Teaching Plan (PHL 101 Physics)

Unit No.	Topic	Number of classes	Total 40
1	**Atomic Physics**		11
	Blackbody radiation-basic (no derivation)		
	Photoelectric effect	2	
	Compton effect	1.5	
	Wave particle duality		
	De Broglie hypothesis	0.5	
	Davisson-Germer experiment		
	De Broglie justification of Bohr's postulate	1	
	De Broglie waves are insignificant in case of macro bodies	1	
	Properties of matter waves	0.5	
	Heisenberg uncertainty principle	0.5	
	Thought experiments - Heisenberg uncertainty principle	1	
	Applications of uncertainty principle		
	Physical significance of Wave function	1	
	Schrodinger wave equation	1	
	Application of Schrodinger wave equation – One dimensional potential well	1	
2	**Band theory of solids**		12
	Free electron theory-Basic (no derivation)		
	The band theory of solids - A qualitative explanation	1	
	Classification of solids		
	Energy band diagram for some typical solids		
	Effective mass	1	
	Fermi energy in metals	1	
3	**Semiconductors**		
	Intrinsic semiconductor		
	Intrinsic conductivity		
	Intrinsic carrier concentration(No derivation)		

	The fraction of electrons in theconduction band	1	
	Variation of intrinsic conductivity with temperature	0.5	
	Determination of band gap of intrinsic semiconductor	0.5	
	Extrinsic semiconductors	1	
	N-type semiconductor		
	Fermi level in N-type semiconductor and variation with temperature(Qualitative)		
	P-type semiconductor		
	Fermi level in P-type semiconductor and variation with temperature(Qualitative)		
	Law of mass action	1	
	Charge neutrality condition		
	Variation of Fermi level with impurity concentration		
	Drift and diffusion currents		
	Hall effect – derivation	1	
	Semiconductor diodes		
	pn junction diode	3	
	Depletion layer,		
	Barrier potential (Vo)		
	pn junction diode under forward bias, Energy Band diagram		
	Diode equation		
	pn junction under reverse bias, Energy Band diagram		
	Bipolar Junction Transistor	1	
	n-p-n and p-n-p transistor		
	Energy band diagram of unbiased semiconductor		
	Biasing of the transistor		
	Transistor action		
	Energy band diagram of a transistor with proper biasing		
	Relation between currents in CB		

	configuration		
4	**Electron Ballistics**		8
	Motion of an electron in a uniform electric field	1.5	
	Electrostatic deflection	1	
	Motion of an electron in a uniform magnetic field		
	Magnetostatic deflection	1	
	Crossed electric and magnetic field configuration	0.5	
	Velocity selector		
	e/m of an electron by Thomson method	1	
5	**Electron Optics**		
	Electron refraction - Bethe's law		
	Electrostatic lens	1	
	Cathode ray tube	1.5	
	Cathode ray oscilloscope		
	Applications of CRO	0.5	
6	**Interference**		7
	Interference in Plane Parallel thin film	1	
	Interference in wedge shape film	1	
	Newton's ring	1	
	Applications of Interference (Testing of surface finish, Anti reflection coating)	1	
	Diffraction		
	Diffraction		
	The two types of diffraction	0.5	
	Fraunhofer diffraction at a single slit, Intensity distribution (qualitative and quantitative)	1.5	
	Fraunhofer diffraction at double slit (qualitative)	1	

7	**Crystal Structures**		2
	Unit cell	1	
	Simple cubic cell		
	Body centered cubic cell		
	Face centred cubic cell		
	Characteristics of unit cell		
	Lattice plane	1	
	Miller indices		
	Bragg's law		

QUANTUM MECHANICS

19^{th} Century – Physics consisted essentially of Newton's Classical Mechanics, and Maxwell's theory of electromagnetism.

The classical mechanics correctly explains the motion of celestial bodies – planets, stars, macroscopic and microscopic terrestial bodies with non-relativistic speeds. Maxwell's Theory for electromagnetism provided the framework to study radn. matter and radn. They were well explained by Lorentz force. dynamics of materials?

Classical theory of Physics – classical Mechanics, classical theory of electromagnetism and thermodynamics — were very successfull.

However;
The classical theory could not explain the

(i) non-relativistic motion of e^-, protons etc. – atomic dimensions.
(ii) Stability of atoms
(iii) spectrad distribution of blackbody
(iv) Origin of descrete spectra in atoms.
(v) Phenomenons like. photo electric effect, compton Effect, Raman Effect ....

Insufficiency of classical Mechanics lead to the development of Quantum Mechanics.

The development of quantum mechanics took place in two stages. First stage began with Max Planck's hypothesis according to which the radiation is emitted or absorbed by matter in descrete packets or quanta of energy equal to $h\nu$. $h \rightarrow$ Planck const. $\nu \rightarrow$ frequency of radn. This theory was not completely satisfactory being a mixture of classical and non-classical concepts.

Second stage of quantum mechanics began with two concepts. observed quantities – freq, intensities were considered unobserved quantities – position-vel. omitted

Matrix mechanics – Heisenberg –
Wave Mechanics – Schroedinger — de Broglie's wave-particle relationship.

Quantum field Theory →

Black Body Radiation.

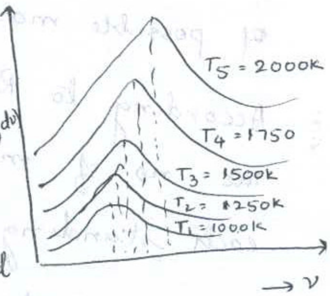
When heated a solid object glows and emits thermal radiation.
As the temperature increases, the object becomes red then yellow
then white. The thermal radiation emitted by glowing solid object
consists of continuous distribution of frequencies ranging from
IR to UV. The continuous pattern of the distribution spectrum
is in sharp contrast to the radiation emitted by heated
gases, as they show discrete distribution spectrum.
Classical theory failed to explain the continuous nature
of Black Body spectrum.

When radiation falls on an object some of it might
be absorbed some might be reflected.
An ideal black body is a material object that absorbs
all radiation falling on it and hence appears black
under reflection when illuminated from outside.
Perfect black body is a perfect absorber and a perfect
reflector (emitter of radiation).
When an object is heated it radiates electromagnetic
radiation (energy) as a result of thermal agitation of
e on its surface. The intensity of this radiation depends
upon its frequency and temperature.

A practical blackbody can be constructed by taking a
hollow cavity whose internal walls perfectly reflect e-m radn.
which has a very small hole on its surface. Radiation
that enters through the hole will be trapped inside the
cavity and gets completely absorbed after successive
reflections on the inner surfaces of the cavity. The hole
thus absorbs radns like a black body.
On the other hand, when the cavity is heated to a
temperature T, the radiation that leaves the hole is a
black body radiation — hole behaves as a perfect emitter.

As the temperature increases the body begins to glow.
To understand the radⁿ coming out of the hole, the spectral distribution of the radiation coming out of the hole should be analyzed.

Black Body radiation - Radiations leaving the hole of a heated hollow cavity - radiation emitted by a blackbody when hot is called black body radiation.



The Experimental measurements made for $E_\nu(d\nu)$ (energy density) for different frequency (ν) at different temperature (T) shows that

(i) The energy is not uniformly distributed in the radiation spectrum of a black body.

(ii) At a given temperature the intensity of radiation increases with increase in ~~temperature~~ wavelength becomes max at a particular λ. On further increasing the wavelength, the intensity of radiation decreases.

(iii) As the temperature increases the frequency corresponding to max intensity (ν_{max}) shifts towards higher freq side. or λ_m shifts towards lower wavelength side. such that $\lambda_m T = $ Const - Weins Displacement Law.

(IV) An increase in temperature causes an increase in the intensity of radiation emitted at all wavelengths.

(V) The area under each curve represents the total energy emitted by the body at a particular temperature. The area increases with increase in temperature. The area is proportional to the fourth power of absolute temperature $E \propto T^4$ Stefan's Law

According to classical

inside the cavity of the black body at an equillibrium temperature T. forms the standing waves. The no. of standing waves (possible modes) that can fit in the cavity depends on the wavelength. i.e., the no. of possible modes is small for large wavelengths.

According to Rayleigh Jeans law, the increase in the no. of modes is proportional to $\frac{1}{\lambda^2}$ or ν^2 and each standing wave possesses ave. K.E $= KT$

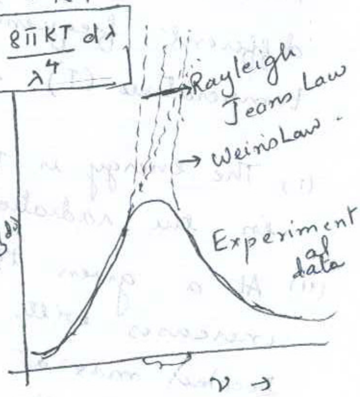
$$\boxed{E_{\lambda}d\lambda = \frac{8\pi KT}{\lambda^4}\,d\lambda}$$

$$E_{\nu}(d\nu) = \frac{8\pi\nu^2}{c^3}\,KT\,d\nu$$

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

$d\nu = -\frac{c}{\lambda^2}\,d\lambda$

$\frac{8\pi \cdot c^2}{\lambda^2 c^3} \cdot \frac{KT c}{\lambda^2}$



It is observed that the Rayleigh Jeans law follows the experimental curve only for low frequencies where as in the higher frequency range it diverges. implying that the cavity contains an infinite amount of energy which is absurd. This is called ultraviolet catastrophe. i.e., diverges for high frequencies (i.e., ultraviolet range).

Catastrophic failure of classical Physics.

The reason for the failure is that the energy exchange between radn and matter is continuous any amount of energy can be exchanged.

Though Wein's data fits remarkably well in high freq region but fails for low frequencies.

Wein's Energy density distribution

$$E_{\nu}(d\nu) = A\nu^3 e^{-\beta\nu/T}$$

$$\boxed{E_{\lambda}d\lambda = \frac{A}{\lambda^5}\,e^{-\beta/\lambda T}\,d\lambda}$$

Planck's Quantum Hypothesis: Atoms of the walls of the black body behave as oscillators an each has characteristic freq. of oscillation

Assumptions:

(i) An oscillator cannot have any ~~ar~~ arbitrary value of energy but can have only descrete engies according to the relation $E = nh\nu$ $n = 0, 1, 2, 3 \ldots$

$h \rightarrow$ Planck's const. 6.6×10^{-34} J-s

This shows that the energy of the oscillation is quantised.

(ii) The oscillator can emit or absorb energy only in the form of packets of energy ($h\nu$) but not continuously. In other words emission/absorption of energy occurs only when the oscillator jumps from one energy state to another.

$$\Delta E = nh\nu$$

$$E_2 - E_1 = (n_2 - n_1) h\nu$$

Planck's Radiation formula for energy density $E_{\nu d\nu}$ in the frequency range ν and $\nu + d\nu$ is

$$E_{\nu d\nu} = \frac{8\pi h\nu^3}{c^3} \cdot \frac{1}{(e^{h\nu/kT} - 1)} d\nu$$

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

For shorter wavelength

$e^{hc/\lambda kT} >> 1$ $\therefore$ 1 can be neglected.

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

$$E_{\lambda d\lambda} = \frac{A}{\lambda^5} e^{-B/\lambda T} d\lambda \longrightarrow \text{Weins Law}$$

For longer ~~smaller~~ wavelengths

$$e^{hc/\lambda KT} \approx 1 + \frac{hc}{\lambda KT},$$

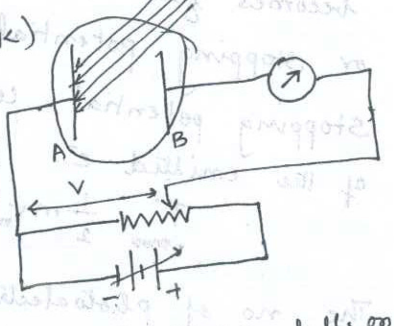
$$E_\lambda d\lambda = \frac{8\pi hc}{\lambda^5} \cdot \frac{1}{\cancel{1} + \frac{hc}{\lambda KT} - \cancel{1}} d\lambda$$

$$= \frac{8\pi \cancel{hc} \cdot \lambda KT}{\lambda^{\cancel{5}} \cdot \cancel{hc}} d\lambda$$

$$E_\lambda d\lambda = \frac{8\pi KT}{\lambda^4} d\lambda \quad \rightarrow \text{Rayleigh Jeans Law}$$

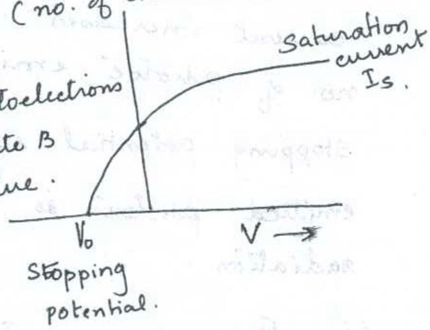
Photoelectric Effect:

When a light of suitable wavelength falls on a metallic surface (UV light on Zn plate or ordinary light on alkali metals Na, K, Li) the emission of e^- from the surface of of the metal takes place. These emitted e^- are called photoelectrons and the phenomenon is called photoelectric effect.



A and B are two metal plates (Na/K) placed in an evacuated quartz bulb. Plate A is connected to −ve terminal and B is connected to +ve terminal thro' a galvanometer G (μA). When no light falls on metal plate A no current flows; But when monochromatic light falls on plate A, the current starts flowing which is indicated by deflection in a galvanometer. This current is called photoelectric current.

For a given photometal A, keeping the intensity and frequency of the incident light constant, if the +ve potential of plate B is increased, the photocurrent increases (no. of emitted photo e^-).



When the pot. difference between the two electrodes is large enough all the photoelectrons emitted by plate A (Cathode) reaches plate B so the photocurrent reaches the max value.

On further increasing the pot. diff. the photocurrent remains const. This current is called saturation photocurrent. Now when the applied pot is brought to zero the photo current still flows in the same direction. ∴ The incident radiation provides not only conductivity but also provides electromagnetic force.

If the pot. diff. is reversed i.e, A → +ve B → −ve. It is observed that for small −ve voltages the current flows in the same direction indicating that e^- are being emitted from the plate A with finite vel.

If negative pot. diff is increased then photoelectric current decreases and finally becomes zero at sharply defined pot. diff.

The negative pot. at which the photoelectric current becomes zero (vanishes) is called the cut off potential or stopping potential.

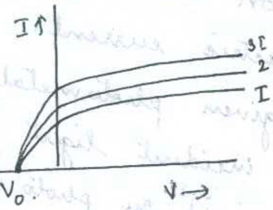
Stopping potential corresponds to the maximum K.E of the emitted e^-.

$$T_{max} = \frac{1}{2} m v_{max}^2 = eV_0.$$

The no. of photoelectrons emitted and their K.E depends upon:
1. The intensity of incident radiation
2. The frequency of incident radiation
3. The photometal used.

(i) Intensity. Frequency + photometal are kept const.

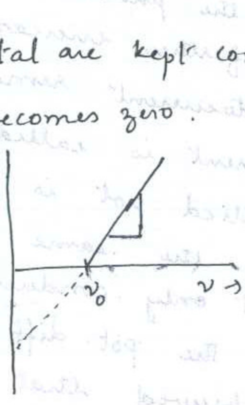
With increase in Intensity of incident radiation, the saturation current increases indicating that no. of photoe^- emitted increases.



Stopping potential remains const → max. K.E of the emitted photoe^- is independent of the Intensity of incident radiation.

(ii) Frequency. Intensity and photometal are kept const.

At frequency ν_0 the stopping potential becomes zero. This is known as threshold frequency. Photoelectric Effect occurs above this ν_0 frequency and ceases below. Thus threshold frequency is the frequency



(i) a part is used to overcome the work function (in releasing the e^- from the metal surface) and (ii) the remaining energy is given to the same e^- as it's additional K.E.

$$\left.\begin{aligned} h\nu &= W + T_{max} \\ T_{max} &= \frac{1}{2} m v_{max}^2 = h\nu - W \end{aligned}\right\} \quad \text{--- (1)}$$

Einsteins photoelectric Equation.

Max. K.E increases with increase in frequency and decreases with decrease in freq. At a particular freq. max. K.E becomes zero. It is called threshold freq.

$$T_{max} = 0 \quad \nu = \nu_0$$

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

There exists a threshold freq (ν_0) such that the e^- is just liberated from the surface of the metal by overcoming the binding Energy.

If the freq. of radiation is below threshold freq — no emission of e^- occurs.

In terms of threshold ~~f~~ frequency Eq (1) can be written as.

$$T_{max} = h\nu - h\nu_0 = h(\nu - \nu_0) \quad \text{--- (3)}$$

If V_0 is the stopping pot. then

$$T_{max} = \frac{1}{2} m v_{max}^2 = eV_0 . \quad \text{--- (4)}$$

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

$$V_0 = \frac{h}{e}\nu - \frac{h}{e}\nu_0 \quad \text{--- (5)}$$

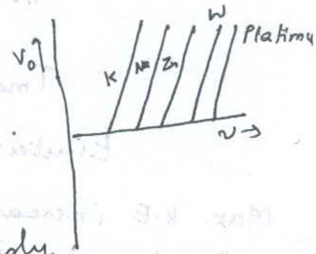
$$y = mx + c.$$

Slope $= \frac{h}{e}$. in V_0 vs ν graph.

e, ν_0 is const, $\quad c = -\frac{h}{e}\nu_0 = -\frac{W}{e}$.

at which the when falling on the metal surface the $\bar{e}$ are just liberated without giving them additional Energy.

(iii) Photometal Intensity const.



Threshold frequency depends on the Photometal ⇒ Threshold freq is the characteristic property of the photometal.

(iv) Time:

Electrons are emitted instantaneously without any time lag even for low intensities. 10^{-8} sec → time lag.

Einsteins Explanation:

Based on Plancks hypothesis Einstein made foll. assumptions.

1. The Energy of e-m rad$^{\underline{n}}$ is not continuously distributed over the wavefront, but remains concentrated in packets of energy $h\nu$ → quanta / photons. They travel with vel. of light.

(ii) Each packet of energy ($h\nu$) is so concentrated that it can transfer the whole energy content to one $\bar{e}$. i.e, One photon is completely absorbed by one $\bar{e}$ which thereby gains the quantum of energy and may be emitted from the metal.

Photoelectric effect → interaction between the single photon with bound $\bar{e}$.

When a photon of energy $h\nu$ is incident on a metal surface. The energy of the photon goes in two parts:

Compton Effect

When a monochromatic beam of high frequency rad^{n} (x-rays, γ-rays) is scattered by a substance, the scattered radiations contain the radiations of lower freq or greater wavelength alongwith the radiations of unchanged wavelength / frequency. The rad^{ns} of unchanged wavelength $\rightarrow$ unmodified rad^{ns}. The rad^{ns} with greater wavelength $\rightarrow$ modified rad^{ns}. This phenomenon is called as Compton Effect.

This is explained on the basis of quantum theory of light according to which rad^{ns} consist of photons of energy $h\nu$. $\rightarrow$ They move with vel. of light c. and ~~move with~~ possess momentum $\frac{h\nu}{c}$, obey all laws of conservation of energy and momentum when they strike the e^- of the scattering substance.

Compton scattering is due to collision between two particles incident photon and e^- of the scattering substance.

When a photon of energy $h\nu$ collides with free e^- of the scattering substance initially at rest, it transfers some of the energy to e^-. Due to this the e^- gains K.E and recoils with vel v. Hence the scattered photon will have lower energy i.e., lower freq or longer wavelength than the incident one. $\rightarrow$ Compton Effect

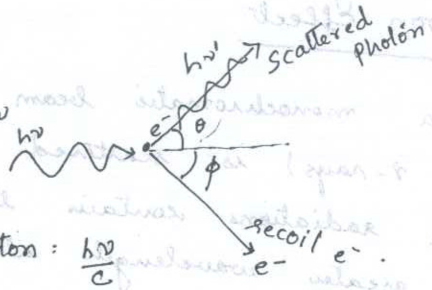
Assumptions:-

(i) Compton Effect is the result of interaction of an individual photon with free e^-

(ii) The collision is relativistic and elastic.

(iii) The laws of conservation of linear momentum and energy holds good.

