhibit both the natures simultaneously.

In 1923 Debroglie extended his explanation to material particles like electron, proton, Neutron, He said that each ~~assosiated~~ material particle can assosiated with one wave and these waves are known as "matter waves".

i.e each wave must assosiated with one wave these are known as "Debroglie waves".

According to him $\lambda = \frac{h}{mv} = \frac{h}{p}$

Explanation :

According to planck's theory energy of photon $E = h\nu$ — (1)

According to Einstein mass energy relation is $E = mc^2$ ——— (2)

from (1) & (2)

$$h\nu = mc^2$$

but $\nu = \frac{c}{\lambda}$ $\Rightarrow$ $\frac{hc}{\lambda} = mc^2$

$\Rightarrow$ $\frac{h}{mc} = \lambda$ $\Rightarrow$ $\boxed{\lambda = \frac{h}{p}}$

If we consider a material particle of mass m and is moved with a velocity v, then the wavelength becomes $\boxed{\lambda = \frac{h}{mv}}$ ——— (4)

i.e $\boxed{\lambda = \frac{h}{p}}$

If the particle moves with velocity v, it has kinetic energy

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

$$\Rightarrow 2mE = m^2v^2 = (mv)^2 \longrightarrow (5)$$

$$\Rightarrow P = mv = \sqrt{2mE} \longrightarrow (6)$$

Substituting (6) in (4)

$$\boxed{\lambda = \frac{h}{\sqrt{2mE}}}$$

Here E is the Kinetic Energy of material particle

Debroglie wavelength associated with electron:

Let us consider an electron is at rest.

The electron is brought into motion by applying a potential difference. V_0

Then the total work done on electron is given by eV_0

($\because W = Vq$)

Due to this work done on electron the electron starts moving with a velocity of v and it gains some Kinetic energy because of this velocity v.

Now KE of $e^- = \frac{1}{2}mv^2$

But According to Law of Conservation of Energy

Work done = KE

$$eV_0 = \frac{1}{2}mv^2$$

$$2eV_0 = \cancel{2}\frac{1}{\cancel{2}}mv^2$$

$$2meV_0 = m^2v^2$$

$$\Rightarrow \quad mv = \sqrt{2meV_0}$$

The Debroglie wavelength λ is given by $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2meV_0}}$

$$\lambda = \frac{6.624 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times V_0}}$$

$$\Rightarrow \quad \boxed{\lambda = \frac{12.26}{\sqrt{V_0}} \text{ Å}}$$

Wave velocity :

Let 'u' be the velocity of wave and 'v' be the frequency and it's wave length is λ

Then velocity of wave is given by $u = v\lambda \longrightarrow (a)$

$[\because V = n\lambda]$

According to planck's theory

$E = hv$

According to Einstein

$E = mc^2$ ————

$\Rightarrow \quad h\nu = mc^2 \Rightarrow \quad \nu = \dfrac{mc^2}{h} \longrightarrow (b)$

but $\quad \nu = \dfrac{c}{\lambda}$

$\Rightarrow \quad \lambda = \dfrac{h}{mv} \longrightarrow (c)$

Sub (b) and (c) in (a)

$\Rightarrow$ wave velocity

$$u = \frac{mc^2}{h} \times \frac{h}{mv}$$

$\Rightarrow \quad \boxed{u = \dfrac{c^2}{v}}$

$v < c$

$u = \dfrac{c^2}{v}$

clearly $u > c$

$\therefore$ velocity of matter wave $>$ velocity of light

$c \longrightarrow$ velocity of light

$v \longrightarrow$ velocity of particle

Wave velocity in terms of wave length :