›efore Collision:



nergy of the incident photon : $h\nu$

ıergy of the e^- = m_0c^2

›mentum of the incident photon : $\frac{h\nu}{c}$

›mentum of the e^- = 0

Aftér Collision:

ıergy of the scattered photon : $h\nu'$

nergy of the ~~scattered~~ recoil e^- : mc^2

Momentum of the scattered photon : $\frac{h\nu'}{c}$

Momentum of the recoil e^- = mv

Energy of the system (e^- + photon) before collision

$$h\nu + m_0c^2$$

Energy of the sys. after collision

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

Applying Law of conservation of energy

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

$$mc^2 = h\nu - h\nu' + m_0c^2 \quad \text{——— (1)}$$

Applying law of conservation of ~~energy~~ momentum along X and Y. axis

$$\frac{h\nu}{c} + 0 = \frac{h\nu'}{c}\cos\theta + mv\cos\phi \quad (X\text{-axis})$$

$$0 = \frac{h\nu'}{c}\sin\theta + mv\sin\phi \quad (Y\text{-axis})$$

$$mvc\cos\phi = h\nu - h\nu'\cos\theta \quad \text{——— (2)}$$

$$mvc\sin\phi = h\nu'\sin\theta \quad \text{——— (3)}$$

Squaring and adding eq (2) + (3)

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

$$= h^2\nu^2 + h^2\nu'^2\cos^2\theta \mp 2h^2\nu\nu'\cos\theta + h^2\nu'^2\sin^2\theta.$$

$$m^2v^2c^2 = h^2\nu^2 + h^2\nu'^2 \mp 2h^2\nu\nu'\cos\theta \quad \text{—— (4)}$$

Squaring eq (1)

$$m^2c^4 = h^2\nu^2 + h^2\nu'^2 + m_0^2c^4 - 2h^2\nu\nu' - 2h\nu' m_0c^2$$
$$+ 2h\nu m_0 c^2 \quad \text{——— (5)}$$

Subtracting (4) from (5)

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

$$m^2c^4 - m^2v^2c^2 = m_0^2c^4 + 2h^2\nu\nu'(1-\cos\theta) - 2h(\cancel{\nu'-\nu})m_0c^2 \quad (6)$$

According to the theory of relativity

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

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

$$m^2c^2 - m^2v^2 = m_0^2c^2$$

$$m^2c^4 - m^2v^2c^2 = m_0^2c^4 \quad \text{——— (7)}$$

Comparing RHS of eq (6) + (7)

$$\cancel{m_0^2c^4} = \cancel{m_0^2c^4} + 2h^2\nu\nu'(1-\cos\theta) - 2h(\nu-\nu')m_0c^2.$$

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

$$\frac{(\nu-\nu')}{\nu\nu'} = \frac{h}{m_0c^2}(1-\cos\theta).$$

$$\frac{1}{\nu'} - \frac{1}{\nu} = \frac{h}{m_0c^2}(1-\cos\theta). \qquad \Delta\lambda = \frac{h}{m_0c}(1-\cos\theta).$$

$$\boxed{\lambda' - \lambda = \frac{h}{m_0c}(1-\cos\theta)}$$

$\theta = 180^\circ$

$$\Delta\lambda = \frac{h}{m_0 c}\left(1-(-1)\right) = \frac{2h}{m_0 c} \simeq 0.05\,\mathring{A}.$$

X-rays or γ-rays with $\lambda = 5\mathring{A}$.

Visible radiation ~ $5000\,\mathring{A} - 6000\,\mathring{A}$. does not Show Compton shift. .001% - max change.

Direction of the recoil e^-,

Dividing (3) / (4)

$$\tan\phi = \frac{h\nu'\sin\theta}{h\nu - h\nu'\cos\theta} = \frac{\frac{c}{\lambda'}\sin\theta}{\frac{c}{\lambda} - \frac{c}{\lambda'}\cos\theta} = \frac{\lambda\sin\theta}{\lambda' - \lambda\cos\theta}$$

K.E of the Recoil e^-.

$$K.E = (m - m_0)c^2 = h\nu - h\nu'$$

$$= \frac{hc}{\lambda} - \frac{hc}{\lambda'} = hc\left[\frac{\lambda' - \lambda}{\lambda\lambda'}\right]$$

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

$$\frac{c}{\nu'} = \frac{c}{\nu} + \frac{h}{m_0 c}(1-\cos\theta)$$

$$\frac{1}{\nu'} = \frac{1}{\nu}\left[1 + \frac{h\nu}{m_0 c^2}(1-\cos\theta)\right]$$

$$\nu' = \frac{\nu}{\left[1 + \frac{h\nu}{m_0 c^2}(1-\cos\theta)\right]} = \frac{\nu}{1 + x(1-\cos\theta)}$$

$$x = \frac{h\nu}{m_0 c^2}$$

Substituting in eq K.E.

$$K.E = h\nu - \frac{h\nu}{1 + x(1-\cos\theta)} = h\nu\left[1 - \frac{1}{1+x(1-\cos\theta)}\right]$$

$$= h\nu\left[\frac{\cancel{1} + x(1-\cos\theta) - \cancel{1}}{1 + x(1-\cos\theta)}\right]$$

$$\boxed{K.E = \frac{h\nu\, x(1-\cos\theta)}{1 + x(1-\cos\theta)}}$$

Wave Particle Duality:

Light exhibits the phenomenon of interference, diffraction, polarisation, photoelectric Effect, Compton Effect discrete emission and absorption.

Interference, diffraction, polarization — Wave theory of Light

$\Rightarrow$ Light possesses wave nature.

Photoelectric effect, Compton Effect, discrete emission and absorption — quantum theory of light.

$\Rightarrow$ Light possesses corpuscular (particle) nature.

$\Rightarrow$ Light possess dual nature.

de Broglie Hypothesis

de Broglie extended the idea of dual nature to all microparticles associating both wave and corpuscular characteristics with every particle.

According to de Broglie Hypothesis any moving particle is associated with a wave. The waves associated with particles are known as de Broglie waves or matter waves. He proposed that the wavelength λ of matter waves associated with a particle moving with velocity v is inversely proportional to the magnitude of momentum of the particle

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

Momentum of a photon $p = \frac{h\nu}{c} = \frac{h}{\lambda}$

$$\Rightarrow \lambda = \frac{h}{p} = \frac{h}{mv}.$$

This equation can also be derived using the gen equation of a standing wave system.

Consider a material particle such as an e^- or proton as a standing wave system in the region of space occupied by the particle. Let ψ be the quantity that undergoes periodic changes giving rise to matter waves then the value of ψ at an instant of time t at pt. (x, y, z)

$$\psi = \psi_0 \sin \omega t$$

$$= \psi_0 \sin 2\pi \nu t \quad \text{——} \quad (1)$$

Let the particle be moving with vel. v in the x-dirtn

$$\psi = \psi_0 \sin \frac{2\pi \nu \left(t' + \frac{v x'}{c^2}\right)}{\sqrt{1 - v^2/c^2}} \quad \text{——} \quad (2)$$

According to inverse Lorentz transformation eqn

$$t = \frac{t' + \frac{v x'}{c^2}}{\sqrt{1 - v^2/c^2}}$$

Standard equation for motion

$$\psi = \psi_0 \sin \left\{ \frac{2\pi}{T'} \left(t' + \frac{x'}{u'} \right) \right\} \quad \text{——} \quad (3)$$

$T' \rightarrow$ periodic time $\quad u' \rightarrow$ phase vel. $\quad \psi_0 \rightarrow$ amplitude.

comparing eq (2) + (3) $\quad \frac{1}{T'} = \nu' = \frac{\nu}{\sqrt{1 - v^2/c^2}} \quad \text{——} \quad (4)$

$$u' = \frac{c^2}{v}$$

~~Comparing eq (2) + (3)~~

According to Einsteins mass energy relation

$$E = m_0 c^2 = h\nu$$

$$\nu = \frac{m_0 c^2}{h} \quad \text{——} \quad (5)$$

Substituting eq (5) in (4)

$$\nu' = \frac{m_0 c^2}{h\sqrt{1 - v^2/c^2}} = \frac{mc^2}{h} \quad \text{——} \quad (6)$$

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

The wavelength of a material particle is given by

$$\lambda = \frac{\text{velocity}}{\text{frequency}} = \frac{u'}{\nu'} = \frac{c^2/v}{mc^2/h} = \frac{h}{mv}.$$

$E_K \rightarrow$ K.E of the particle

$$p = \sqrt{2mE_K}$$

$\therefore$ de Broglie wavelength of particle in terms of K.E

$$\lambda = \frac{h}{\sqrt{2mE_K}}.$$

If a charged particle carrying charge q is accelerated through a pot. diff V volts then kinetic Energy $E_K = qV$.

de-Broglie Wavelength of charged particle

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

For a material particles in thermal equillibrium at temp T, then they possess Maxwellian distribution of vel. such that their ave. K.E is

$$E_K = \frac{1}{2} m v_{rms}^2 = \frac{3}{2} kT.$$

de Broglie wavelength for a material particle at temp T in thermal equillibrium.

$$\lambda = \frac{h}{\sqrt{2mE_K}} = \frac{h}{\sqrt{\cancel{2}m\frac{3}{\cancel{2}}kT}} = \frac{h}{\sqrt{3mkT}}.$$

Method for obtaining an expression for de-Broglie wavelength indicates that a material particle in motion involves two different velocities. One refers to mechanical motion of the particle represented by u. The rel^n connecting two velocities

$$u = \frac{c^2}{v}.$$

de Broglie justification of Bohr's postulate.

Bohr's theory of atomic structure remained without a valid theoretical justification for a long time.

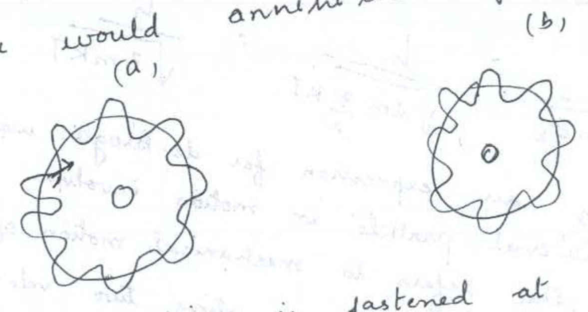
The Postulate of Bohr theory:

"Only those e^- orbits are allowed as stationary orbits whose angular momentum is an integral multiple of $\frac{h}{2\pi}$,

$$L = \frac{nh}{2\pi} \qquad n = 1, 2, 3 \ldots$$

de-Broglie suggested that if wave properties are associated with e^- then a sort of resonance might occur when the circumference of the orbit is equal to an integral multiple of the wavelength of the wave associated with the electron.

As the e^- travels around in one of the circular orbits, the ~~Accordingly~~, associated matter waves propagate along the circumference again and again. A wave must meet itself after going round one full circumference. If it did not meet, the wave would be out of phase with itself after going round one full circle. After a large no. of orbits all possible phases would be obtained and the wave would annihiliate by destructive interference.



If a stretched string is fastened at both ends an is made to vibrate, standing waves are formed provided the length of the string is an integral multiple of half wavelength

If the the string is formed into a circular loop the condⁿ for standing waves is that the circumference of the loop should be an integral multiple of whole wavelength. If r is the radius of the circular loop

$$2\pi r = n\lambda \quad . \; n = 1, 2, \ldots$$

Above eqn can be applied to $\bar{e}$ waves taking λ as the de-Broglie wavelength

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

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

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

$$L = mvr$$

$$L = n\frac{h}{2\pi} \rightarrow \text{Bohr's postulate.}$$

de-Broglie thus demonstrated the quantization of angular momentum as a direct consequence of wave nature of $\bar{e}$.

In case of macroscopic bodies:

As the mass m of the body increases, the wavelength tends to become insignificant

For a cricket ball of mass 500gm. flying with the vel. 50km/hr

$$\lambda = \frac{6.6\times10^{-34}\,J\text{-}s}{500\times10^{-3}\,kg\times13.9\,m/s} = 10^{-34}\,m = 10^{-24}\,\mathring{A}.$$

$\Rightarrow$ wavelength becomes insignificant as compared to the size of the ball.

For an e^- with energy 100eV

$$\lambda = \frac{h}{\sqrt{2meV}} = \frac{6.6\times10^{-34}}{\sqrt{2\times 9.1\times10^{-31}\times 1.6\times10^{-19}\times 100}} = 1.33\,\text{Å}$$

As the size of the $e^- \to 10^{-5}$ Å than the wavelength 1.33 Å.

$\Rightarrow$ e^- behaves more as a wave than a particle ~~under~~

Properties of Matter Waves:

1. Matter waves are produced by the motion of the particles and are independent of the charge. They are neither e-m nor acoustic waves but are new kind of waves.
2. They can travel thro' vacuum and do not require material medium to travel.
3. Smaller is the vel - longer is the wavelength associated with it.
4. Lighter is the particle - longer is the wavelength
5. Vel. of matter waves depends upon the vel. of the particle and is not a const.
6. They exhibit diffraction/interference phenomenon as any other waves.

Vel of de Broglie Waves:

$$v_p = \nu\lambda$$

$$= \frac{\omega}{2\pi}\cdot\frac{2\pi}{k}$$

$v_p = \frac{\omega}{k}$ — phase vel. vel. of propagation of waves. The vel. with which the plane of equal phase travels in a medium

$$E = h\nu \qquad \lambda = \frac{h}{p}$$

$$\nu = E/h$$

$$v_p = \frac{E}{k}\cdot\frac{k}{p} = \frac{E}{p}$$

Non relativistic case.

$$E = mc^2 \qquad p = mv \qquad v_p = \frac{\cancel{m}c^2}{\cancel{m}v} = \frac{c^2}{v}$$

As $v << c$ $\quad v_p$ of deBroglie waves $>> c$. $\to$ Absurd.

Wave Packet comprises of group of waves each with slightly different velocity and wavelength with phases and amplitudes so chosen that they interfere constructively over a small region of space where the particle may be located outside which they produced destructive interference.

The wave packet moves with the vel. (G) = Group Velocity

Individual waves forming the wave packet possess average vel. $u \rightarrow$ phase velocity.

Velocity of material particle is v.

$$y = A \sin \omega\left(t - \frac{x}{u}\right) = A \sin(\omega t - kx)$$

$$y' = A \sin \omega'\left(t - \frac{x}{u'}\right) = A \sin(\omega' t - k' x).$$

$\omega = 2\pi\nu$, $\omega' = 2\pi\nu'$ $\quad k = \frac{2\pi}{\lambda} = \frac{\omega}{u}$, $k' = \frac{2\pi}{\lambda'} = \frac{\omega}{u'}$

Superposition of the two waves gives $A \sin(\omega' t - k' x)$.

$$y_1 = y + y' = A \sin(\omega t - kx) + A \sin(\omega' t - k' x)$$

$$= 2A \sin\left(\frac{\omega t - kx + \omega' t - k' x}{2}\right) \cos\left(\frac{\omega t - kx - (\omega' t - k' t)}{2}\right)$$

$$y = 2A \sin\left(\frac{\omega + \omega'}{2} t - \frac{k + k'}{2} x\right) \cos\left(\frac{\omega - \omega'}{2} t + \frac{k - k'}{2} x\right)$$

This eqn. represents vibration of amplitude

$$2A \cos\left(\frac{\omega - \omega'}{2} t + \frac{k - k'}{2} x\right] \qquad \text{freq } \frac{\omega - \omega'}{2}$$

Propagation const $= \frac{k + k'}{2}$

Phase moves with vel. $\frac{\omega + \omega'}{k + k'}$ $\quad \left(\because u = \frac{\omega}{k}\right)$

Amplitude $\cos\left(\frac{\omega - \omega'}{2} t + \frac{k - k'}{2} x\right]$ moves with the signal vel called Group Vel. $G = \frac{\omega - \omega'}{k - k'} = \frac{d\omega}{dk} = \frac{d(2\pi\nu)}{d(2\pi/\lambda)} = \frac{d\nu}{d(1/\lambda)}$

$$\left(G = \frac{d\nu}{d\left(\frac{\nu}{u}\right)} \qquad \frac{1}{G} = \frac{d(\nu/u)}{d\nu}\right)$$

$$\frac{1}{2}mv^2 = E - V$$

Particle vel $\quad v = \left[\frac{2(E-V)}{m}\right]^{1/2}$

Using de Broglie eqn.

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

$$\frac{1}{\lambda} = \frac{mv}{h} = \frac{m}{h}\left[\frac{2(E-V)}{m}\right]^{1/2}$$

$$\frac{1}{G} = \frac{d(1/\lambda)}{d\nu} = \frac{d}{d\nu}\left[\frac{m}{h}\left(\frac{2(E-V)}{m}\right)^{1/2}\right]^{1/2}$$

$E = h\nu$

$$= \frac{d}{d\nu}\left(\frac{m}{h}\left[2\left(\frac{h\nu - V}{m}\right)\right]^{1/2}\right]$$

$$= \frac{1}{h}\frac{d}{d\nu}\left[2m(h\nu - V)\right]^{1/2}$$

$$= \frac{1}{\cancel{h}}\cdot\frac{1}{\cancel{2}}\left(2m(h\nu - V)\right)^{-1/2}\cdot \cancel{2}m\cancel{h}$$

$$= \cancel{2m}\,\frac{m}{\left[2m(h\nu - V)\right]^{1/2}}$$

$$\frac{1}{G} = \left[\frac{m}{2(h\nu - V)}\right]^{1/2} = \frac{1}{v}$$

Group vel = particle velocity

$$\Rightarrow \underline{G = v}$$

$v_w = \nu\lambda \qquad E = h\nu \qquad \nu = \frac{E}{h} \qquad \lambda = \frac{h}{mv}$

For a free particle $E = \frac{1}{2}mv^2$ $\qquad$ Phase vel $= \frac{1}{2}$(Gp vel)

$$v_w = \frac{E}{\cancel{h}}\,\frac{\cancel{h}}{mv} = \frac{\frac{1}{2}\cancel{m}v^{\cancel{2}}}{\cancel{mv}}$$

$\boxed{v_w = \frac{1}{2}v}$ Relationship between phase vel. & gp. vel for a non relativistic free particle.

Heisenberg's Uncertainity Principle:

Heisenberg's showed that the product of uncertainity in x- coordinate of the quantum particle Δx and the uncertainity in the x component of the momentum Δp_x would always be of the order of Planck's constant h.

$$\therefore \quad \Delta x \, \Delta p_x \simeq h$$

$$\Delta x \, . \, \Delta p_x \geq \frac{\hbar}{2} \text{ or } \frac{h}{4\pi}$$

This is known as Heisenbergs uncertainity principle for position and momentum. It is stated as

It is not possible to know simultaneously and with ~~accurately~~ exactness both the position and momentum of a microparticle.

According to it the more precisely we know the position of the particle the less precise is our information about its momentum.

Energy ~~momentum~~ Time uncertainity.

$$\Delta E \, . \, \Delta t \geq \frac{\hbar}{2}.$$

The physical significance of the energy time uncertainity is that if ΔE is max uncertainity in the determination of the energy of the particle Then minimum time interval for which the particle remains in that state is

$$\Delta t_{min} = \frac{\hbar/2}{\Delta E_{max}}$$

If the particle remains in a particular energy state for a max time Δt_{max} then minimum uncertainity in the particle energy $\Delta E_{min} = \dfrac{\hbar/2}{\Delta t_{max}}$

Consider a particle ~~moving~~ of mass m and moving with vel v. Then its K.E is

$$E = \frac{1}{2} m v^2$$

Uncertainity in energy $\Delta E = \Delta(\frac{1}{2} m v^2) = m v \Delta v = v \Delta p$.

As vel. $v = \frac{\Delta x}{\Delta t}$.

$$\Delta E = \frac{\Delta x}{\Delta t} \cdot \Delta p$$

$$\Delta E \cdot \Delta t = \Delta x \cdot \Delta p$$

$$\Delta x \cdot \Delta p \geq \frac{\hbar}{2}.$$

$$\Delta E \cdot \Delta t \geq \frac{\hbar}{2}.$$

Proof of Uncertainity Principle using de Broglie Concept.

Group velocity of de Broglie Waves associated with a material particle $G = \frac{d\omega}{dk} = \frac{d\omega}{2\pi\, d(\frac{1}{\lambda})} = -\frac{\lambda^2}{2\pi}\frac{d\omega}{d\lambda}$.

$$\lambda = \frac{h}{p} \qquad d\lambda = -\frac{h\,dp}{p^2}$$

$$G = -\frac{h^2}{2\pi p^2}\cdot\frac{d\omega}{\left(-\frac{h\,dp}{p^2}\right)} = \frac{h}{2\pi}\frac{d\omega}{dp}.$$

As the group vel represents the particle moving along x-axis $v = \frac{\Delta x}{\Delta t}$.

$$v = G \qquad \frac{\Delta x}{\Delta t} = \frac{h}{2\pi}\frac{d\omega}{dp}$$

$$\Delta x\, \Delta p = \hbar\, \Delta\omega \cdot \Delta t.$$

If the angular frequency of the wave is to be measured, the least time of measurement will be time required for one complete wavelength to pass a reference point. $\Delta t \geq \frac{1}{\Delta\omega}$ $\qquad \Delta t\,\Delta\omega \geq 1$

$$\boxed{\Delta x \cdot \Delta p \geq \hbar}$$

Heisenberg's gamma ray microscope:

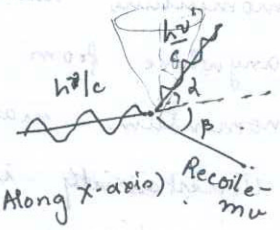
If the position of e^- is to be determined using a high resolution microscope of high power, the limit of resolution depends upon the wavelength of light is given by

$$\Delta x = \frac{\lambda}{2\sin\theta} \quad \text{——— (1)}$$

$\Delta x \rightarrow$ distance between two pts. that can be just resolved by microscope. $\rightarrow$ uncertainity in determination of position.

To minimize uncertainity γ- rays should be used — Compton Effect

The scattered photon can travel anywhere in the microscope it transfers the momentum to e^-. The uncertainity in momentum is calculated as:



According to the principle of momentum

$$\frac{h\nu}{c} = \frac{h\nu'}{c}\cos\alpha + mv\cos\beta \quad (\text{Along x-axis})$$

$$p_x : mv\cos\theta = \frac{h\nu}{c} - \frac{h\nu'}{c}\cos\alpha$$

Limits of α with in microscope are $(90-\theta)$ to $(90+\theta)$

$$\frac{h}{c}\left[\nu - \nu'\cos(90-\theta)\right] \le p_x \le \frac{h}{c}\left[\nu - \nu'\cos(90+\theta)\right]$$

$$\frac{h}{c}(\nu - \nu'\sin\theta) \le p_x \le \frac{h}{c}(\nu + \nu'\sin\theta)$$

uncertainity in momentum is given by

$$\Delta p_x = \frac{h}{c}\left[\nu + \nu'\sin\theta\right] - \frac{h}{c}\left[\nu - \nu'\sin\theta\right]$$

$$= \frac{h}{c}\left[\cancel{\nu} + \nu'\sin\theta - \cancel{\nu} + \nu'\sin\theta\right]$$

$$\Delta p_x = \frac{2h\nu'\sin\theta}{c} = \frac{2h}{\lambda}\sin\theta \quad \text{——— (2)}$$

Multiplying eq (1) & (2)

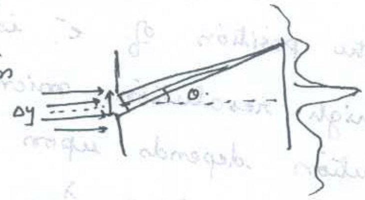
$$\Delta x \cdot \Delta p_x = \frac{\cancel{\lambda}}{\cancel{2}\cancel{\sin\theta}} \cdot \frac{\cancel{2}h}{\cancel{\lambda}}\cancel{\sin\theta}$$

$$\Delta x \cdot \Delta p_x = h.$$

$$\Delta x \cdot \Delta p_x \geq \frac{h}{2\pi}$$

Diffraction of a beam of e^- by a slit.

The uncertainity in determination the position of e^- along Y-axis is



ΔY - slit width

$$\Delta y = \frac{\lambda}{\sin\theta} \quad \text{— (1)}$$

Initially the e^- were moving along x-axis - component of momentum along Y-axis was 0. After being deviated they acquire the momentum along Y-dirn.

If p is the momentum of the e^-, then component of momentum along Y-axis is $p\sin\theta$. As the e^- can be anywhere from $-\theta$ to $+\theta$. The Y component of momentum may be anywhere $p\sin\theta$ to $-p\sin\theta$

uncertainity in determining Y. component of momentum

$$\Delta p_y = p\sin\theta - (-p\sin\theta)$$

$$= 2p\sin\theta = 2\frac{h}{\lambda}\sin\theta \quad \text{— (2)}$$

Multiplying (1) & (2)

$$\Delta y \cdot \Delta p_y = \frac{\lambda}{\cancel{\sin\theta}} \cdot \frac{2h}{\lambda}\cancel{\sin\theta}$$

$$= 2h.$$

$$\Delta y \cdot \Delta p_y \geq \frac{\hbar}{2}$$

Applications of Uncertainity Principle:

1. Non existance of e^- in the nucleus:

Radius of the nucleus of an atom is of the order of 10^{-14}m

So if the e^- is present in the nucleus, the uncertainity in its position must not be greater than 2×10^{-14} m.

According to uncertainity principle.

$$\underbrace{\Delta q}_{\text{uncertainity in position}} \cdot \underbrace{\Delta p}_{\text{uncertainity in momentum}} \simeq \hbar$$

$$\Delta p = \frac{\hbar}{\Delta q} \qquad \Delta q = 2\times10^{-14} m.$$

$$\Delta p = \frac{6.6\times10^{-34}}{2\times3.14\times2\times10^{-14}} = 5.275\times10^{-21}\ kg\text{-}m/s.$$

K.E of the e^-

$$T = \frac{\Delta p^2}{2m} = \frac{5.275\times10^{-21}}{2\times9.1\times10^{-31}\times1.6\times10^{-19}} = 9.7\times10^{5}\ eV$$

$$= 97\ MeV$$

Experimental observations show that no e^- in the atom possesses energy greater than 4 MeV.

$\Rightarrow$ e^- cannot exist inside the nucleus.

2. Radius of Bohr's first orbit:

Let Δx and Δy be uncertainities in determining the position and momentum of the e^- in the first orbit.

$$\Delta x.\ \Delta p \simeq \hbar$$

$$\Delta p \simeq \frac{\hbar}{\Delta x} \quad — (1)$$

Uncertaining in K.E

$$\Delta T = \frac{(\Delta p)^2}{2m} \quad — (2)$$

From (1) & (2)

$$\Delta T = \frac{\hbar^2}{(\Delta x)^2 . 2m}$$

The uncertainity in potential energy of the same e^-

$$\Delta V = \frac{-1}{4\pi\varepsilon_0} . \frac{Ze^2}{\Delta x}.$$

Uncertainity in total energy,

$$\Delta E = \Delta T + \Delta V = \frac{\hbar^2}{2m(\Delta x)^2} - \frac{1}{4\pi\varepsilon_0} . \frac{Ze^2}{\Delta x}.$$

The condn. for the unertainity to be min.

$$\frac{d(\Delta E)}{d(\Delta x)} = 0.$$

$$-\frac{\hbar^2}{2m(\Delta x)^3} + \frac{1}{4\pi\varepsilon_0} . \frac{Ze^2}{(\Delta x)^2} = 0$$

$$\Delta x = \frac{\hbar^2(4\pi\varepsilon_0)}{mZe^2}$$

Radius of Bohr's first orbit

$$r = \Delta x = \frac{\hbar^2 (4\pi \varepsilon_0)}{m Z e^2} = \frac{\varepsilon_0 h^2}{\pi m Z e^2}$$

Energy of a Particle in a Box :

Consider a particle having mass m in infinite potential well of width L. The max. uncertainity in position of the particle $(\Delta x)_{max} = L$

$$\Delta x \cdot \Delta p \simeq \hbar$$

$$\Delta p = \frac{\hbar}{\Delta x} = \frac{\hbar}{L}$$

$$K.E = \frac{p^2}{2m} = \frac{\hbar^2}{2mL^2}$$

Schroedinger's time independent wave Equation:

The non dissipation of the wave packet of the material particle is explained by assuming the necessity of guiding wave which obeys Schroedinger's wave equation.

Consider a system of stationary waves to be associated with the particle. Let $\psi(r,t)$ be the wave displacement for the deBroglie waves at pt $r = x\hat{i} + y\hat{j} + z\hat{k}$ at time t.

Then differential equation for wave motion according to Maxwell's wave eqn. is

$$\nabla^2\psi = \frac{1}{u^2}\frac{\partial^2\psi}{\partial t^2} \qquad u \to \text{wave velocity.}$$

$$\frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial y^2} + \frac{\partial^2\psi}{\partial z^2} = \frac{1}{u^2}\frac{\partial^2\psi}{\partial t^2} \quad \text{--- (1)}$$

The solution to eq (1) is

$$\psi(r,t) = \psi_0(r)\, e^{-i\omega t} \quad \text{--- (2)}$$

$\psi_0 \to$ amplitude at a pt. r.

Differentiating eq (2) twice w.r.t 't'

$$\frac{\partial\psi}{\partial t} = -i\omega\psi_0 e^{-i\omega t}$$

$$\frac{\partial^2\psi}{\partial t^2} = -\omega^2\psi_0 e^{-i\omega t}$$

$$\frac{\partial^2\psi}{\partial t^2} = -\omega^2\psi(r,t) \quad \text{--- (3)}$$

Substituting eq (3) in (2)

$$\frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial y^2} + \frac{\partial^2\psi}{\partial z^2} = -\frac{\omega^2}{u^2}\psi(r,t)$$

$$\omega = 2\pi\nu = \frac{2\pi u}{\lambda}$$

$$\frac{\omega}{u} = \frac{2\pi}{\lambda}$$

$$\nabla^2\psi = -\frac{4\pi^2}{\lambda^2}\psi(r,t)$$

$$\nabla^2\psi + \frac{4\pi^2}{\lambda^2}\psi(r,t) = 0 \quad \text{--- (4)}$$

Introducing the concept of wave mechanics. According to de Broglie $\lambda = \frac{h}{mv}$. ——— (5)

Substituting (5) in (4)

$$\nabla^2\psi + \frac{4\pi^2 m^2 v^2}{h^2}\psi = 0 \quad \text{———} \quad (6)$$

$$E = \frac{1}{2}mv^2 + V$$

$$\frac{1}{2}mv^2 = E - V$$

$$mv^2 = 2(E-V)$$

$$m^2v^2 = 2m(E-V)$$

Substituting this in eq (6)

$$\nabla^2\psi + \frac{4\pi^2\, 2m(E-V)}{h^2}\psi = 0 .$$

$$\nabla^2\psi + \frac{8\pi^2 m}{h^2}(E-V)\psi = 0 \quad \text{———} \quad (7)$$

$$\hbar = \frac{h}{2\pi} \qquad \boxed{\nabla^2\psi + \frac{2m}{\hbar^2}(E-V)\psi = 0}$$

Schroedinger's time Independent Wave Equation

for Free particle

$$V = 0$$

$$\nabla^2\psi + \frac{2mE}{\hbar^2}\psi = 0 .$$

Time Dependent Schroedinger Wave Equation:

Differentiating eq (2) once w.r.t t.

$$\frac{\partial\psi}{\partial t} = -i\omega\,\psi_0\, e^{-i\omega t}$$

$$= -i(2\pi\nu)\,\psi_0\, e^{-i\omega t} . \qquad \because E = h\nu,\ \nu = \frac{E}{h}$$

$$= -\frac{i\,2\pi E}{h}\psi \times \frac{i}{i}$$

$$i\hbar\frac{\partial\psi}{\partial t} = E\psi \quad \text{———} \quad (8)$$

The wave function ψ is in general a complex fn.
But the probab. must be real. Therefore to make probab real quantity ψ is to be multiplied by its complex conjugate $\int_{-\infty}^{\infty} \psi \psi^* dV = 1$.

$\Rightarrow$ ψ has no significance but $|\psi|^2$ gives the probab. of finding the atomic particle in a particular region.

Normalization condition:

$$\int_{-\infty}^{\infty} |\psi_N(x,y,z)|^2 \, dx\, dy\, dz = |c|^2 \int_{-\infty}^{\infty} |\psi(x,y,z)|^2 \, dx\, dy\, dz = 1$$

$\psi_N(x,y,z) \longrightarrow$ Normalized wave function.

$C \rightarrow$ Normalization constant.

This condn. is known as normalization condn.

$$|c|^2 = \frac{1}{\int_{-\infty}^{\infty} |\psi(x,y,z)|^2 \, dx\, dy\, dz}$$

$|\psi_N(x,y,z)|^2 \rightarrow$ probability density.

Conditions to be satisfied by wave function (ψ)

1. ψ must be finite: ψ, must remain finite for all values of x, y, z.
2. ψ must be single valued: ψ cannot take two values at any given pt.
3. ψ must be continuous: ψ cannot be discontinuous.

When the wave fns. satisfy these condns. they are said to be well behaved wave fns.

Substituting eq (8) in (7)

$$\nabla^2\psi + \frac{2m}{\hbar^2}\left[i\hbar\frac{\partial\psi}{\partial t} - V\psi\right] = 0.$$

$$\nabla^2\psi = -\frac{2m}{\hbar^2}\left[i\hbar\frac{\partial\psi}{\partial t} - V\psi\right]$$

$$-\frac{\hbar}{2m}\nabla^2\psi = i\hbar\frac{\partial\psi}{\partial t} - V\psi$$

$$-\frac{\hbar}{2m}\nabla^2\psi + V\psi = i\hbar\frac{\partial\psi}{\partial t}$$

$$\left[-\frac{\hbar}{2m}\nabla^2 + V\right]\psi = i\hbar\frac{\partial\psi}{\partial t}.$$

$$-\frac{\hbar}{2m}\nabla^2 + V = H \rightarrow \text{Hamiltonian}$$

$$H\psi = E\psi.$$

Schroedinger wave equation (time dependent) for a non relativistic material particle.

Physical Significance of wave function (ψ):

The square of the magnitude of the wave function $|\psi|^2$ evaluated in a particular region represents the probability of finding the particle in that region.

Probability P, of finding the particle in an infinitesimal vol $dV = dx\,dy\,dz$ is proportional to $|\psi(x,y,z)|^2$ $|\psi(x,y,z)|^2 dx\,dy\,dz$ at time t.

$$P \propto |\psi(x,y,z)|^2 dV.$$

$|\psi|^2 \rightarrow$ probability density $\quad \psi \rightarrow$ probability amplitude.

Since the particle is somewhere in space, the probab $P = 1$ and the integral over the entire space is unity $\int_{-\infty}^{\infty}|\psi|^2 dV = 1$.

Particle in a 1-D ~~square well~~ Infinitely deep potential Well.

~~Let~~ Suppose a particle is restricted to move in 1-D between two points such that $0 \le x \le a$. Assuming absolutely impenetrable walls at $x = 0$ and $x = a$ such that the particle is reflected at $x = 0$ and $x = a$.

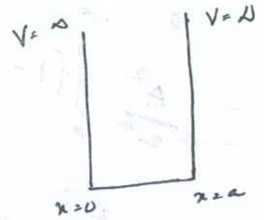
The potential function

$$V(x) = \infty \text{ for } x < 0 \text{ and } x > a$$
$$= 0 \text{ . for } 0 \le x \le a \text{ .}$$

Probab. of finding the particle at $x = 0$ and $x = a$ is zero.

$$\psi(0) = \psi(a) = 0$$
$$\psi(x) = \text{finite} \quad 0 < x < a.$$

The equation of motion of the particle in the region $0 < x < a$



$$\frac{\partial^2\psi}{\partial x^2} + \frac{2m}{\hbar^2} E\psi = 0 \quad \text{—— (1)}$$

$$\frac{\partial^2\psi}{\partial x^2} + k^2\psi = 0$$

Gen. Sol. for this eq

$$\psi(x) = A \sin kx + B \cos kx. \quad \text{—— (2)}$$

$$k = \sqrt{\frac{2mE}{\hbar}} \quad \text{—— (3)}$$

Using boundary condition

$$\psi(x) = 0 \text{ for } x = 0.$$

$$B = 0 \quad \text{—— (4)}$$

Substituting B in eq (2)

$$\psi(x) = A \sin kx.$$

$\psi(x) = 0$ for $x = a$ $\qquad A = 0 \rightarrow$ not possible

or

$$\sin ka = 0$$

$$A \sin ka = 0 \qquad n = 1, 2, 3 \ldots$$

$$ka = (n+1)\pi \qquad k = \frac{(n+1)\pi}{a} \quad \text{—— (5)}$$

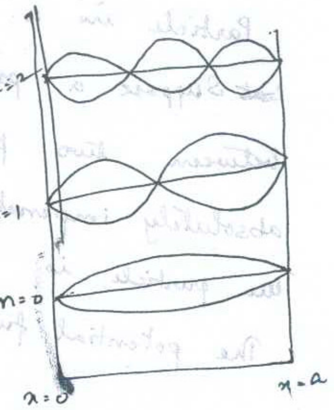
∴ Soln. to eq (1)

$$\psi(x) = \sin\left(\frac{(n+1)\pi x}{a}\right)$$

Comparing eq (3) and (5)

$$\frac{\sqrt{2mE}}{\hbar} = \frac{(n+1)\pi}{a}$$

$$\boxed{E_n = \frac{\hbar^2 \pi^2}{2ma^2}(n+1)^2}$$



Normalization of wave function

$$\int_0^a |\psi(x)|^2 \, dx = 1$$

$$\int_0^a A^2 \sin^2\left(\frac{(n+1)\pi}{a} x\right) dx = 1$$

$$\frac{A^2}{2} \int_0^a \left[1 - \cos^2 \frac{2(n+1)\pi x}{n}\right] dx = 1$$

$$\frac{A^2}{2} \cdot a = 1$$

$$a = \sqrt{\frac{2}{a}}$$

$\therefore$ Normalized wave function

$$\psi_n(x) = \sqrt{\frac{2}{a}} \sin\left(\frac{(n+1)\pi}{a}\right) x$$

$$v_p = \nu \lambda$$

$$\nu = \frac{E}{h} \qquad \lambda = \frac{h}{mv}$$

free Particle

Total Energy $E = \frac{1}{2} m v^2$

$$v_p = \frac{\frac{1}{2} \cancel{m} v^2}{\cancel{h}} \cdot \frac{\cancel{h}}{\cancel{m} \cancel{v}}$$

$$\nu = \frac{\frac{1}{2} m v^2}{h}$$

$$\boxed{v_p = \frac{1}{2} v}$$

The normalized state of a free particle is represented by

$$\psi(x) = N e^{-x^2/2a^2 + ikx}.$$

Find N.

In what region of space the particle is most likely to be found.

$$\int_{-\infty}^{\infty} \psi^* \psi \, dx = \phi$$

$$\int_{-\infty}^{\infty} N^* e^{-x^2/2a^2 - ikx} \cdot N e^{-x^2/2a^2 + ikx} \, dx = 1$$

$$|N|^2 \int_{-\infty}^{\infty} e^{-x^2/a^2} dx = 0.$$

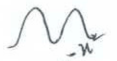
$$|N|^2 a\sqrt{\pi} = 1$$

$$|N| = \frac{1}{\sqrt{a\sqrt{\pi}}} = \frac{1}{a^{1/2}\pi^{1/4}}.$$

$\psi = 1, 2$

Probability density

$$\psi^*\psi = |\psi|^2 = |N|^2 e^{-x^2/a^2} = \frac{1}{a\sqrt{\pi}} e^{-x^2/a^2}$$



e^{-x^2}

$x = 1,$

$x = -1$

Postulates of Wave Mechanics

1. There is a wave fn. associated with every physical state of the sys which contains the entire discription.
2. For every physical observable there is a corresponding linear operator
3. The only possible value which an observable can yeild are eigen values.
4. The ave. or expectation value of a dynamical quantity is the mathematical expectation for the result of a single measurement. or ave. of result of large no. of measurements.

Normalize the wave function

$$\psi(x) = e^{-|x|} \sin \alpha x .$$

Let Normalized wave fn. be

$N \to$ Normalization const.

$$\phi(x) = N \psi(x)$$

$$\int_{-\infty}^{\infty} \phi^* \phi \, dx = 1$$

$$\int_{-\infty}^{\infty} N^* \psi^*(x) \cdot N \psi(x) \, dx = 1$$

$$|N|^2 \int_{-\infty}^{\infty} e^{-|x|} \sin \alpha x \cdot e^{-|x|} \sin \alpha x) \, dx = 1$$

$$|N|^2 \int_{-\infty}^{\infty} e^{-2|x|} \sin^2 \alpha x \, dx = 1$$

$$\frac{|N|^2}{2} \int_{-\infty}^{\infty} e^{-2|x|} 2 \sin^2 \alpha x \, dx = 1$$

$$\frac{|N|^2}{2} \int_{-\infty}^{\infty} e^{-2|x|} (1 - \cos 2\alpha x) \, dx = 1$$

$$\frac{|N|^2}{2} \left[\int_{-\infty}^{\infty} e^{-2|x|} dx - \int_{-\infty}^{\infty} e^{-2|x|} \cos 2\alpha x \, dx \right] = 1$$

$$\frac{|N|^2}{2} \left[0 - \left(-\frac{\alpha^2}{1-\alpha^2} \right) \right] = 1$$

$$\frac{|N|^2}{2} \cdot \frac{\alpha^2}{1-\alpha^2} = 1$$

$$|N| = \frac{2(1-\alpha^2)}{\alpha^2}$$

60

1, 2, 4, 5, 6, 7, 9,
10, 11, 12, 13, 14, 15, 16
17, 18, 20, 21, 22, 23,
25, 26, 27, 28, 29
30, 32, 33, 34, 35, 36
37, 38, 39, 40, 41, 42
43, 44, 45, 46, 47, 48
49, 50, 51, 53, 54,
55, 56, 57, 58, 63, 64, 65,
66, 67, 68, 69, 70, 71, 72
73, 74, 75, 76, 77, 79,
80, 81, 82, 83, 84, 85
86, 87, 88, 89, 90, 91

CRYSTAL STRUCTURE

Solids may be divided into two broad categories

1. Amorphous Solids: Those solids which lack regular arrangement of atoms/molecules. Eg: Glass. plastic

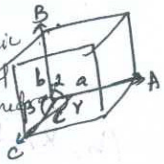
2. Crystalline Solids: Those solids which contain regular repeated pattern of atoms/molecules. NaCl, Diamond.

Lattice – Parallel net-like arrangement of points provided the environment about any point is identical with the environment about any other point.