$h\nu = E = \frac{1}{2} mv^2 = eV_0$

$\Rightarrow \quad h\nu = eV_0 \Rightarrow \quad \nu = \dfrac{eV_0}{h}$

$$\Rightarrow \quad \nu = \frac{\frac{h}{2m} eV_0}{\frac{h}{2m} \cdot h}$$

$$\Rightarrow \quad v = \frac{h}{2m} \cdot \frac{2meV_0}{h^2}$$

$$\left(\lambda = \frac{h}{\sqrt{2meV_0}}\right)$$

$$\Rightarrow \quad v = \frac{h}{2m\lambda^2}$$

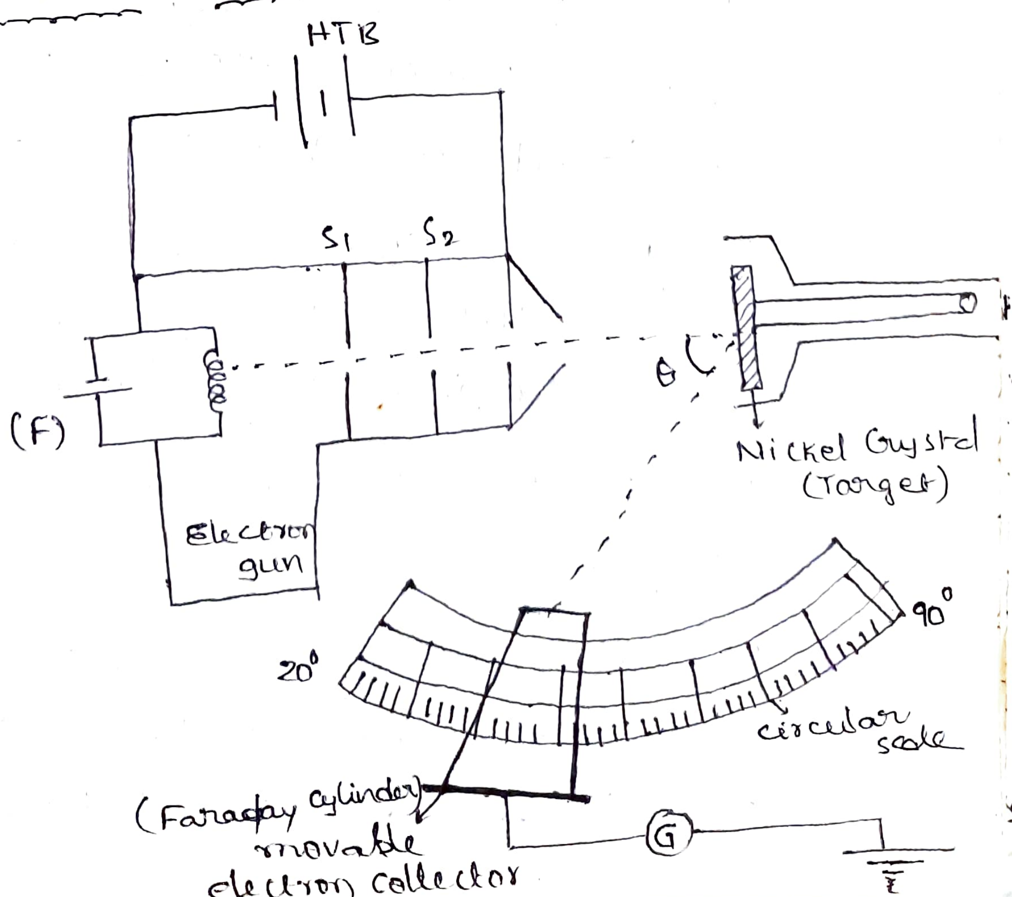
Now $u = v\lambda = \frac{h}{2m\lambda^2}(\lambda)$

$$\Rightarrow \quad \boxed{u = \frac{h}{2m\lambda}}$$

which is nothing but velocity of wave in terms of wavelength

Davisson & Germer's Experiment :

Experimental evidence for matter wave :



First experimental evidense of existance of matter waves was given by Two American physists Davisson & Germer in 1927

They proved that electron suffers diffraction which is one of the properity of wavenature. i.e electrons have wave nature. From this

∴ Matter wave's exist

Construction:

The Apparatus consists of

1) Electron gun → which produces or Supplies $\bar{e}$'s with required velocity

2) Inside the electron gun, there is a tungston filament (F) which is heated with High Tension Battery from which electron's are emitted by thermianic emission

3) Inside Electron gun contains two slit's to get a thin ~~[illegible]~~ fine electron beam

4) Nickel crystal acts as a target

5) A circular scale attached with movable electron collector is taken at the bottom part

6) A Galvanometer to get the deflection according to scattering angle

Working :

1) Inside electron gun, there is a tungstun filament, which is heated with battery, so that electrons are emitted due to thermionic emission.

2) These emitted electrons are passed through S_1 & S_2. So that we get fine beam of electrons

3) The electrons can be accelerated in the electric field with known voltage. In this way electron gun gives fine electron beam.

4) Now this electron beam incident on Nickel crystal which acts as a target.

5) The electrons are scattered in all directions from the Nickel crystal.

6) These electrons are collected by movable electron collector or Faraday detector which gives the angular distribution

of electrons, in between 20°
& 90°

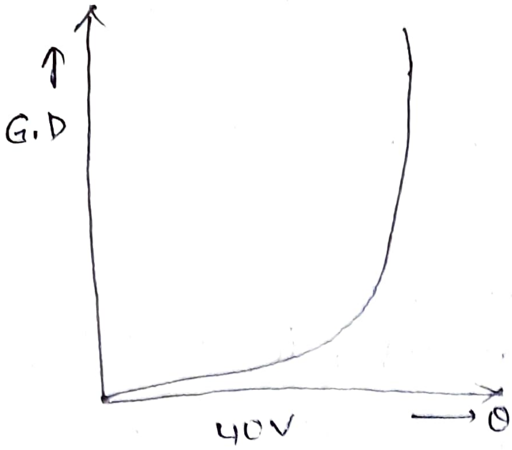
7) This Faraday detector is
Connected to Galvanometer
which gives the intensity
of incident electrons.