2-D - plane lattice, 3-D - Space Lattice

Seven crystal systems → on the basis of the shape of the unit cell. depending upon their axial ratio (a:b:c) and angles bet. them (α, β, γ)

(Draw) Cubic, Triclinic, Monoclinic, orthorhombic, Tetragonal, Hexagonal, Rhombohedral



→ 14 types of crystal lattices.

Unit Cell: Smallest portion of the space lattice which can generate the complete crystal by repeating itself in various directions is called unit cell.

a, b, c — Lattice const.

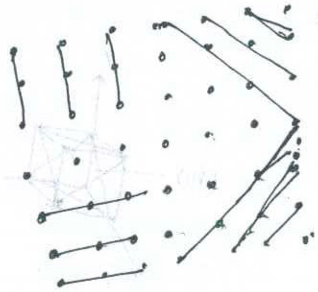
Primitive unit cell: — minimum vol. unit cell.

Cubic.

Simple Cubic (SC)

Body Centered (BCC)

Face Centered (FCC)



Lattice Planes: A crystal is made up of large no. of parallel equidistant planes known as lattice planes.

Miller indices. The integers that determine the orientation of crystal planes in relation to the ~~three~~ three crystallographic axes are called Miller incides.

Steps to determine Miller Indices.

(i) Consider the intercepts of a lattice plane.

pa qb rc.

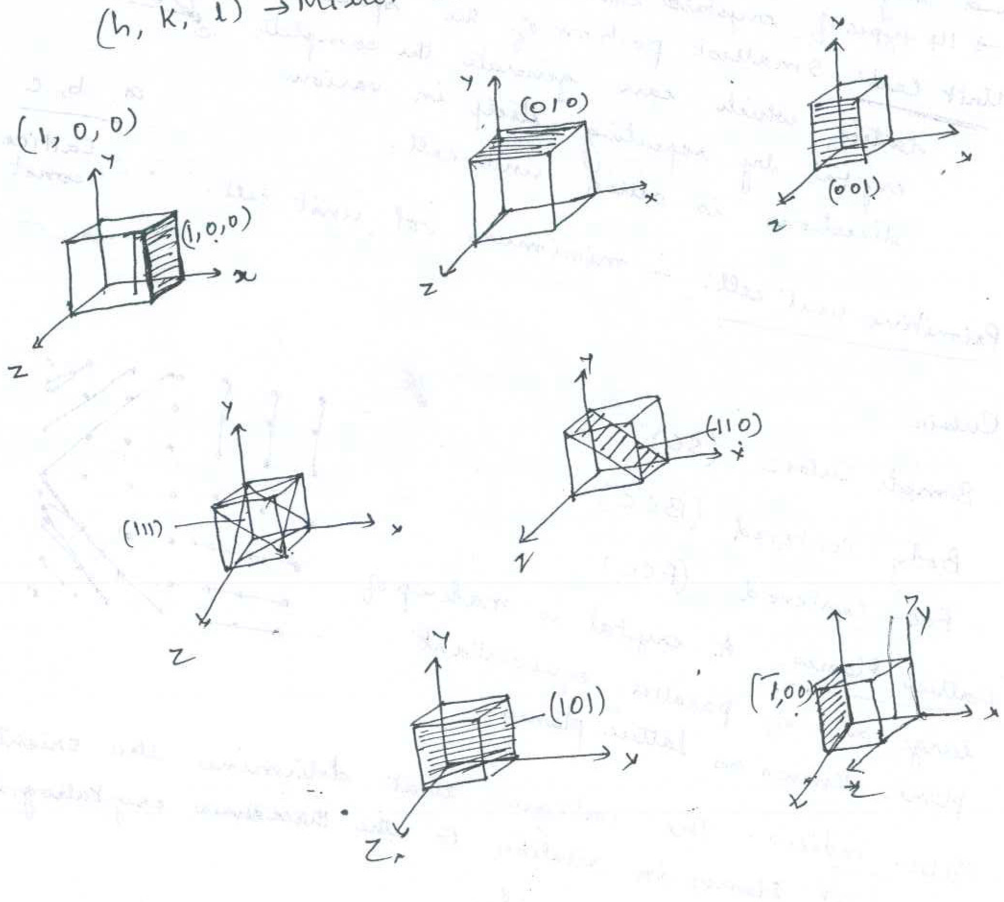
(ii) Take the reciprocal of p, q, r

$\frac{1}{p}$, $\frac{1}{q}$, $\frac{1}{r}$.

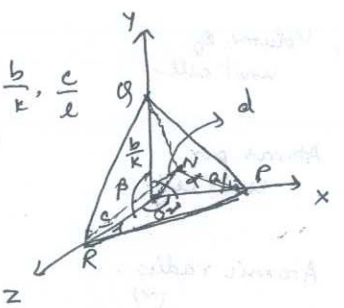
(iii) Find the LCM and multiply with it such that the fraction is cleared

$h, k, l = \frac{1}{p}, \frac{1}{q}, \frac{1}{r}$

(h, k, l) → Miller Indices



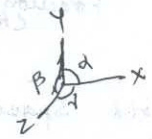
Interplanar Spacing :



Let the plane PQR make intercept $\frac{a}{h}, \frac{b}{k}, \frac{c}{l}$
Let the plane PQR (h, k l) be parallel to the plane passing through the origin. Draw a $\perp^{lr}$ from O to N

ON = d. $\rightarrow$ distance bet adjacent planes or interplanar spacing bet. parallel planes.

α, β γ be the angles made by ON with x, y, z axis.



$\Delta ONP \qquad \cos\alpha = \frac{d}{a/h} = \frac{dh}{a}$

$\Delta ONQ \qquad \cos\beta = \frac{d}{b/k} = \frac{dk}{b}$

$\Delta ONR \qquad \cos\gamma = \frac{d}{c/l} = \frac{dl}{c}.$

Law of ~~addition~~ addition of direction cosines.

$$\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1$$

$$d^2\left[\frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}\right] = 1$$

$$d^2 = \frac{1}{\left[\frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}\right]}$$

$$\boxed{d = \frac{1}{\sqrt{\left(\frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}\right)}}}$$

For cubic $a = b = c$

$$\boxed{d = \frac{a}{\sqrt{h^2 + k^2 + l^2}}}$$

For ~~t~~.

	SC	BCC	FCC.
Volume of unit cell	a^3	a^3	a^3.
Atoms per unit cell.	$\frac{1}{8} \times 8 = 1$	$\frac{1}{8} \times 8 + 1 = 2$.	$\frac{1}{8} \times 8 + \frac{1}{2} \times 6 = 1 + 3 = 4$.
Atomic radius. (r)	$\frac{a}{2}$	$\frac{a\sqrt{3}}{4}$ Bodydiagonal.	$\frac{a}{2\sqrt{2}}$ face diagonal.
Coordination no.	6	8	12
Atomic Packing Fraction (APF)	$\pi/6$	$\frac{\pi\sqrt{3}}{8}$	$\frac{\pi}{3\sqrt{2}}$.
Void Space.	48%.	32%.	26%.
Density (ρ)	$\frac{M}{N_A a^3}$	$\frac{2M}{N_A a^3}$.	$\frac{4M}{N_A a^3}$

Atomic Packing Fraction $\frac{Z v}{V}$.

$Z \rightarrow$ No. of atoms / unit ~~coordination no~~ cell.

$v \rightarrow$ vol. of atom.

$V \rightarrow$ Vol. of unit cell.

$r = \frac{a}{2\sqrt{2}}$

$a = r \cdot 2\sqrt{2}$

$$\frac{4 \times \frac{4}{3}\pi r^3}{a^3} = \frac{4 \times \frac{4}{3}\pi r^3}{(2\sqrt{2}r)^3} = \frac{4 \times 4 \pi r^3}{\cancel{8\sqrt{2}} r^3} \; \frac{4\pi}{\cancel{2}}$$

Void Space.

Percentage Void space $= (1 - APF) \times 100$.

$$\frac{4 \times \frac{4}{3}\pi r^3}{(2\sqrt{2}r)^3} = \frac{\frac{4 \times 4}{3}\cancel{r^3}\pi}{\cancel{16}\sqrt{2}\cancel{r^3}}$$

$$= \frac{\pi}{3\sqrt{2}}$$

Density $\rho = \frac{ZM}{N_A V} = \frac{4M}{N_A a^3}$ (FCC)

$$\frac{Mass}{Vol.} = \frac{ZW}{V} = \frac{ZM}{N_A V}$$

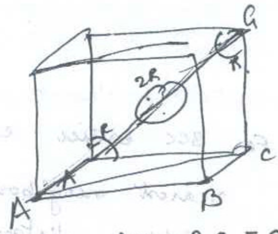
BCC

$$(AG)^2 = (AC)^2 + (GC)^2$$

$$(4R)^2 = (AB)^2 + (BC)^2 + (CG)^2$$

$$(4R)^2 = 3a^2$$

$$R = \frac{\sqrt{3}\,a}{4}$$



AB = BC = CG = a.

FCC

$$(AF)^2 = (AB)^2 + (BF)^2$$

$$(4R)^2 = 2a^2$$

$$R = \frac{\sqrt{2}\,a}{4}$$

$$R = \frac{a}{2\sqrt{2}}$$

FCC

Free Electron Theory:

Classical FET.

Drude developed free e^- theory of metals. According to this, the metals consist of the ion cores and valance e^-. The ion cores are immobile and consist of the nucleus and bound e^-. The valence e^- get detached from the parent atoms during the formation of metal and move randomly among these cores. Hence they are known as free e^-.

The pot. field of the ion core is assumed to be const. throughout the metal and mutual repulsion among the e^- is neglected. The behaviour of free e^- moving with in the metal is considered similar to that of atoms in perfect gas. Hence they are referred to as free e^- gas.

As the pot. energy of the stationary e^- inside the metal is less than the pot. energy of an identical e^- just outside it. ∴ the movement of the e^- is restricted to boundaries of the metal. This energy difference forms a barrier and stops the free e^- from leaving the surface of metal. Thus the free e^- gas is confined to pot. energy box. The free e^- are called conduction e^- → responsible for conduction of electricity.

Lorentz Drude assumed that at ordinary temperatures, free e^- move in metals randomly with an ave. speed of the order of $10^5 m/s$. During random motion these e^- collide with themselves and atoms or ions of lattice and have no practical contribution to electrical and thermal conductivities.

Hence in the absence of ext. electrical field the contribution of e^- to current in metals is zero. If an external electric field is applied to the metals, the e^- will be accelerated in the opposite dirln to the applied electric field and produces a current.

In thermal equillibrium e^- are assumed to follow Maxwell's Boltzman distribution.

Drawbacks of Classical Free electron theory:

The Free electron theory of metals could successfully explain many physical properties of metals like high electrical and thermal conductivity etc. However it failed to account for some other properties like.

(1) Monovalent metals are found to show higher electrical conductivity, than divalent and trivalent metals. If $\sigma \propto ne\mu$ then monovalent metals should have lesser electrical conductivity as compared to divalent and trivalent metals.

2. The classification of materials into conductors, semiconductors or Insulators could not be explained by this theory.

3. Metals are expected to exhibit $-ve$ Hall coeff. $\therefore$ current carriers are e^-. However some of the metals are like Zn have $+ve$ values for R_H. $\rightarrow$ FET could not explain the $+ve$ values of R_H.

4. According to classical FET, all valence e^- can absorb thermal energy. According to the Law of equipartition each free e^- possesses an ave. $K.E = \frac{3}{2}kT$

For a monovalent crystal each atom contributes one valence e^- to the e^- gas and there will be N free e^- per unit vol. of the crystal. Then the total energy of the $e^- = \frac{3}{2}NkT$.

When the metal is heated, free e^- absorb a part of free energy and electronic sp. heat is

$$(C_v)_{el} = \frac{dE}{dT} = \frac{3}{2}Nk = 12.5\ kJ/kmole/K.$$

This values is 100 times > experimentally measured value.

$\Rightarrow$ free e^- do not contribute to significantly to heat capacity of the metal. $\Rightarrow$ Law of equipartition & hence Maxwells-Boltzman stat. is not applicable for free e^-.

Quantum Free Electron Theory:

Assumptions:—

- The eigen values of conduction e^- are quantised and are realised in terms of set of energy states.
- The distribution of e^- in various allowed energy levels takes place according to Pauli's Exclusion Principle.
- The e^- move in const. pot. inside the metal and are confined with in boundaries.
- Mutual attraction bet. e^- and lattice ions and repulsion bet. e^- can be ignored.

Drift vel: $v_d = \frac{eE\tau}{m}$

Conductivity = $\sigma = ne\mu$.

Mobility $\mu = \frac{v_d}{E}$.

$\frac{d^2\psi}{dx^2} + \alpha^2\psi = 0 \quad 0 < x < a$

$\frac{d^2\psi}{dx^2} - \beta^2\psi = 0 \quad -b < x < 0$

$\alpha^2 = \frac{8\pi^2 m}{h^2}$ $\beta^2 = \frac{8\pi^2 m}{h^2}(V_0 - E)$

Wiedmann Franz Law:

Ratio of thermal to electrical conductivity of a metal is $\propto T$

$\psi(x) = u(x)\, e^{ikx}$
$u(x) = u(x+a)$

$\frac{K}{\sigma} = T$

$\frac{K}{\sigma T} = L$ $\quad L \rightarrow$ Lorentz no.

$L = \frac{3}{2}\left(\frac{k}{e}\right)^2 = 1.12 \times 10^{-8}\, W\,\Omega / deg^2$ (Classical F-E)

$= \frac{\pi^2}{3}\left(\frac{k}{e}\right)^2 = 2.45 \times 10^{-8}\, W\,\Omega / deg^2$ (Quantum theory) FE

Kronig Penny Model.

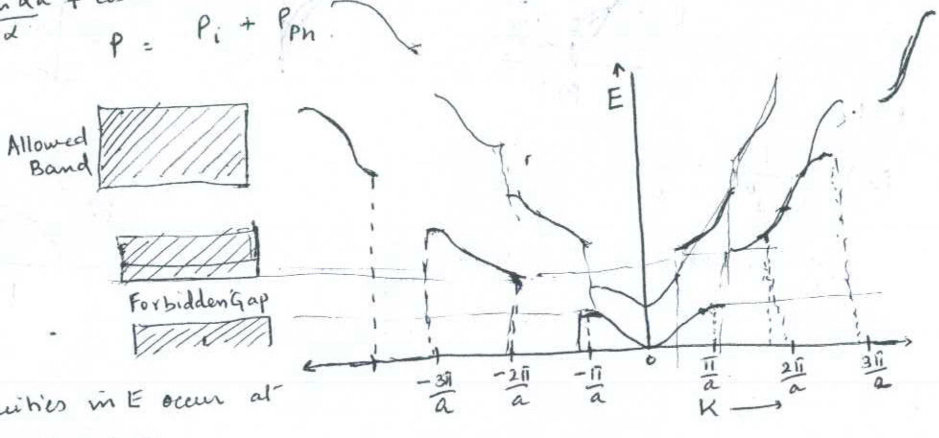
$\frac{d^2\psi}{dx^2} + \frac{2mE}{\hbar^2}\psi = 0 \quad 0 < x < a$

$\frac{d^2\psi}{dx^2} + \frac{2m(E-V_0)}{\hbar^2}\psi = 0 \quad -b < x < 0$

$\frac{maV_0 b}{\hbar^2} \cdot \frac{\sin \alpha a}{\alpha a} + \cos \alpha a = \cos ka$

$P = P_i + P_{ph}$

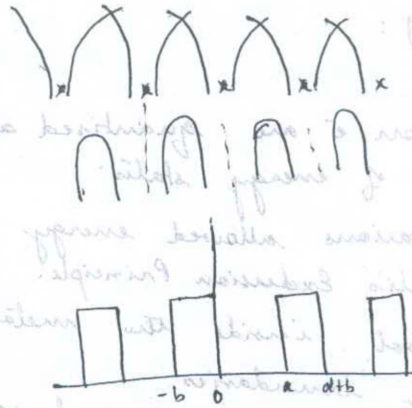
$\alpha = \frac{\sqrt{2mE}}{\hbar}$



Discontinuities in E occur at

$ka = \pm n\pi$

$K = \pm\frac{\pi}{a}, \pm\frac{2\pi}{a}, \pm\frac{3\pi}{a} \ldots$



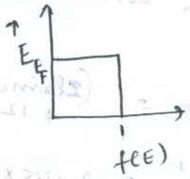
Variation of potential inside the metal crystal with the periodicity of the lattice.

<u>Fermi Dirac Distribution</u> fn → defines the probability of an $\bar{e}$ occupying a particular energy level.

$$f(E) = \frac{1}{1 + e^{(E-E_F)/kT}}$$

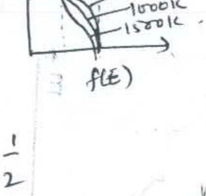
E_F → <u>Fermi level</u>.

At $T=0$



Effect on

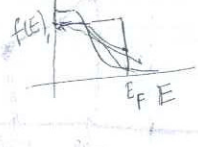
At $T>0$



$E = E_F$

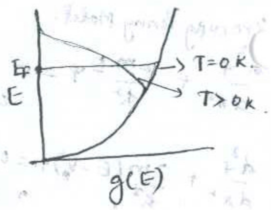
$$f(E) = \frac{1}{1+e^{0/kT}} = \frac{1}{2}$$

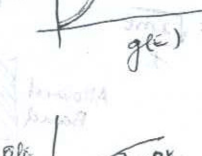
$= 50\%$ probab.

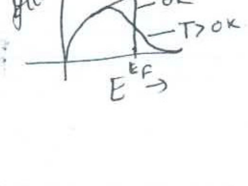


<u>Density of States</u>.

$$g(E)\,dE = \frac{4\pi}{h^3}(2m)^{3/2} E^{1/2} dE$$







Effective Mass

Generally the mass of the electron in solid is assumed to be same as that of a free e^-. However, experimentally measured values indicate that in some solids the e^- mass is larger while for some slightly smaller than that of free e^-. Actually the e^- in the crystal are not completely free but interact with crystal lattice. As a result, their behaviour towards external forces is different from that of free e^-. The deviation of e^- behaviour in the crystal lattice from the free e^- behaviour can be taken into account by considering the e^- to have altered value of mass called Effective Mass m^* which is different from mass m of the e^- in free space.

The effective mass m^* depends on the nature of the crystal lattice and varies with the direction of motion of the free e^-.

Suppose an e^- is moving along the x-axis in a crystal in the presence of an external electric field E. So it experiences a force eE. If the e^- gains vel v over a distance dx in time dx under the action of this force.

Work done = $dE = \overset{F\,dx}{e E v\,dt} = eE\,dx$ —— ① $\quad v = \frac{dx}{dt}$

As the vel. of the particle (e^-) is same as group vel.

$$v_g = \frac{d\omega}{dk} \qquad dE = eEv_g\,dt \quad \text{—— (2)}$$

$$E = h\nu = \frac{h}{2\pi}\omega \quad \text{—— (3)}$$

Differentiating

$$dE = \frac{h}{2\pi}\frac{d\omega}{dk}\cdot dk$$

$$dE = \frac{h}{2\pi}v_g\,dk \quad \text{—— (4)}$$

Comparing eq (2) and (4)

$$eE\cancel{v_g}\,dt = \frac{h}{2\pi}\cancel{v_g}\,dk$$

$$eE\,dt = \frac{h}{2\pi}dk$$

$$\frac{dk}{dt} = eE \cdot \frac{2\pi}{h} \quad \text{——— (5)}$$

Group vel. $v_g = \dfrac{d\omega}{dk} = \dfrac{2\pi}{h}\dfrac{dE}{dk}$ from Eq (4) (2)

Differentiating $\dfrac{dv_g}{dt} = \dfrac{2\pi}{h} \cdot \dfrac{d^2E}{dt\,dk} =$

$$= \frac{2\pi}{h} \cdot \frac{d^2E}{(dk)^2} \cdot \frac{dk}{dt},$$

$$\frac{dv_g}{dt} = \frac{2\pi}{\cancel{h}} \cdot \frac{d^2E}{(dk)^2} \cdot eE \cdot \frac{2\pi}{\cancel{h}}$$

$$\frac{dv_g}{dt} = \frac{4\pi^2 eE}{h^2} \cdot \frac{d^2E}{(dk)^2} = \left(\frac{4\pi^2}{h^2}\frac{d^2E}{(dk)^2}\right) eE. \quad \text{——— (6)}$$

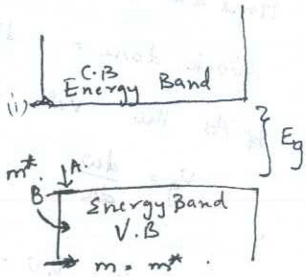
The eqns. connects the force eE' on ~~b~~ moving e^- with acceleration $\frac{dv_g}{dt}$ thro' a proportionality $\left(\frac{4\pi^2}{h^2}\frac{d^2E}{(dk)^2}\right)$

$$F = ma \qquad a = F/m.$$

$$\frac{1}{m^*} = \frac{4\pi^2}{h^2}\frac{d^2E}{(dk)^2}$$

$\frac{1}{m^*}$ is the reciprocal of effective mass of the e^- in the crystal lattice.

$$\boxed{m^* = \frac{\hbar^2}{d^2E/dk^2}}$$



(i) Near the bottom of the C. band, the e^- behaves as the free e^- ∴ In this region $m = m^*$.

(ii) At the pt. B. $\frac{1}{m^*} \simeq 0$, $m^* \simeq \infty$. External field inside the V.B cannot exert any action on the motion of the e^-.

(iii) Near the top of the allowed energy band (V.B), the Effective mass m^* of the e^- occupying levels near the top of the band is $\underline{-ve}$. $\frac{1}{m^*} < 0$

The concept of Effective mass provides a satisfactory description of the charge carriers in the crystal. In crystals like alkali metals which have partially filled energy ~~levels~~ bands the conduction takes place thro' e⁻. However in crystals for which the energy band is nearly full, the −ve charge and −ve mass vacancies may be considered as +e charge and +ve mass particles called holes. This explains the origin of the Hall Coefficient.

Density of States: It is given by the no. of available e⁻ states per unit vol per unit energy range at a certain energy level

$$g(E)\,dE = \frac{4\pi}{h^3}(2m)^{3/2} E^{1/2}\,dE.$$

$g(E) \rightarrow$ density of state function. It may be noted that $g(E)$ is independent of the dimensions of the potential box. ∴ $g(E)$ is defined as the no. of available states per unit energy interval centered around E.

Fermi Dirac Distribution function: To know how e⁻ are distributed among various energy levels in a conductor at a given temperature, Maxwell Boltzman Distribution function is applied to e⁻ as they obey Paulis Exclusion principle and they are indistinguishable. The statistical distribution fn. applicable to quantum particle is Fermi Dirac ~~Dif~~ Distribution fn.

The probab. that an e⁻ will occupy an energy state E at thermal equillibrium is

$$f(E) = \frac{1}{1 + \exp(E-E_F)/KT}$$

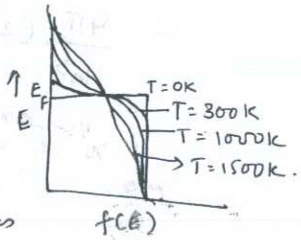
$f(E) \rightarrow$ Fermi Dirac distribution function.

At T = 0K.

$f(E) \rightarrow 0 \rightarrow 1.$

Above 0K.

T > 0K



Probab. of finding the e⁻ below E_F ↓ses and probab. of finding the e⁻ above E_F ↑ses.

Carrier Concentration: (Electron density)

Let dn be the no. of e^- whose energy lies in the energy interval E and $E+dE$ in conduction Band.

$$dn = g(E)\, f(E)\, dE.$$

$$n = \int_{E_c}^{\infty} g(E)\, f(E)\, dE)$$

$$g(E)\,dE = \frac{4\pi}{h^3}(2m_e^*)^{3/2}(E-E_c)^{1/2}\,dE.$$

$$f(E) = \frac{1}{1+\exp(E-E_F)/KT}.$$

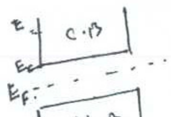
When the no. of particles is very small compared to the available energy states. The probab. of an energy state being occupied by more than one e^- is very small. $\therefore\ E-E_F >> 3KT$.

Under such sircumstances, the no. of available energy states in the conduction band is much larger than the no. of e^- in the band. $\therefore$ Fermi dirac fn. may be approximated to

$$f(E) = \exp(-(E-E_F)/KT)$$

$$e^{-[E-E_c+E_c-E_F]}$$

$$e^{-(E_c-E_F)}\cdot e^{-(E-E_c)}$$



$$n = \int_{E_c}^{\infty} \frac{4\pi}{h^3}(2m_e^*)^{3/2}(E-E_c)^{1/2}\,dE\cdot e^{-(E-E_F)/KT}\,dE.$$

$$= \frac{4\pi}{h^3}(2m_e^*)^{3/2}\, e^{(E_F-E_c)}\int_{-\infty}^{\infty}(E-E_c)^{1/2}\, e^{-(E-E_c)/KT}\,dE.$$

$$\int_{0}^{\infty} x^{1/2} e^{-ax}\,dx = \frac{\sqrt{\pi}}{2a\sqrt{a}}.$$

$$a = 1/KT$$

$$x = (E-E_c)^{1/2}$$

$$= \frac{4\pi}{h^3}(2m_e^*)^{3/2}\, e^{(E_F-E_c)}\cdot\frac{\sqrt{\pi}\,(KT)^{3/2}}{2}$$

Rearranging

$$n = 2\left[\frac{2\pi m_e^* kT}{h^2}\right]^{3/2} e^{-(E_c - E_F)/kT}$$

$$\boxed{n = N_c\, e^{-(E_c - E_F)/kT}}$$

$$N_c = \left[\frac{2\pi m_e^* kT}{h^2}\right]^{3/2}$$

$N_c \rightarrow$ Temp dependent materials constant.

Hole density.

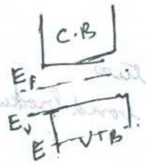
$1 - f(E)$.

$$p = \int_{-\infty}^{E_v} g(E)\,(1 - f(E))\, dE$$

$$p = 2\left[\frac{2\pi m_h^* kT}{h^2}\right]^{3/2} e^{-(E_F - E_v)/kT}$$

$$p = N_v\, e^{-(E_F - E_v)/kT}$$

$$N_v = 2\left[\frac{2\pi m_h^* kT}{h^2}\right]^{3/2}$$



$$[1 - f(E)] = 1 - \frac{1}{1+e^{(E-E_F)/kT}}$$

$$= \frac{1 + e^{(E-E_F)/kT} - 1}{1 + e^{(E-E_F)/kT}}$$

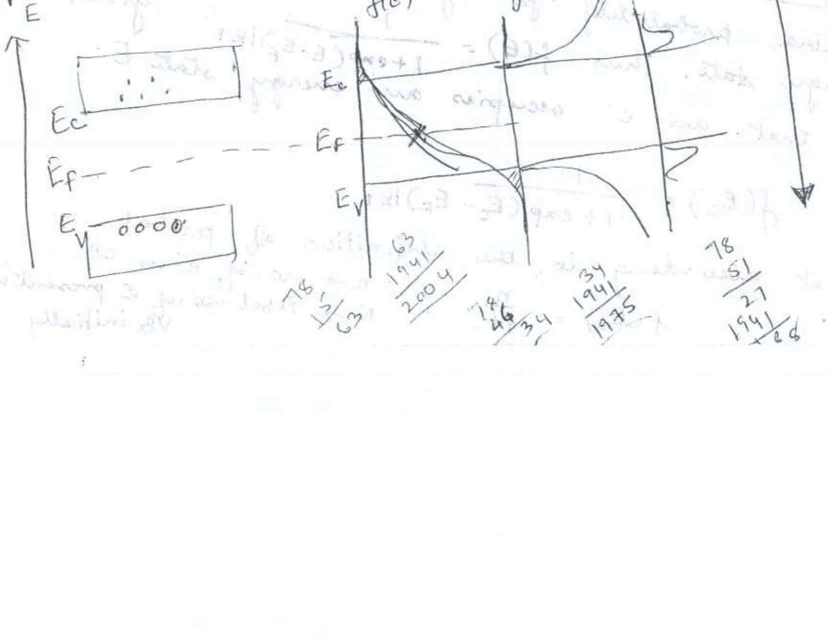
$$= \frac{e^{(E-E_F)/kT}}{1 + e^{(E-E_F)/kT}}$$

$$= \frac{1}{1 + e^{(E_F - E)/kT}}$$

$$\simeq e^{-(E_F - E)/kT}$$

$E_F - E$

$[(E_F - E_v) + (E_v - E)]$



Intrinsic carrier concenteration:

In an intrinsic semiconductor

$$n = p = n_i$$

$$n_i^2 = np$$

$$= \left(N_c\, e^{-(E_C - E_F)/KT}\right)\left(N_V\, e^{-(E_F - E_V)/KT}\right)$$

$$= N_c \cdot N_V\, e^{-(E_C - E_V)/KT}.$$

$$E_C - E_V = E_g.$$

$$n_i^2 = N_c \cdot N_V \cdot e^{-E_g/KT}.$$

$$n_i^2 = 4 \cdot \left[\frac{2\pi KT}{h^2}\right]^3 (m_e^* m_h^*)^{3/2}\, e^{-E_g/KT}$$

$$\boxed{n_i = 2\left[\frac{2\pi KT}{h^2}\right]^{3/2} (m_e^* m_h^*)^{3/4}\, e^{-E_g/2KT}}.$$

- The intrinsic carrier conc. is independent of Fermi level.
- The intrinsic conc. has exponential dependence on the band ~~gg~~ gap E_g.
- n_i is dependent on Temp.
- The factor 2 in the exponent indicates that two charge carriers are produced for one covalent bond broken

Fraction of Electrons in Conduction Band:

The fermi Dirac probability fn. gives the functional occupancy of the energy state. Thus $f(E) = \frac{1}{1+\exp(E-E_F)/KT}$ gives the probability that an e^- occupies an energy state E.

$$f(E_c) = \frac{1}{1+\exp(E_c - E_F)/KT}$$

But according to the definition of probab.

$$f(E_c) = \frac{n}{N}.$$

$n \rightarrow$ no. of e^- in CB
$N \rightarrow$ Total no. of e^- present in VB initially

$$\frac{n}{N} = \frac{1}{1+\exp(E_c-E_F)/kT}.$$

$$E_c - E_F = E_g/2$$

$$\frac{n}{N} = \frac{1}{1+\exp[E_g/2kT]}$$

$E_g >> 2kT$, the factor 1 may be neglected in comparison to the exponent.

$$\frac{n}{N} = \frac{1}{e^{E_g/2kT}} = e^{-E_g/2kT}.$$

Fraction of e^- in the conduction band.

Fermi Level in Intrinsic Semiconductor.

In an intrinsic semiconductor the electron and hole concentration are equal.

$$n = p.$$

$$N_c e^{-(E_c-E_F)/kT} = N_v e^{-(E_F-E_v)/kT}$$

$$-\frac{(E_c-E_F)}{kT} = \ln\frac{N_v}{N_c} - \frac{(E_F-E_v)}{kT}.$$

$$-(E_c-E_F) = kT\ln\left(\frac{N_v}{N_c}\right) - (E_F-E_v).$$

$$+2E_F = kT\ln\frac{N_v}{N_c} + \frac{(E_v+E_c)}{\cancel{kT}}.$$

$$2E_F = kT\ln\left(\frac{m_h^*}{m_e^*}\right)^{3/2} + E_c + E_v.$$

$$E_F = \frac{kT}{2}\ln\left(\frac{m_h^*}{m_e^*}\right)^{3/2} + \frac{E_c+E_v}{2}$$

If $m_h^* = m_e^*$

$$E_F = \frac{E_c+E_v}{2}.$$

$$= \frac{E_c+E_v-E_v+E_v}{2}$$

$$E_F = \frac{E_c-E_v}{2} + E_v.$$

$E_v = 0$

$$E_F = \frac{E_c-E_v}{2}$$

$$\boxed{E_F = \frac{E_g}{2}}$$

Hall Effect

If a metal or a semiconductor carrying current I is placed in transverse magnetic field B, a potential difference V_H is produced in a direction to both mag. field and current direction. This is called the Hall Effect.

Applications: It helps in determining

(i) type of semiconductor

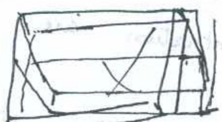
(ii) sign of majority charge carrier

(iii) Majority charge carrier concentration

(iv) Mobility of majority charge carriers.

(v) Mean drift vel. of majority charge carriers.

Let the semiconductor by p-type semiconductor. Let pot. diff V be applied. A current of strength I flows thro' it along the x-dirtn. Holes are majority charge carriers in p-type semiconductor.



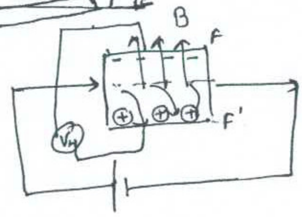
$$I = peAv_d.$$

$p \rightarrow$ hole concentration

$A \rightarrow$ Area of cross section

e - charge.

$v_d \rightarrow$ drift vel.



The current density

$$J_x = \frac{I}{A} = pev_d.$$

Any plane $\perp^r$ to current flow dirtn. is an equipot. surface $\therefore$ Pot. diff. between the front and rare surface is zero.

If mag. field B is applied perpendicular to the dirtn. of flow of current, then a transverse pot. diff. is produced between faces F and F'. It is known as Hall Voltage V_H.

Before the application of mag. field holes moves $\parallel^{el}$ to face FF'. On application of mag. field the holes experience a sideways deflection due to mag. force F_L $\quad F_L = eBv_d$.

Holes are deflected towards the face F and pile up. Corresponding equivalent -ve charge is left on the rare face F'. These opp. charges produce transverse ~~op~~ electric field E_H. whose dirn is from F to F'.

In equillibrium condn.

$$F_L = F_E.$$

$$eE_H = ev_dB.$$

If ω is the width of the semiconductor $E_H = \frac{V_H}{\omega}$.

$$\frac{V_H}{\omega} = v_dB.$$

$$v_d = \frac{J}{pe}.$$

$$\frac{V_H}{\omega} = \frac{J}{pe}B.$$

$$V_H = \frac{J\omega B}{pe} = \frac{\omega BI}{peA}.$$

$$A = \omega t.$$

$$V_H = \frac{\cancel{\omega}BI}{pe\cancel{\omega}t} = \boxed{\frac{BI}{pet} = V_H}.$$

Hall Coefficient defined as Hall field per unit current density per unit mag. induction.

$$R_H = \frac{E}{J_xB} = \frac{V_H/\omega}{JB} = \frac{BI\omega t}{pet \cdot I B\omega} = \frac{1}{pe}$$

Hall Voltage is $V_H = \frac{R_H BI}{t}$.

$$\boxed{R_H = \frac{V_H t}{BI}.}$$

Drift vel: According to equillibrium $F_E = F_L$

$$\cancel{e}\left(\frac{V_H}{\omega}\right) = \cancel{e}Bv_d.$$

$$\boxed{v_d = \frac{V_H}{\omega B}}$$

Carrier conc. $\boxed{p = \frac{1}{R_H e}}$ $R_H = \frac{1}{ne}$

$$\boxed{n = \frac{1}{R_H e}}$$

Doping conc. level can be estimated using the relation

$p = N_A$.

With the dirtn. of mag. field and current as taken the sign of the Hall voltage is +ve for n-type semiconductor Hall vol. will be −ve when dirtn of B and I are kept same.

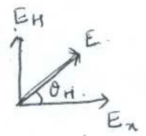
Hall Mobility defined as drift vel. acquired in unit electric field $J = pe v_d$ $J = \sigma E$

$$pe v_d = \sigma E$$

$$\frac{v_d}{E} = \frac{\sigma}{pe}$$

$$\boxed{\mu_h = \sigma R_H}$$

Hall Angle: Net electric field in a semiconductor is a vector sum of E_x and E_H. It acts an angle θ.



$$\tan\theta_H = \frac{E_H}{E_x}$$

$$E_H = \frac{V_H}{\omega} = \frac{BJ}{pe}$$

$$E_x = \frac{J}{\sigma} = \rho J$$

$$\tan\theta_H = \frac{BJ}{pe} \Big/ \rho J$$

$$= \frac{B}{pe\rho}$$

$$= R_H B \sigma$$

$$\boxed{\tan\theta_h = \mu_H B}$$

Intrinsic Conductivity:

At any temperature T, in an intrinsic semiconductor [illegible] and hole concentration are equal $n = p$

In a semiconductor under thermal equillibrium condn, free e move in the conduction band and holes in the valance band, which are in the state of random motion. At temp T they possess an ave. K.E

$$\frac{1}{2}mv^2 = \frac{3}{2}kT.$$

when a pot. diff. is applied across a solid the equillibrium condn is disturbed. The electric field accelerates the e^- and holes but their motion is hindered due to interaction with lattice vibrations. In steady state condn, there arises a net movement of e^- in the opposite dirtn to that of the electric field. This and movement of holes in the dirtn of electric field and their net movement of e^- and holes is called drift. The drift motion is corresponding mean vel as drift vel (v_d). The drift motion of the superimposed on the random thermal motion is directional and causes charge carriers. The drift motion is called as conduction current. drift current flow which is given by

Drift vel is $v_d = \mu E$.

Drift vel. of e^- is designated as v_{de} and that of holes is designated as v_{dh}. |||ly mobility of e^- - μ_e and holes - μ_h.

Current density due to e^-

$$J_e = ne\,v_{de} = ne\mu_e E$$

current density due to holes

$$J_h = pe\,v_{dh} = pe\,\mu_h E$$

Consider a sample of semiconductor across which a pot. diff V is applied. The pot. diff V establishes an electric field E in the semiconductor causes a current I_e due to e^- drifting in conduction band and a current I_h due to holes drifting in VB

Total current thro' the semiconductor

$I = I_e + I_h$

Current density $J = \frac{I_e}{A} + \frac{I_h}{A}$

$J = J_e + J_h$

$J = (ne\mu_e + pe\mu_h)E$

∴ Intrinsic Conductivity

$\boxed{\because J = \sigma E}$

$\sigma = (ne\mu_e + pe\mu_h)$

$n = p = n_i$

$\sigma = n_i e(\mu_e + \mu_h)$ —— (1)

This equation does not explain the temperature dependance of electrical conductivity in semiconductors. In gen, the variation of mobility with temp is too small and the large variation in electrical conductivity in semiconductors is linked to change in e^- conc. with temp. ∴ μ_e, μ_h and e can be taken as const

$\sigma(T) \propto n_i(T)$

Subtituting the expression for n_i in eq (1)

$$\sigma = (N_c N_v)^{1/2} e(\mu_e + \mu_h) e^{-E_g/2kT}$$

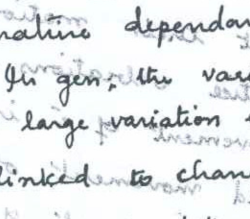
$$\sigma = \sigma_0 e^{-E_g/2kT} \text{ —— (2)}$$

$\sigma_0 \to$ const.

Eq (2) gives the temp dependance of conductivity on temp

Taking $\log_e$ on both sides

$$\ln\sigma = \ln\sigma_0 - \frac{E_g}{2kT}$$



Plot of $\ln\sigma$ vs $1/T$ shows conductivity increases with temp

$E_g = (\text{Slope})(2k)$

Law of Mass Action

For intrinsic semiconductors

$$n \times p = n_i^2 = N_c N_v e^{-E_g/KT}.$$

The electron and hole conc. in n-type extrinsic semiconductors may be given by

$$n_n = N_c e^{-(E_c - E_F)/KT}$$

$$p_n = N_v e^{-(E_F - E_v)/KT}.$$

$$n_n p_n = N_c N_v e^{-E_g/KT}$$

$$n_n p_n = n_i^2$$

IIIly for p-type extrinsic semiconductor

$$n_p = N_c e^{-(E_c - E_F)/KT}.$$

$$p_p = N_v e^{-(E_F - E_v)/KT}.$$

$$n_p p_p = N_c N_v e^{-E_g/KT}.$$

$$n_p p_p = n_i^2$$

This shows that the product of majority and minority carrier concentrations in an extrinsic semiconductor at a particular temp is a const and is equal to square of the intrinsic concentration at that temp.

The Law of mass action is very important because it in conjunction with charge neutrality condn. enables us to calculate minority carrier conc.

The Law of mass action states that the product of majority and minority charge carriers remains const. in an extrinsic semiconductor and it is independent of the amount of donor and acceptor impurity conc.

Carrier Concentration in n-type Semiconductor:

Let N_D be the donor concentration of the material. At 0K the donor conc. atoms are not ionised and are at level E_D, which is very near to E_C. When the temp is raised above 0K the donor atoms get ionised and free e^- appears in C.B. With increase in temp more and more donor atoms get ionised and the e^- conc. in C.B ↑ses.

∴ the e^- conc, n in the conduction band

$$n = N_D^+$$

$$n = N_D - N_D^0$$

N_D^+ is the no. of donor atoms that are ionised. N_D^0 - unionised atoms left at energy level E_D.