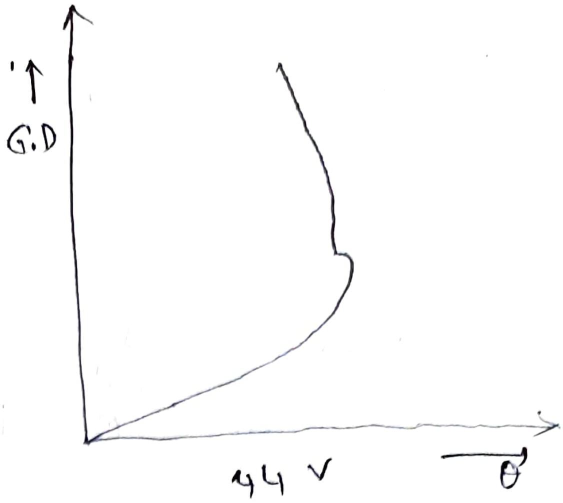
Theory :

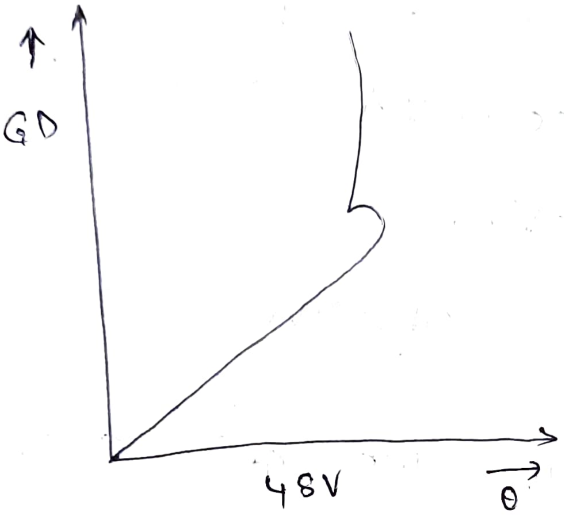
When ever we incident
electron beam on Nickel
Crystal, e^-'s are scattered
in all directions.

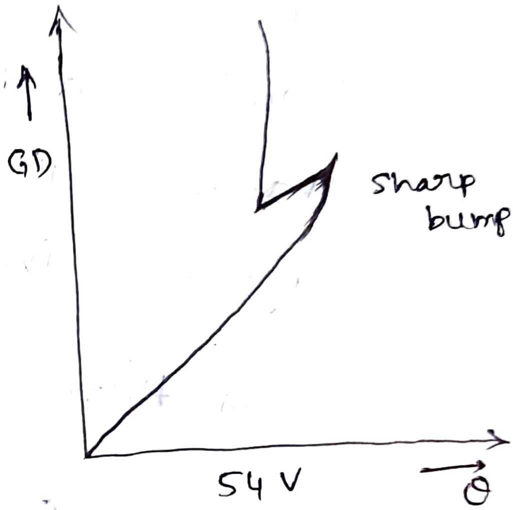
Here we measure the
Scattering angle between
incident & Scattered electron
beams Correspond to the
Galvanometer deflection or
intensity (depending up on
applied Voltage) at different
voltages.

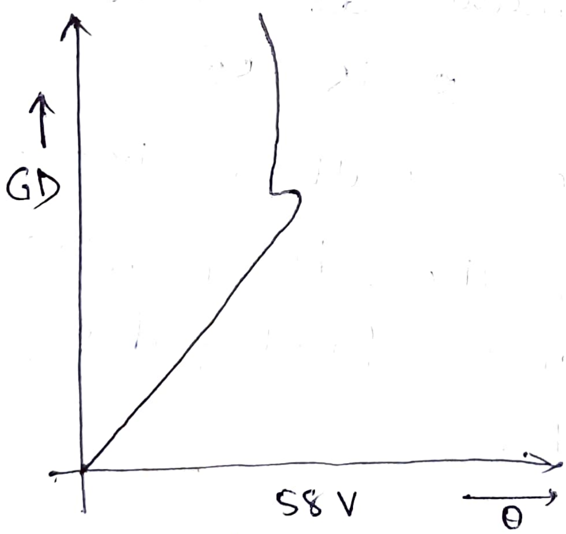
Now plotted graphs
between θ and intensity
or galvanometer deflection at
different voltages.