Conc. of Ionised donors $N_D - N_D^0 = N_D(1 - f(E_D))$

$$n = \frac{N_D}{1 + e^{(E_D - E_F)/KT}}$$

From the defn. of Fermi level, it is expected that Fermi level in n-type lies few KT above E_D.

$$\therefore \; n = N_D \, e^{(E_D - E_F)/KT}$$

But e^- conc. in C.B is given by

$$n = N_c \, e^{-(E_c - E_F)/KT}.$$

$$N_D \, e^{(E_D - E_F)/KT} = N_c \, e^{-(E_c - E_F)/KT}.$$

$$e^{(E_D - E_F)/KT} = \frac{N_c}{N_D} e^{-(E_c - E_F)/KT}.$$

Taking $\log_e$ on both sides.

$$\frac{E_D - E_F}{KT} = \ln \frac{N_c}{N_D} - \frac{(E_c - E_F)}{KT}.$$

$$E_D - E_F + E_c - E_F = KT \ln \frac{N_c}{N_D}$$

$$(E_D + E_c) - 2E_F = KT \ln \frac{N_c}{N_D}$$

$$2E_F = \frac{E_D + E_c}{2} - KT \ln \frac{N_c}{N_D}$$

$0K \quad N_C = 0$

$$E_F = \frac{E_D + E_C}{2}$$

i.e., in Equillibrium state Fermi level lies midway between bottom of the CB and donor level.

$$e^{(E_F - E_C)/kT} = \exp\left[\frac{E_D + E_C}{2kT} + \left(\frac{1}{2}\right)\ln \frac{N_D}{2\left[2\pi m_e^* kT/h^2\right]^{3/2}} - \frac{E_C}{kT}\right]$$

$$= \exp\left[\frac{E_D - E_C}{2kT} + \left(\frac{1}{2}\right)\ln \frac{N_D}{2\left[\frac{2\pi m_e^* kT}{h^2}\right]^{3/2}}\right]$$

$$= \exp\left[\frac{E_D - E_C}{2kT} + \ln\sqrt{\frac{N_D}{2\left[\frac{2\pi m_e^* kT}{h^2}\right]^{3/2}}}\right]$$

$$= \exp\left(\frac{E_D - E_C}{2kT}\right) \cdot \left[\frac{N_D}{2\left[\frac{2\pi m_e^* kT}{h^2}\right]^{3/2}}\right]^{1/2}$$

$$n = N_c\, e^{(E_F - E_C)/kT} = 2\left[\frac{2\pi m_e^* kT}{h^2}\right]^{3/2} e^{\left(\frac{E_D - E_C}{2kT}\right)} \cdot \left(\frac{N_D}{2\left[\frac{2\pi m_e^* kT}{h^2}\right]^{3/2}}\right)^{1/2}$$

$$n = (2N_D)^{1/2}\left[\frac{2\pi m_e^* kT}{h^2}\right]^{3/4} e^{(E_D - E_C)/2kT}$$

$\therefore$ The e^- conc. in conduction band of an n-type semiconductor is proportional to square root of the donor conc. at moderately low temp.

|||ly for a p-type semiconductor

$$E_F = \frac{E_V + E_A}{2}$$

$$p = 2(N_A)^{1/2}\left[\frac{2\pi m_h^* kT}{h^2}\right]^{3/2} e^{(E_V - E_A)/kT}$$

Calculation of Internal Potential Barrier V_0. (Junction Diode)

The magnitude of the pot. ~~barrier~~ V_0 can be estimated from the knowledge of the e^- conc. in p- and n-region of the diode. E_g is the edge of the conduction band on the n-side

$$n_n = N_c e^{-(E_g - E_F)/KT} \quad \text{—— (1)}$$

The edge of the conduction band on the p-side is given by $E_g + eV_0$. The e^- conc. on p-side will be expressed as

$$n_p = N \exp -((E_g + eV_0) - E_F)/KT \quad \text{—— (2)}$$

Dividing eqn (1) / (2):

$$\frac{n_n}{n_p} = e^{eV_0/KT} \quad \text{—— (3)}$$

Eq (3) shows that at thermal equillibrium the conc. of e^- on both sides of the junctions are related thro' the factor $e^{eV_0/KT}$. The conc. of holes on both sides are related by similar eqn.

Taking loge on both sides.

$$V_0 = \frac{KT}{e} \ln \frac{n_n}{n_p}$$

$$n_p = n_n e^{\left(-\frac{eV_0}{KT}\right)}$$

$$V_0 = V_0 - V_F$$

$$n_p^* = n_n e^{-\left(\frac{e(V_0 - V_F)}{KT}\right)} = n_n e^{-eV_0/KT} e^{eV_F/KT}$$

$$n_p^* = n_p e^{eV_F/KT}$$

$$= \frac{KT}{e} \ln \frac{n_n p_p}{n_p p_p}$$

At room temp all the impurities are ionised ∴

$$\therefore \; n_n = N_D \quad \text{and} \quad p_p = N_A.$$

$$n_p \cdot p_p = n_i^2$$

$$\boxed{V_0 = \frac{KT}{e} \ln \frac{N_D \cdot N_A}{n_i^2}}$$

This equation indicates that the barrier pot. in a jn diode depends on the equillibrium conc. of the impurities in p- and n- regions and does not depend upon the charge density in the depletion region.

The Diode Equation:

When the diode is forward biased, the pot. barrier is lowered by an amount of energy eV_F and the probab. of majority charge carrier crossing the jn increases by the factor $e^{eV_F/KT}$ ∴ ~~Majority~~ Diffusion current density ↑ses by $e^{eV_F/KT}$.

The diffusion current density components in FB mode are

$$J_{hp}^* = J_{hp} e^{eV_F/KT} = J_{hn} e^{eV_F/KT}.$$

$$J_{en}^* = J_{en} e^{eV_F/KT} = J_{ep} e^{eV_F/KT}.$$

where J_{hp} and J_{en} are diffusion current density in unbiased mode. The drift current density components have not changed and have the same magnitude in equillibrium ~~in~~ across FB jn. in mode. ∴ Net hole current hole density

$$J_h = J_{hp}^* - J_{hn} = J_{hn}\left[e^{eV_F/KT} - 1\right]$$

|||ly Net electron current density across the jn is

$$J_e = J_{en}^* - J_{ep} = J_{ep}\left(e^{eV_F/KT} - 1\right)$$

Total current density across the FB p-n jn is sum of e^- and hole current ~~density~~ components.

$$J = J_e + J_h.$$

$$= \left(J_{hn} + J_{ep}\right)\left(e^{eV_F/KT} - 1\right)$$

$$J = J_0\left(e^{eV_F/KT} - 1\right) \quad \text{—— (1)}$$

$$J_0 = J_{hn} + J_{ep}.$$

If $A \rightarrow$ Area of cross section of the jn. then $I = J.A$

$I_0 = J_0 A$

$$I = I_0\left(e^{eV_F/KT} - 1\right).$$

When the diode is reverse biased, the connection from voltage source is reversed and a voltage $-V_R$ is applied to the diode.

∴ Substituting $-V_R$ instead of V_F.

$$J = J_0\left(e^{-eV_R/KT} - 1\right) \quad \text{—— (2)}$$

for Larger values of V_R ∴ $e^{-eV_R/KT} \rightarrow 0$

$$J = -J_0 \qquad I = -I_0.$$

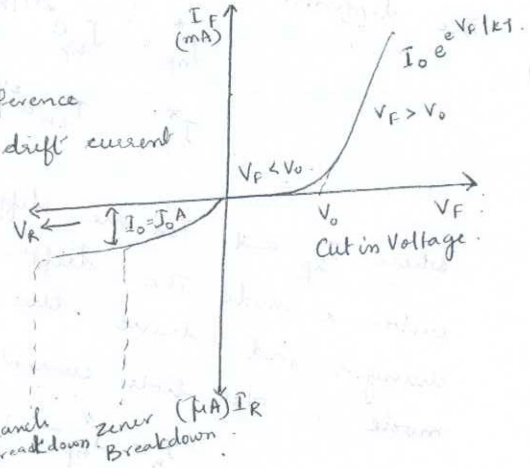
Eqn. 1 and 2 can be combined in a single eqn. by denoting FB | RB voltages by a symbol V.

$$J = J_0 \left(e^{eV/KT} - 1 \right)$$

$$\boxed{I = I_0 \left(e^{eV/KT} - 1 \right)} \longrightarrow \text{Diode Equation}$$

$V = V_F \rightarrow FB \qquad V = -V_R \rightarrow RB.$

$I_0 \rightarrow$ Reverse Saturation Current



Forward Current is equal to the difference between the diffusion current and drift current

$$I_F = I_0 e^{eV_F/KT} - I_0$$

$$= I_{diff} - I_{drift}.$$

Reverse current is given by

$$I_R = I_{drift} - diff.$$

$$= (-I_0) - I_0 e^{-eV_R/KT}$$

For a transitor in CB configuration the emitter current divides itself into the current and collector current. Thus.

$$I_E = I_B + I_C.$$

Assuming that the emitter current I_E remains const, it is seen from the relation that the smaller the base current the larger the collector current. In order to make the collector current as large as possible, the base current current I consists of two components:

(i) fraction of emitter current $\alpha_{dc} I_E$ and

(ii) the reverse leakage current I_{CBO}

$$I_C = \alpha I_{I_E} + I_{CBO}$$

$$\alpha_{dc} = \frac{I_C - I_{CBO}}{I_E}.$$

$$\alpha = \frac{I}{I_E} \qquad \because I_{CBO} \rightarrow \text{is very small.}$$

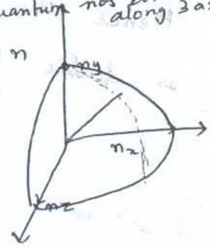
Density of Energy States:

Consider a specimen of a metal in the shape of a cube of side 'L'. Let the free e^- travel freely within the volume of this specimen. The sea of e^- obeying Pauli's Exclusion principle is called Fermi Gas. Since the e^- are confined within the specimen, their wave properties limit the energy values that they may take.

Application of Schroedinger wave equation to the e^- motion in 3-D reveals that the e^- energy is quantised. The quantised value of energy is $E = \frac{h^2}{8mL^2}(n_x^2+n_y^2+n_z^2)$ $\quad n^2 = n_x^2+n_y^2+n_z^2$

$$E = \frac{n^2h^2}{8mL^2} \quad \text{—— (1)}$$

Quantum no. space is an imaginary space where the values of quantum nos are denoted along 3 axes.



All pts. on the surface of the sphere of radius n will correspond to same energy. All pts. with in the sphere represent quantum states with energies lesser than E.

Since the quantum nos. have only the values n can only be defined in the positive octant of the sphere.

$\therefore$ No. of energy states within one octant of the sphere of radius n $= \frac{1}{8}\times\frac{4}{3}\pi n^3$ —— (2)

$\|^{ly}$ No. of energy states within one octant of a sphere of radius $(n+dn)$ corresponding to energy $E+dE$ $= \frac{1}{8}\times\frac{4}{3}\pi(n+dn)^3$ —— (3)

No. of energy states bet. E & $E+dE$ is

$$N(E)\,dE = \frac{1}{8}\left[\frac{4}{3}\pi(n+dn)^3\right] - \frac{1}{8}\left[\frac{4}{3}\pi n^3\right]$$

$$\simeq \frac{1}{8}\frac{4}{3}\frac{\pi}{}(3n^2dn) = \frac{\pi}{2}n^2dn$$

$$N(E)\,dE = \frac{\pi}{2}n^2dn \quad \text{—— (4)}$$

From Eq (1) $\quad n^2 = \frac{8mL^2}{h^2}E$ —— (5)

$$n = \left(\frac{8mL^2}{h^2}\right)^{1/2}E^{1/2} \quad \text{—— (6)}$$

Differentiating eq (5) $\quad 2n\,dn = \frac{8mL^2}{h^2}dE$

$$n\,dn = \frac{4mL^2}{h^2}\,dE \qquad \text{——— (7)}$$

From Eq (4)

$$N(E)\,dE = \frac{\pi}{2}\,n\,(n\,dn) \qquad \text{——— (8)}$$

Substituting eq (6) and (7) in (8)

$$N(E)\,dE = \frac{\pi}{2}\left(\frac{8mL^2}{h^2}\right)^{1/2} E^{1/2} \times \frac{4mL^2}{h^2}\,dE$$

$$N(E)\,dE = \frac{\pi}{4}\left[\frac{8mL^2}{h^2}\right]^{3/2} E^{1/2}\,dE \qquad \text{——— (9)}$$

There are two spin states $m_s = \pm\frac{1}{2}$ for an e^-. According to Pauli's Exclusion Principle, two e^- of opposite spins can occupy one state. Hence the no. of energy states available for e^- occupancy is double the above

$$N(E)\,dE = \frac{\pi}{2}\left(\frac{8mL^2}{h^2}\right)^{3/2} E^{1/2}\,dE$$

$$N(E)\,dE = \frac{4\pi}{h^3}(2m)^{3/2} L^3 E^{1/2}\,dE \qquad \text{——— (10)}$$

The density of states is given by the no. of available energy states per unit vol. per unit energy range at a certain level E

$$\boxed{g(E)\,dE = \frac{4\pi}{h^3}(2m)^{3/2} E^{1/2}\,dE}$$

$$J_{drift} = J_{hn} + J_{ep}$$

$$J_{diff} = J_{hp} + J_{en}$$

0.599×10^{-3}
0.877×10^{-3}
1.476

In thermal Equillibrium

$$J_{diff} = J_{drift}$$

$$J_{hp} + J_{en} = J_{hn} + J_{ep}$$

Also, the hole + e^- currents must seperately be zero to preserve the neutrality of p + n. regions.

$$J_{hp} - J_{hn} = 0 \quad \Rightarrow \quad J_{hp} = J_{hn}$$

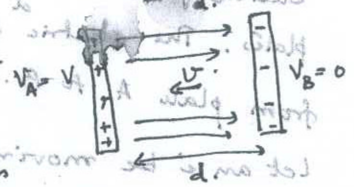
$$J_{en} - J_{ep} = 0 \quad \Rightarrow \quad J_{en} = J_{ep}.$$

ELECTRON BALLISTICS

Motion of an Electron in a Uniform Electric Field.

(a) Electric Field parallel to Initial Velocity.

Let an e^- of mass m and charge $-e$ enter the region of uniform electric field E, which is directed from the plate A to $-$ve plate B. $E = \frac{V}{d}$



The e^- experiences a force F due to electric field

$$F = -eE$$

$-$ve sign indicates that the force acts in the opp. dirn to the e^- motion. As a result, the e^- moves with the acceleration a in the dirn opp. to the field

According to Newton's 2nd Law

$$ma = -eE$$

$$a = \frac{-eE}{m}$$

$$|a| = \frac{eE}{m}.$$

As e, m and const, E is uniform electric field. Hence a is uniform. $\therefore$ e^- is uniformly accelerated in a direction opp. to the field.

- As the electric field acts along st. lines, the path of the e^- is st. line. Electron motion resembles the motion of a freely falling body in gravitational field.
- Even though acceleration due to gravity is same for all bodies - the acceleration for different charged particles will be different as it depends on e/m ratio.

Equation of Kinematics for rectilinear motion can be applied for motion of e^- in an electric field.

$$x = v_0 t + \left(\frac{-eE}{2m}\right) t^2 = \left(\frac{-eE}{2m}\right) t^2$$

$$v = v_0 + \left(-\frac{eE}{m}\right) t = \left(\frac{-eE}{m}\right) t$$

$$v^2 = v_0^2 \mp \left(\frac{-2eE}{m}\right) x = \left(-\frac{2eE}{m}\right) x$$

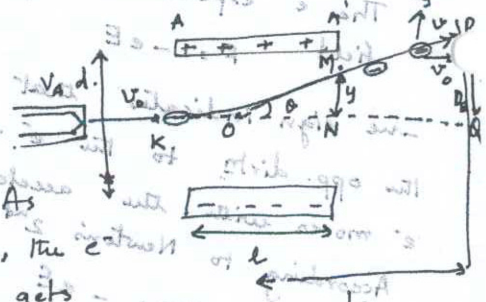
$$K.E = \frac{1}{2} m v^2 = \frac{1}{2} m v_0^2 + \frac{1}{2} m \left(\frac{-2eE}{m}\right) x = (-e) E x. \quad \because Ex = V$$

$$= (K.E)_0 + (-e) E x \qquad K.E = eV$$

$$v = \sqrt{\frac{2eV}{m}} \propto \sqrt{V}$$

(b). Electric field $\perp^{lr}$ to Electron Motion

Consider an electric field applied $\perp^{lr}$ to the initial dirtn. of motion of e^-. Let A and B be two plane $\|^{el}$ metal plates of length 'l' oriented horizontally and seperated by a small distance 'd'. If a potential diff 'V' is applied across the plates, the uniform electric field $E = \frac{V}{d}$ is produced in the region between the plates. The electric field is directed vertically downwards from plate A to B.



Let an e^- be moving in x-dirtn with vel v_0. The e^- vel. in y-dirtn. is initially zero. At pt. K the e^- enters the uniform electric field. As the electric field acts in y-dirtn, the e^- experiences an upward force and gets deflected upwards in y-dirtn. The acceleration acquired by an e^- in y-dirtn.

$$a_y = \frac{eE}{m}. \quad \text{——— (1)}$$

Vel. attained by an e^- after travelling for time t in electric field.

$$v_y = \frac{eE}{m} t. \quad \text{——— (2)}$$

If y is the displacement of the e^- in the field dirtn. during time t.

$$y = \frac{eE}{2m} t^2 \quad \text{——— (3)}$$

Since the initial vel v_0 is in dirtn $\perp^{lr}$ to electric field E it remains unchanged. ∴ Horizontal ~~component~~ of displacement of e^- in x-dirtn. in time t is

$$x = v_0 t \quad \text{——— (4)}$$

∴ Coordinates of e^- after time t : $x = v_0 t$
$y = \frac{eE}{2m} t^2$.

transit time $t = \frac{x}{v_0}$.

Eliminating 't' from (3) + (4)

$$y = \frac{eE}{2m}\left(\frac{x}{v_0}\right)^2 \qquad y = \left(\frac{eE}{2mv_0^2}\right) x^2 \quad \text{——— (5)}$$

$$y = Kx^2$$

This is an equation of parabola
$\Rightarrow e^-$ moving with uniform vel. follows a parabolic path when it passes thro' transverse uniform electric field.

The electric field terminates at MN and the electron does not experience force to the rt. of the plates beyond MN. The e^- then onwards follows a rectilinear path. It travels along the line MP and strikes the flourescent screen at P. If the electric field is switched off the e^- moves without deviation and strikes the screen at Q. $\therefore$ QP is the linear deflection caused by the electric field. When the line MP is extended backwards it cuts the axis QK at O and PO represents the tangent to the parabola KM at M. The angle θ $\angle POQ$ represents the angular displacement of the electron path.

$\therefore$ Electrostatic deflection $D_E = L \tan\theta$.

$$\tan\theta = \left.\frac{dy}{dx}\right|_{x=l} = \frac{d}{dx}\left[\frac{eEx^2}{2mv_0^2}\right]_{x=l}$$

$$= \left.\frac{eEx}{mv_0^2}\right|_{x=l} = \frac{eEl}{mv_0^2} \quad \text{— (6)}$$

$$D_E = \frac{LeEl}{mv_0^2} \quad \text{— (7)}$$

If the stream of e^- have same e/m value but have different initial velocities along x-dirn. The e^- are deflected according to the velocities. All the e^- with a given value of v_0 will reach the pt. P on the screen. If the initial vel has been obtained by passing the e^- thro' the voltage V_A,

$$v_0 = \sqrt{\frac{2eV_A}{m}} \quad \text{— (8)}$$

$$D_E = \frac{L\cancel{e}El}{\cancel{m}} \cdot \frac{\cancel{m}}{2\cancel{e}V_A}$$

$$D_E = \frac{LVl}{2dV_A}. \quad \text{— (9)}$$

D_E is proportional to deflecting voltage V and inversely proportional to V_A.

The deflection sensitivity S of the deflection plates

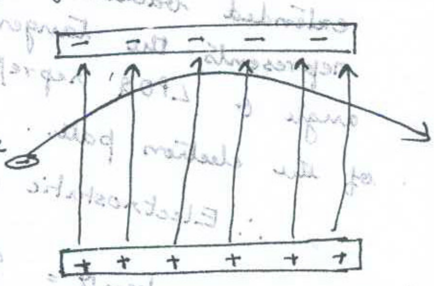
$$S = \frac{D_E}{V} = \frac{L\,l}{2dV_A}$$

Reciprocal ~~to~~ of deflection sensitivity is called deflection factor

$$G = \frac{1}{S} = \frac{2dV_A}{Ll}$$

(c) Electron projected at an angle into uniform Electric field

Initial vel. of the e^- may not be $\parallel^{el}$ to x or y axes. Suppose an e^- projected into a uniform electric field at an angle θ with the initial vel v_0. As the electric field dirtn is along +ve y-dirtn, the e^- gets accelerated along -ve y-dirtn with const. acceleration.



$$a = \frac{e}{m}E$$

As a is const. the e^- closely resembles motion of a projectile in gravitational field.

x-component of velocity — $v_0 \cos\theta$

y-component of vel $\rightarrow$ $v_0 \sin\theta$

Horizontal component of vel. $v_0\cos\theta_0$ remains const. during motion while $v_0 \sin\theta_0$ ↓ses initially and again ↑ses when the e^- reverses its path.

$s = ut + \frac{1}{2}at^2$

$v = u + at$

$v^2 - u^2 = 2as$

$$v_x = v_0 \cos\theta \longrightarrow \text{const.}$$

$$v_y = v_{y_0} + at = v_0 \sin\theta + at$$

Coordinates of e^- after time

$$x = v_x t = (v_0 \cos\theta_0)\,t$$

$$y = v_{y_0} t + \frac{1}{2}at^2 = t v_0 \sin\theta_0 + \frac{1}{2}at^2$$

Eliminating t from above equations.

$$y = (\tan\theta_0)\,x + \left(\frac{a}{2\,v_0^2\cos^2\theta}\right)x^2$$

$$y = ax + bx^2 \longrightarrow \text{parabola}$$

$\therefore$ Trajectory of an e^- projected into a uniform electric field is a parabola.

The max height that an e^- attains in the uniform electric field is

$$H = \frac{v_0^2 \sin^2\theta}{2a}.$$

Time taken by an e^- to reach max. height

$$t = \frac{v_0 \sin\theta}{a}$$

The time of flight T. i.e., time taken by e^- to return to it's initial position along x-dirtn.

$$T = \frac{2v_0 \sin\theta}{a}$$

Range 'R' — Horizontal distance traveled by e^- from the starting position at which it returns to original position along x-dirtn

$$R = \frac{v_0^2 \sin 2\theta}{a}.$$

Motion of an e^- in a uniform Magnetic field.

Let an e^- enter the region where a uniform magnetic field acts. If θ is the angle between the vel. of the e^- and the dirtn of the uniform mag. field, then the mag. force on the e^- is given by

$$F = e(v \times B)$$

$$F = evB\sin\theta$$

Mag. Field Parallel to initial vel.

A static magnetic field does not act on electron which is at rest $v = 0$

$$F = evB\sin\theta = 0$$

When an e^- enters a uniform mag. field $\parallel^{el}$ to mag. field lines, the mag. force acting on the e^- is zero.

$$\theta = 0$$

$$F = evB\sin\theta = 0$$

As the force acting on the e^- is zero in the above cases the e^- continues to move along initial dirtn. of motion without suffering any change in its speed or dirtn. of motion

Magnetic Field $\perp^{r}$ to Initial Vel.

Consider a case of an e^- entering a uniform mag field. $\theta = 90°$ $\sin 90 = 1$ with an initial vel. $\perp^{r}$ to the field.

$$F = evB \quad \text{— (1)}$$

Force due to mag. field acts $\perp^{r}$ to the vel^{r} and B. This force does not perform work on the e^- hence cannot change the magnitude of e^- vel. However, the action of the force is to deflect the e^- and hence changes the dirtn of vel. As the force F deflects the e^-, the dirtns of v and F change continuously and the electron follows the curved path. As the dirtn. of force needs to be always $\perp^{r}$ to the vel of the particle, it is centrepetal force that causes the e^- to move in circular path in a plane $\perp^{r}$ to mag. field.

$$F = \frac{mv^2}{R} \quad \text{— (2)}$$

Comparing eqns ① and ②

$$evB = \frac{mv^2}{R}$$

$$R = \frac{mv}{eB} \quad \text{③}$$

Radius of the circle depends on the momentum 'mv' of the e^-. $R \propto mv$.

Larger is the momentum larger is the radius of e^- path and smaller is curvature.

$$\text{Time period} = \frac{\text{Distance travelled by the } e^- \text{ in one revolution}}{\text{Speed of the } e^-}$$

$$= \frac{\text{Circumference of the path}}{\text{speed of } e^-}$$

$$T = \frac{2\pi R}{v} = \frac{2\pi}{\cancel{v}} \cdot \frac{m\cancel{v}}{eB}$$

$$T = \frac{2\pi m}{eB}$$

Frequency of revolution

$$\nu = \frac{1}{T} = \frac{eB}{2\pi m}.$$

Time period and freq. are independent of vel of e^-. This is because v and R adjust themselves in such a way that for a given mag field B, T and ν remain const.

~~Smaller~~ Slower e^- move in smaller circles while faster e^- move in larger circles but all of them take same time for completion of one revolution.

$$K.E \text{ of } e^- = \frac{1}{2}mv^2$$

$$v = \frac{eBR}{m}$$

$$E_K = \frac{1}{2} m \frac{e^2B^2R^2}{m^2}$$

$$E_K = \frac{e^2B^2R^2}{2m}.$$

Magnetic Field acting at an angle to initial vel.

Let an e^- enter a uniform magnetic field B with its vel. at any angle θ. The vel. v may be resolved into parallel and $\perp^{lr}$ components w.r.t mag. field dirtn.

$$v_{\parallel} = v\cos\theta$$

$$v_{\perp} = v\sin\theta$$

Parallel component of vel. causes uniform rectilinear motion

$$F = e v_{\parallel} B = 0$$

$v_{\parallel} \rightarrow$ remains const. due to mag. field. The e^- continues to move along the field dirtn with vel $v_{\parallel}$.

Perpendicular component of vel. causes circular motion.

$$F = e v_{\perp} B$$

Due to the normal component of force the e^- moves in circular dirtn around the field dirtn. with const speed $v_{\perp}$.

Resultant motion is helical motion around the mag. field dirtn.

Actual motion of the e^- is the resultant of the above two motions

— uniform rectilinear motion ||lel to the field.

— uniform circular motion $\perp^{lr}$ to the field.

Superposition of two results in motion along helical or spiral path.

Radius of the helix is

$$R = \frac{m v_{\perp}}{eB} = \frac{m v \sin\theta}{eB}$$

Time period of revolutions

$$T = \frac{2\pi R}{v_{\perp}} = \frac{2\pi \, \cancel{m v \sin\theta}}{eB \cdot \cancel{v \sin\theta}} = \frac{2\pi m}{eB}$$

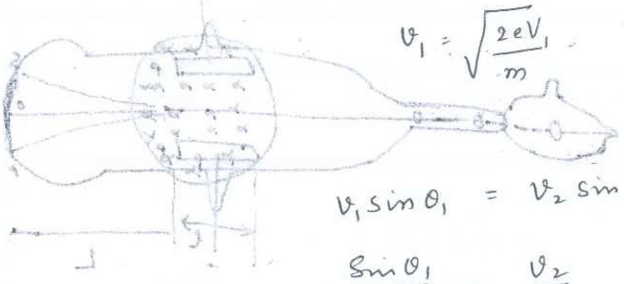
Distance covered in one revolution — pitch of the helix.

$$p = v_{\parallel} T$$

$$= v\cos\theta \cdot \frac{2\pi m}{eB}$$

$$\boxed{p = \frac{2\pi m v \cos\theta}{eB}}$$

Bethe's Law



$$v_1 = \sqrt{\frac{2eV_1}{m}} \qquad v_2 = \sqrt{\frac{2eV_2}{m}}$$

$$v_1 \sin\theta_1 = v_2 \sin\theta_2$$

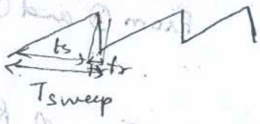
$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_2}{v_1} = \frac{\sqrt{2eV_2/m}}{\sqrt{2eV_1/m}}$$

$$\boxed{\frac{\sin\theta_1}{\sin\theta_2} = \sqrt{\frac{V_2}{V_1}}}$$

CRO

1. CRT
2. Time Base Generator - Variable frequency oscillator which produces an o/p voltage of sawtooth shape.

$$T_{sweep} = t_s + t_r$$

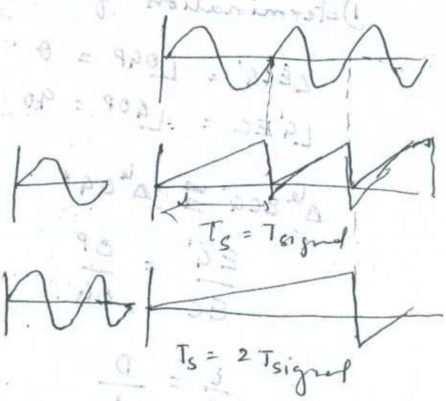


Trigger ckt.

Synchronisation

$$T_{sweep} = n T_{signal}$$

$$f_{signal} = n f_{sweep}$$

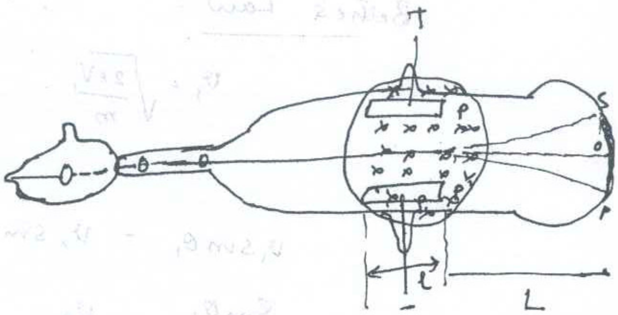


3. Vertical ckt Y-i/p
4. Horizontal ckt X-i/p

} amplifier, attenuator

5. Low Voltage power supply
6. High Voltage power supply.

e/m of Election



$$F_R = F_E - F_B = 0.$$

$$eE - evB = 0$$

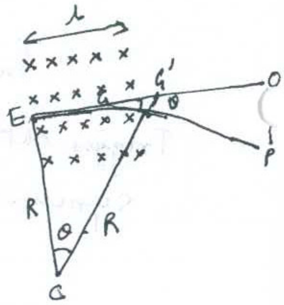
$$v = \frac{E}{B}. \quad \text{—— (1)}$$

The electric field is now switched off the e^- beam experiences a force due to mag. field along. evB. It gets deflected along circular arc of radius R and strikes the screen P. The centre of curvature of the trajectory is at c. and radius R of the curvature

$$R = \frac{mv}{eB}.$$

$$\frac{e}{m} = \frac{v}{BR}. \quad \text{—— (2)}$$

From (1) and (2) $\quad \frac{e}{m} = \frac{E}{B^2R}. \quad$ —— (3)



Determination of R.

$\angle ECG' = \angle OGP = \theta.$

$\angle G'EC = \angle GOP = 90$

$\Delta^{le} ECG' \cong \Delta^{le} OGP$. (congruent triangles)

$$\frac{EG'}{EC} = \frac{OP}{OG}.$$

$$\frac{l}{R} = \frac{D}{L}$$

$$R = \frac{lL}{D} \quad \text{—— (4)}$$

Using (3) and (4) $\quad \frac{e}{m} = \frac{E}{B^2} \cdot \frac{D}{lL}$

$$E = \frac{V}{d}$$

$$\boxed{\frac{e}{m} = \frac{VD}{B^2Lld}.}$$

Crossed Electric and Magnetic field.

$$F_E = eE$$

$$F_B = evB$$

$$F_R = F_E - F_B$$

$F_E > F_B \rightarrow e^-$ deflected upwards

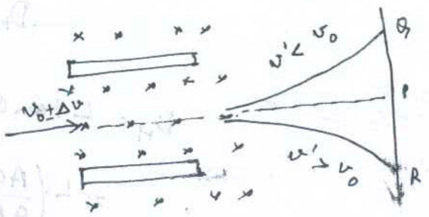
$F_B > F_E \rightarrow e^-$ deflected downwards.

$$F_E = F_B$$

$$F_R = F_E - F_B = 0$$

$$qE = qvB$$

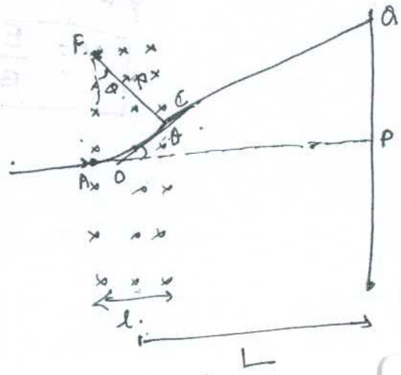
$$\boxed{v = \frac{E}{B}}$$



Magnetostatic Deflection

Deflection produced in the path of electron by mag. field is called magnetostatic deflection.

Consider an e^- beam travelling in horizontal dirtn with vel. v which enters a region where a uniform mag. field acts in transverse dirtn. As the beam travels thro' the mag. field, it bends through an arc of radius R. Before it completes a revolution it emerges from the field as mag. field of limited extension. After emerging from mag. field the beam travel along a straight line and strikes the fluorescent screen at Q. In the absence of the mag. field the e^- would have struck the screen at P. $\therefore$ PQ $\rightarrow$ deflection experienced by the e^- beam due to mag. field.



$$D_H = PQ.$$

$$D_H = L \tan\theta$$

$$= L\left(\frac{AC}{AF}\right) \approx \frac{lL}{R}.$$

$$R = \frac{mv}{eB}.$$

$$v = \sqrt{\frac{2eV_A}{m}}.$$

$$D_H = \frac{Ll}{mv} eB.$$

$$= \frac{LleB}{m} \cdot \sqrt{\frac{m}{2eV_A}}$$

$$\boxed{D_H = LlB\sqrt{\frac{e}{2mV_A}}}$$

$$D_H \propto \frac{1}{V_A}.$$

Deflection sensitivity $= S = \dfrac{D_H}{B} = Ll\sqrt{\dfrac{e}{2mV_A}}$

Deflection factor

$$G = \frac{1}{S} = \frac{1}{Ll}\sqrt{\frac{2mV_A}{e}}$$

OPTICS INTERFERENCE

Principle of Superposition:

This principle states that the resultant displacement of the particle of the medium acted upon by two or more waves simultaneously is the algebraic sum of the displacements of the same particle due to individual waves in the absence of the others.

$$R = y_1 + y_2$$

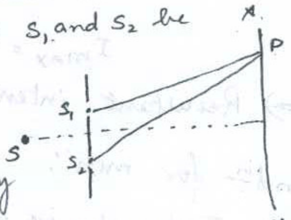
Interference of light:

When two light waves superimpose, then the resultant amplitude (intensity) in the region of superposition is different from the amplitude (intensity) of individual waves. The modification in the distribution of intensity in the region of superposition is called interference.

When the resultant amplitude is the sum of the amplitudes due to individual waves → constructive interference.

When the resultant amplitude is equal to the difference of two amplitudes → destructive interference.

Intensity at a point:



Consider a monochromatic source S emitting waves and S_1 and S_2 be two narrow pin holes equidistant from the source. The waves arriving at S_1 and S_2 from S will be in phase at all times. The resultant intensity at pt. P of the screen XY is to be investigated.

Let a_1 and a_2 be the amplitudes of the waves from S_1 and S_2 and δ be the phase difference between the two waves reaching at pt. P

y_1 and y_2 are the displacements of the waves

$$y_1 = a_1 \sin \omega t \qquad (1)$$

$$y_2 = a_2 \sin(\omega t + \delta) \qquad (2)$$

According to principle of superposition, the resultant displacement

$$y = y_1 + y_2 = a_1 \sin \omega t + a_2 \sin(\omega t + \delta)$$

$$= a_1 \sin \omega t + a_2 \sin \omega t \cos \delta + a_2 \cos \omega t \sin \delta$$

$$= a_1 \sin \omega t + a_2 \sin \omega t \cos\delta + \cos \omega t (a_2 \sin \delta) \qquad (3)$$

$$y = \sin \omega t (a_1 + a_2 \cos \delta) + \cos \omega t (a_2 \sin \delta)$$

Let $a_1 + a_2 \cos \delta = R \cos \theta$ $\qquad a_2 \sin \delta = R \sin \theta \qquad (4)$

Substituting eq (4) in (3)

$$y = \sin\omega t\, R\cos\theta + \cos\omega t\, R\sin\theta$$

$$y = R\sin(\omega t + \theta) \quad \text{--- (5)}$$

Squaring and adding eq (4)

$$R^2\cos^2\theta + R^2\sin^2\theta = (a_1 + a_2\cos\delta)^2 + (a_2\sin\delta)^2$$

$$R^2 = a_1^2 + a_2^2 + 2a_1a_2\cos\delta \quad \text{--- (6)}$$

$\therefore$ Intensity at P is, given by

$$I = R^2 = a_1^2 + a_2^2 + 2a_1a_2\cos\delta \quad \text{--- (7)}$$

Phase difference δ bet. the two waves arriving at P is

$$\delta = \frac{2\pi}{\lambda}(\text{Path diff})$$

$$= \frac{2\pi}{\lambda}(S_2P - S_1P).$$

Condn. for max:

Intensity is max when $\cos\delta = +1$

$\Rightarrow$ Phase diff $\delta = 2n\pi \quad n = 0, 1, 2, 3 \ldots$

$$\delta = 0, 2\pi, 4\pi, \ldots$$

or Path diff $(S_2P - S_1P) = n\lambda$

$$I_{max} = a_1^2 + a_2^2 + 2a_1a_2 = (a_1 + a_2)^2.$$

$\Rightarrow$ Resultant intensity is > sum of individual intensities.

Condn. for min:

Intensity is min when $\cos\delta = -1$

Phase diff $\delta = (2n+1)\pi \quad n = 0, 1, 2, 3 \ldots$

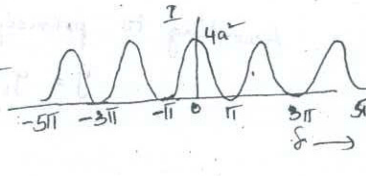
$$\delta = \pi, 3\pi, 5\pi, \ldots$$

Path diff $S_2P - S_1P = (2n+1)\frac{\lambda}{2}$

$$I_{min} = a_1^2 + a_2^2 - 2a_1a_2 = (a_1 - a_2)^2.$$

$\Rightarrow$ The resultant intensity is less than the sum of two two intensities.

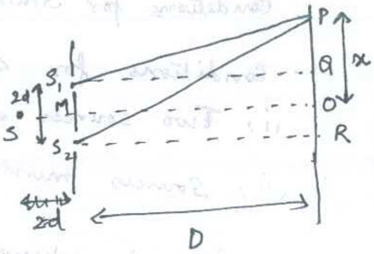
Spl case: when $a_1 = a_2$



$$I_{max} = a^2 + a^2 + 2a^2 = 4a^2$$

$$I_{min} = a^2 + a^2 - 2a^2 = 0.$$

Theory of Interference Fringes:



From rt. angled triangle S_1QP

$$(S_1P)^2 = (S_1Q)^2 + (QP)^2$$

$$(S_1P)^2 = D^2 + (x-d)^2$$

|||ly from $\Delta^{le}\ S_2RP$

$$(S_2P)^2 = (S_2R)^2 + (RP)^2$$

$$(S_2P)^2 = D^2 + (x+d)^2$$

$$(S_2P)^2 - (S_1P)^2 = \cancel{D^2} + (x-d)^2 - \cancel{D^2} - (x+d)^2$$

$$= (x+d)^2 - (x-d)^2$$

$$= \cancel{x^2} + \cancel{d^2} + 2xd - \cancel{x^2} - \cancel{d^2} - 2xd$$

$$(S_2P - S_1P)(S_2P + S_1P) = 4xd.$$

$$D >> 2d \quad \therefore S_2P + S_1P \simeq 2D$$

$$(S_2P - S_1P) = \frac{4xd}{2D}$$

Path difference $(S_2P - S_1P) = \dfrac{2xd}{D}$.

For Bright fringe.

$$S_2P - S_1P = n\lambda$$

$$\frac{2xd}{D} = n\lambda$$

$$x = \frac{n\lambda D}{2d}$$

$x_1 = \dfrac{\lambda D}{2d}$. $\quad n = 1$

$x_1 = 2.\dfrac{\lambda D}{2d}$. $\quad n = 2$

$x_3 = 3\dfrac{\lambda D}{2d}$. $\quad n = 3$

For dark fringe.

$$S_2P - S_1P = (2n+1)\frac{\lambda}{2}$$

$$\frac{2xd}{D} = (2n+1)\frac{\lambda}{2}$$

$$x = (2n+1)\frac{\lambda D}{4d}.$$

$x_0 = \dfrac{\lambda D}{4d}$.

$x_1 = 3\dfrac{\lambda D}{4d}$

$x_2 = \dfrac{5\lambda D}{4d}$.

$x_2 - x_1 = 2.\dfrac{\lambda D}{4D}$

$= \dfrac{\lambda D}{2d}$.

Distance bet. consecutive bright fringe

$$x_2 - x_1 = \frac{\lambda D}{2d}.$$

$$\boxed{\text{Fringe Width } \beta = \frac{\lambda D}{2d}.}$$

Conditions for Stationary Interference Pattern:

1. Conditions for sustained Interference.

(i) Two sources must be coherent.

(ii) Sources must be monochromatic

2. Condns for observations of fringes.

2d must be small.

D must be large.

3. Condns for good contrast.

$a_1 = a_2 = a \rightarrow$ amplitudes must be same.

B. Sources must be narrow

Types of Interference.

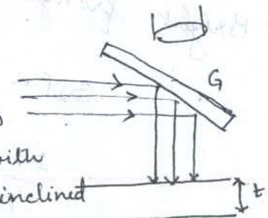
Division of Wavefront $\rightarrow$ wave front is divided into two parts using reflection, refraction diffraction — travel unequal distances reunite at an angle. — Fresnel's Biprism.

Division of Amplitude — Amplitude is divided using reflection + refraction — travel different paths reunite

Broad light source may be employed.

Newton's Rings ; Michelson's Interferometer.

Interference by plane parallel Film:



Let a plane wavefront be allowed to be incident normally on a thin film of uniform thickness t. The plane wavefront is obtained with the help of partially reflecting glass plate G inclined at an angle 45° with a parallel monochromatic beam of light. The plane wave front is partly reflected at the upper surface of the film and partly transmitted into the film. The transmitted wavefront is reflected again from the bottom surface of the film and emerges through the first surface. The wavefront reflected from the upper surface and from the lower surface interfere with each other. The resulting interference pattern can be observed without obstructing the incident wavefront.