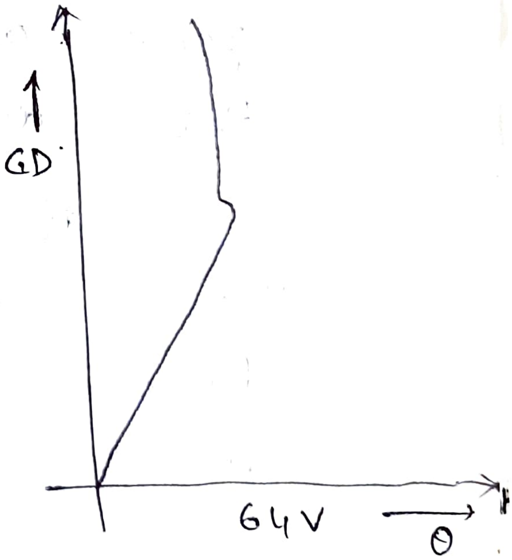

G.D
40V
θ


G.D
44 V
θ


GD
48V
θ


GD
sharp bump
54 V
θ


GD
58 V
θ


GD
64V
θ


GD
68V
θ

From graph's we observe

1) As voltage increase the graph moves up.

2) As voltage increases
As θ increasely, intensity of electron beam increases slowly and at a particular value it decreases and then again increases.

3) Here we observe a bump

4) ~~At~~ 54 volts we get a sharp peak or bump at which the angle θ is 50°

If we further increase the voltage, the bump size decreases and finally disappear at 68 volts.

Why this bump appears? is studied by Davission and Germer, They said that this is mainly due to the scattering of electron which gives max & minima but not total max & total min.

Now Debroglie wavelength at 54 volts

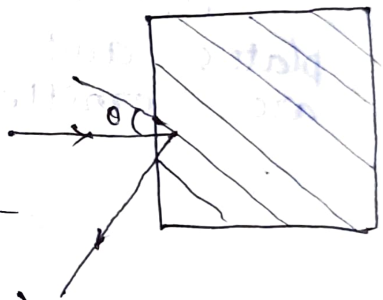
$$\lambda = \frac{12.26}{\sqrt{V_0}} = \frac{12.26}{\sqrt{54}}$$

$$\boxed{\lambda = 1.67\,A^{\circ}}$$

But according to Bragg's

$$n\lambda = 2d\sin\theta$$

$n = 1$
$d = 0.91\,A^{\circ}$
θ = Bragg's angle
(Angle between incident radiation & Bragg's plane)



$$\lambda = 2d\sin\theta = 2 \times 0.91 \times \sin 65^{\circ} = 1.65\,A^{\circ}$$

Bragg's wavelength

$$\boxed{\lambda = 1.65\,A^{\circ}}$$

Debroglie wavelength of Davisson and Germer coincide with Bragg's wavelength which proves the Diffraction of electron.

From this we can say that according to Davisson and Germer electrons posses

Quantum physics

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

$m \longrightarrow \downarrow \longrightarrow \lambda \uparrow$

$v \longrightarrow \downarrow \longrightarrow \lambda \uparrow$

$\rightarrow$ Velocity of matter wave > Velocity of light

$E = mc^2$, $E = h\nu$

$mc^2 = h\nu \Rightarrow \nu = \frac{mc^2}{h}$

$\lambda = \frac{h}{mv} \Rightarrow \omega = \nu\lambda = \frac{mc^2}{\cancel{h}} \times \frac{\cancel{h}}{mv}$

$$\Rightarrow \boxed{\omega = \frac{c^2}{v}}$$

wave packet $\longrightarrow$ (group of waves)

Consider

velocity is not able to determine position can

velocity can be determined but position can't

Heisenberg Uncertainity principle:

Depending on Debroglies concept of matter wave, Heisenberg proposed an interesting theory in 1927. According to this It is impossible to determine the position and velocity of a particle simultaneous and accurately at a time.

$\Delta x \rightarrow$ Uncertainity in determining the position

$\Delta p \rightarrow$ uncertainity in momentum

The product of uncertainity in position and momentum is nearly equal to a constant, which is planck's constant".

$$\Delta x . \Delta P \simeq h$$

(or) $$\Delta x . \Delta h \geq \frac{h}{2\pi} (\hbar)$$

Similarly: $$\Delta E \Delta t \simeq h$$

(or) $$\Delta E \Delta t \geq \frac{h}{2\pi} (\hbar)$$

Similarly

$$\Delta J \Delta \theta \simeq h$$

$$\Delta J \Delta \theta \geq \frac{h}{2\pi} (\hbar)$$