(i) The wave reflected from the lower surface of the film traverses an additional path $2\mu t$.

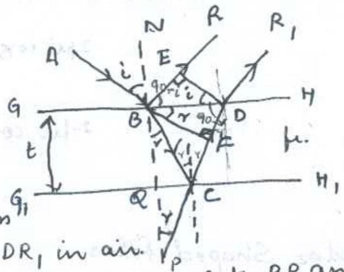
(ii) When the film is placed in air, the wavefront reflected from the upper surface undergoes an additional phase change of π. No phase change takes place at lower surface because the reflection takes place at surface of rarer medium. Thus the cond$^{\underline{ns}}$ for max and min. are changed.

$$2\mu t = n\lambda \rightarrow \text{min.}$$

$$= (2n+1)\frac{\lambda}{2} \rightarrow \text{max.}$$

Oblique Incidence of a Plane Wave on a thin film.

Let GH and G_1H_1 be the two surfaces of a transparent film of uniform thickness t and refractive index μ. Suppose ray AB be incident on the upper surface. This is partly reflected along BR and refracted along BC. After one internal reflection at C and refraction at D, the ray finally emerges out along DR_1 in air. DR_1 is $\parallel^{lel}$ BR. To find the effective pathdifference bet BR and DR_1 Draw a normal DE on BR and normal BF on DC. Also extend DC in backward direction which meets BQ at P



$\angle ABN = i$.

$\angle EBD = 90 - i$

$\angle QPC = r$

$\angle QBC = r$

$\angle BDE = i$

$\angle DBF = r$.

$90 + 90 - i + x = 180$

$x = i$

The optical path diff. bet two reflected rays.

$$\Delta = \text{Path } (BC + CD) \text{ in film} - \text{Path BE in air}$$

$$= \mu(BC + DC) - BE$$

$$\mu = \frac{\sin i}{\sin r} = \frac{BE/BD}{FD/BD}$$

Δ^{le} BDE

Δ^{le} BFD.

$$\mu = \frac{BE}{FD}.$$

$$BE = \mu(FD).$$

$$\Delta = \mu(BC + DC) - \mu(FD)$$

$$= \mu(CF + FD + BC) - \mu(FD)$$

$$= \mu(CF + BC)$$

$$BC = CP$$

$$\Delta = \mu(CF + CP)$$

$$\Delta = \mu(PF)$$

Δ^{le} BFP

$$\cos r = \frac{FP}{BP}$$

$$PF = BP\cos r$$

$$PF = 2t\cos r$$

$\boxed{\text{optical Path diff} : \quad 2\mu t \cos r}$ Cosine Law.

Ray reflected by a surface of denser medium undergoes a an abrupt phase change of π and or an additional path diff of $\lambda/2$

Maxima occurs

$$2\mu t \cos r \pm \frac{\lambda}{2} = n\lambda$$

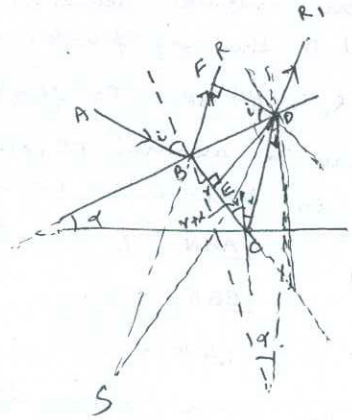
$$2\mu t \cos r = (2n \pm 1)\frac{\lambda}{2}$$

Minima occurs

$$2\mu t \cos r \pm \frac{\lambda}{2} = (2n \pm 1)\frac{\lambda}{2}$$

$$2\mu t \cos r = n\lambda.$$

Wedge Shaped Film :



Path diff $= \mu(BC + CD) - BF$.

$= \mu(BE + EC + CD) - (BE)\mu$.

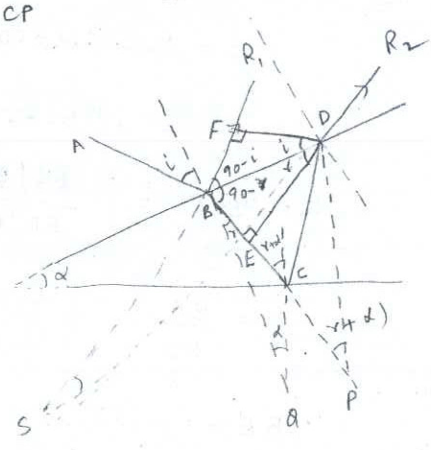
$BF = \mu(BE)$

$= \mu(EC + CD)$

$CD = CP$

$= \mu(EC + CP)$

$= \mu(EP)$



Δ^{le} DEP

$$\cos(r+\alpha) = \frac{EP}{DP}$$

$$EP = DP\cos(r+\alpha)$$

$$= 2t\cos(r+\alpha).$$

Path diff $= 2\mu t \cos(r+\alpha)$.

Due to reflection from the surface of denser medium additional phase change of $\lambda/2$ is introduced.

$$\Delta = 2\mu t \cos(r+\alpha) \pm \frac{\lambda}{2}$$

max. $\quad 2\mu t \cos(r+\alpha) = (2n \pm 1)\frac{\lambda}{2}$ Bright

min $\quad 2\mu t \cos(r+\alpha) = n\lambda$. dark.

Spacing bet. two consecutive bright bands.

n^{th} max.

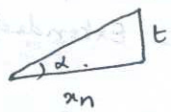
$$2\mu t \cos(r+\alpha) = (2n+1)\frac{\lambda}{2}$$

For normal incidence. $r = 0$

If $\mu = 1$

$$2t \cos\alpha = (2n+1)\frac{\lambda}{2} \quad \text{—} \ (1)$$

Let this be obtained at a distance x_n from the edge



From the fig.

$$\tan\alpha = \frac{t}{x_n}$$

$$t = x_n \tan\alpha. \quad \text{—} \ (2).$$

From (2)

$$2 . x_n \tan\alpha \cos\alpha = (2n+1)\frac{\lambda}{2}$$

$$2 x_n \sin\alpha = (2n+1)\frac{\lambda}{2}$$

for $(n+1)^{th}$ fringe.

$$2 x_{n+1} \sin\alpha = (2(n+1)+1)\frac{\lambda}{2}$$

$$= (2n+3)\frac{\lambda}{2}.$$

$$2(x_{n+1} - x_n) \sin\alpha = \lambda..$$

$$x_{n+1} - x_n = \frac{\lambda}{2\sin\alpha}$$

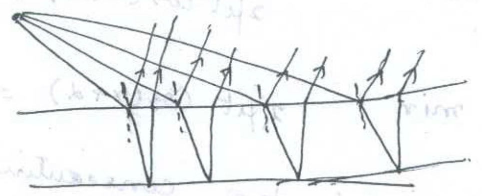
$$\boxed{\beta = \frac{\lambda}{2\alpha}}$$

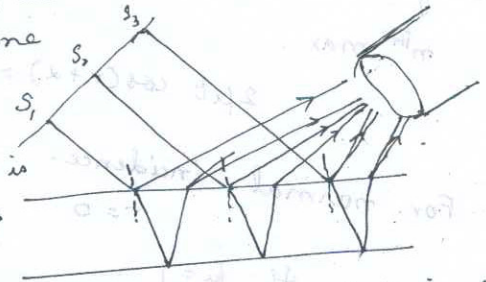
$\because \sin\alpha$ is very small.

$\sin\alpha \simeq \alpha$..

Necessity of an Extended Source

For different angle of incidence, different pairs of interferening rays are obtained each pair being parallel. If film is viewed by keeping the eye in a particular position the whole film cannot be viewed. In order to view the whole film, the eye has to be shifted from one position to another.

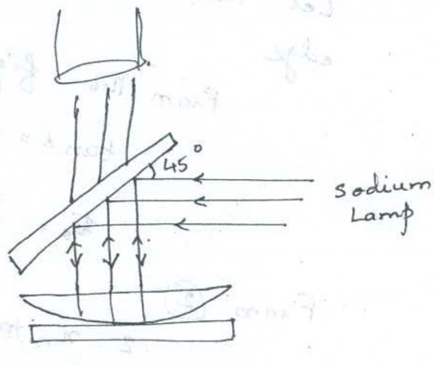


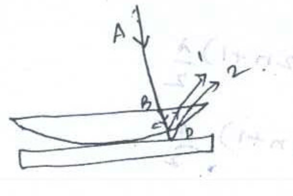


If an extended source of light is used (which may be made up of large no. of point sources $S_1, S_2, S_3 \ldots$). The light reflected from every point in the film reaches the eye. Hence by placing the eye in a suitable position entire film can be viewed simultaneously.

Extended Source.

Newton's Rings:

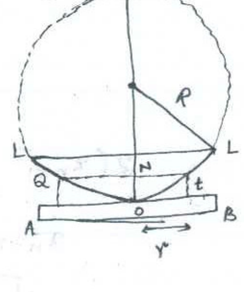




Let LOL' be the lens placed on the glass plate AB.

R → Radius of curvature of the lens.

r → radius of the ring corresponding to constant film thickness 't'



For normal Incidence.

$$2t + \frac{\lambda}{2} = n\lambda$$

$$2t = (2n-1)\frac{\lambda}{2} \quad \text{Bright ring}$$

$$2t = n\lambda \longrightarrow \text{dark ring}$$

$$n = 0, 1, 2, 3 \ldots$$

From the property of the circle

$$NP \times NQ = NO \times ND$$

$$r \times r = t \times (2R - t)$$

$$r^2 = 2Rt - t^2 \qquad R >> t.$$

$$r^2 \simeq 2Rt.$$

$$t = \frac{r^2}{2R}$$

For Bright ring

$$2\left(\frac{r^2}{2R}\right) = (2n-1)\frac{\lambda}{2}$$

$$r^2 = \frac{(2n-1)R\lambda}{2}$$

$$r^2 = \frac{D^2}{4}. \qquad \frac{D^2}{4} = \frac{(2n-1)R\lambda}{2}.$$

$$D = \sqrt{2\lambda R}\,\sqrt{(2n-1)}$$

$$D \propto \sqrt{(2n-1)}$$

Diameter of ring is proportional to square root of odd natural nos.

IIIly for dark ring

$$2\left(\frac{r^2}{2R}\right) = n\lambda$$

$$r^2 = n\lambda R.$$

$$\frac{D^2}{4} = n\lambda R$$

$$D = 2\sqrt{n\lambda R}.$$

Diameter of dark rings are proportional to the square root of natural nos.

Fringewidth decreases with the order of fringe and fringes get closer with increase in their order.

$$D_n^2 = 4n\lambda R$$

$$D_{n+p}^2 = 4(n+p)\lambda R$$

$$D_{n+p}^2 - D_n^2 = 4p\lambda R$$

$$\lambda = \frac{D_{n+p}^2 - D_n^2}{4\lambda R}$$

Antireflecting Coating:

Optical Instruments such as telescope and camera use multicomponent glass lenses. When light is incident on the lens, part of incident light is reflected and that much amount of light is wasted and lost. When more surfaces are there, the no. of reflections will be large and the quality image produced by a device will be poor.

solar cells →

It is found that coating a surface with a thin transparent film of suitable refractive index can reduce loss of energy due to reflection at surface. Such coatings are called anti reflection coating.

Antireflection coatings are thin transparent coating of optical thickness of one quarter ~~thickness~~ wavelength given on a surface in order to suppress reflections from the surface.

A thin film can act as AR coating if it meets the following two conditions.

(i) Phase condition: The waves reflected from top and bottom surface of the film are in opp. phase such that their overlapping leads to destructive interference.

(ii) Amplitude condition: The waves are of equal amplitude.

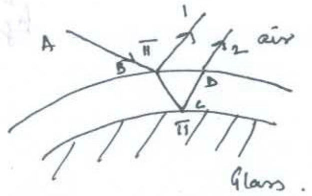
The above condns enable to determine respectively

a. the required thickness of the film.

b. Refractive index of the material to be used for the film.

Phase condition and min. Thickness of the film

Let the thickness of the film be t and the refractive index of the film material be μ_f. The phase condⁿ requires that the waves reflected from the top and bottom surface of the film be 180° out of phase.



$$\Delta = 2\mu_f t - \frac{\lambda}{2} - \frac{\lambda}{2}$$

$$= 2\mu_f t - \lambda$$

Addition or Subtraction of full wavelength does not affect the original phase condⁿ.

For ray 1 & 2 to interfere destructively the path diff

$$\Delta = (2n+1)\lambda/2$$

$$2\mu_f t = (2n+1)\lambda/2$$

For film to be transparent its thickness should be min. which happens ~~on~~ $n=0$

$$2\mu_f t_{min} = \frac{\lambda}{2}$$

$$t_{min} = \frac{\lambda}{4\mu_f} \qquad \mu_f < \mu_g.$$

⇒ Optical thickness of AR coating should be of one quarter wavelength. Such $\frac{\lambda}{4}$ coating film suppress the reflection and cause the light to pass into transmitted component.

(ii) Amplitude condition:

This condition requires that the amplitude of reflected rays 1&2 must be equal $E_1 = E_2$

$$\left(\frac{\mu_f - \mu_a}{\mu_f + \mu_a}\right)^2 = \left(\frac{\mu_g - \mu_f}{\mu_g + \mu_f}\right)^2$$

$\mu_a = 1$
$$\left(\frac{\mu_f - 1}{\mu_f + 1}\right)^2 = \left(\frac{\mu_g - \mu_f}{\mu_g + \mu_f}\right)^2$$

Expanding
$$\frac{\mu_f^2 - 2\mu_f + 1}{\mu_f^2 + 2\mu_f + 1} = \frac{\mu_g^2 + \mu_f^2 - 2\mu_f\mu_g}{\mu_g^2 + \mu_f^2 + 2\mu_f\mu_g}$$

$$4\mu_f^3 \mu_g + 4\mu_f \mu_g = 4\mu_f^3 + 4\mu_f \mu_g^2$$

Dividing by $4\mu_f$ and rearranging

$$\mu_f^2 - \mu_g \mu_f + \mu_g^2 - \mu_g = 0$$

$$\mu_f^2 = \mu_g(\mu_f - \mu_g + 1)$$

$$\mu_f^2 \simeq \mu_g \qquad \mu_f \simeq \mu_g$$

$$\boxed{\mu_f = \sqrt{\mu_g}}$$

$\Rightarrow$ refractive index of thin film should be less than that of the substrate near to the its square root.

The materials which have refractive index nearer to this value are MgF_2 (1.38) and Cryolite $3NaF\,AlF_3$ (1.36)

Apart from RI the material should possess some more additional properties. The film should adhere well, durable, scratch proof and insoluble in ordinary solvents.

$MgF_2 \rightarrow$ widely used.

Min thickness cond^{n} will be satisfied for one wavelength wavelength normally chosen is 5500 Å for which is eye is most sensitive. This λ is in Y - G wavelength region.

$\therefore$ Reflection of red and violet will is larger in white light.

Multilayer AR Coating.

A single AR coating is effective only at a particular ~~λ~~ wavelength. A much wider coverage is possible with multiple coating — multilayers. Usually 3 Layer coating are widely used.

Central layer is $\lambda/2$ (half wave) thick. and is of high RI ZrO_2 (2.1) outside layer of MgF_2 having $\lambda/4$ thickness and layer adjacent to substrate again $\lambda/4$ thickness. CeF_2 (1.63)

Diffraction of light

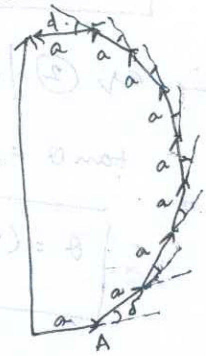
When light falls on obstacles or small apertures whose size is comparable to the wavelength of light, there is departure from straight line propagation, the light bends around the corners of the obstacles or apertures. This bending of light is called diffraction. Diffraction

Types of Diffraction

1. Fraunhofer Diffraction : source and the screen are placed at infinitely large distance. wavefront → plane

2. Fresnels Diffraction . Source and the screen are placed at finite distance from the aperture wavefront → cylindrical or spherical.

Resultant of n simple harmonic Vibrations



Let there be n vibrations of same period, amplitude and phase diff d. between successive vibns which act on a particle simultaneously

R → Resultant amplitude

θ → Resultant phase

Resultant amplitude is resolved into its horizontal and vertical components

$$R\cos\theta = a + a\cos d + a\cos 2d + a\cos 3d + \dots\; a\cos(n-1)d$$

$$= a\left[1 + \cos d + \cos 2d + \cos 3d + \dots \cos(n-1)d\right]$$

Multiplying by $2\sin\frac{d}{2}$.

$$R\cos\theta \cdot 2\sin\frac{d}{2} = a\left[2\sin\frac{d}{2} + 2\cos d\sin\frac{d}{2} + 2\cos 2d\cdot\sin\frac{d}{2} + \dots 2\cos(n-1)d\cdot\sin\frac{d}{2}\right]$$

$$= a\left[2\sin\frac{d}{2} + \left\{\sin\frac{3d}{2} - \sin\frac{d}{2}\right\} + \left\{\sin\frac{5d}{2} - \sin\frac{3d}{2}\right\} + \dots + \left\{\sin\left(n-\tfrac{1}{2}\right)d - \sin\left(n-\tfrac{3}{2}\right)d\right\}\right]$$

$$= a\left[\sin\frac{d}{2} + \sin\left(n-\tfrac{1}{2}\right)d\right]$$

$$= 2a\sin\frac{nd}{2}\cos\left(\frac{n-1}{2}\right)d$$

$$R\cos\theta = a\frac{\sin n\alpha/2}{\sin \alpha/2}\cos\frac{(n-1)\alpha}{2} \quad \text{—— (1)}$$

|||ly $$R\sin\theta = a\frac{\sin n\alpha/2}{\sin\alpha/2}\sin\frac{(n-1)\alpha}{2} \quad \text{—— (2)}$$

Squaring and adding eq (1) & (2)

$$R^2 = a^2\frac{\sin^2 n\alpha/2}{\sin^2\alpha/2}$$

$$\boxed{R = a\frac{\sin n\alpha/2}{\sin\alpha/2}}$$

$n\alpha/2 = \alpha$.

$n\alpha = 2\alpha$.

$$a\frac{\sin\alpha}{\sin\alpha/n} = a\frac{\sin\alpha}{\alpha/n}$$

$\because \frac{\alpha}{n}$ is very small.

Dividing eq (2) / (1)

$$\tan\theta = \tan\frac{(n-1)\alpha}{2}$$

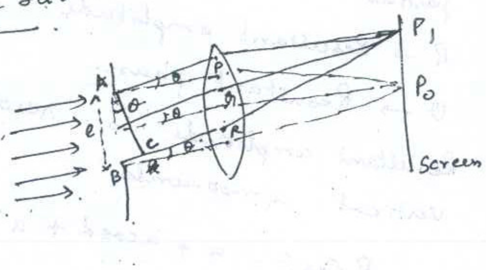
$$\boxed{\theta = \frac{(n-1)\alpha}{2}.}$$

$$R = na\frac{\sin\alpha}{\alpha}.$$

$$\boxed{R = A\frac{\sin\alpha}{\alpha}}$$

$na = A$.

Fraunhofer Diffraction at Single Slit.



Path difference between secondary wavelets from A and B in the direction θ

$= BC$

$= AB\sin\theta$.

$= e\sin\theta$.

Let the width of the slit is divided into 'n' equal parts and amp of wave from each part is same.

Phase diff. bet any two consecutive waves from these parts

$$\frac{1}{n}(\text{Total phase diff}) = \frac{1}{n}\left(\frac{2\pi}{\lambda}e\sin\theta\right) = \alpha$$

Resultant Amp $$R = A\frac{\sin n\alpha/2}{\sin\alpha/2}$$

$$R = \frac{a \sin\left(\frac{\pi e \sin\theta}{\lambda}\right)}{\sin\left(\frac{\pi e \sin\theta}{n\lambda}\right)}$$

$$= a \frac{\sin\alpha}{\sin\alpha/n} \qquad \alpha = \frac{\pi e \sin\theta}{\lambda}.$$

$$= \frac{a \sin\alpha}{\alpha/n} \qquad \because \alpha/n \text{ is very small}$$

$$= n a \frac{\sin\alpha}{\alpha}$$

$$R. = A \frac{\sin\alpha}{\alpha}$$

$$I = R^2 = A^2 \frac{\sin^2\alpha}{\alpha^2}.$$

Intensity Distribution

Principal Max.

$$R = \frac{A}{\alpha}\left[\alpha - \frac{\alpha^3}{3!} + \frac{\alpha^5}{5!} - \frac{\alpha^7}{7!} + \cdots\right]$$

$$= A\left[1 - \frac{\alpha^2}{3!} + \frac{\alpha^4}{5!} - \frac{\alpha^6}{7!} + \cdots\right]$$

If -ve terms vanish the value of R will be max.

$$\alpha = 0.$$

$$\alpha = \frac{\pi e \sin\theta}{\lambda} = 0$$

$$\Rightarrow \sin\theta = 0$$

$$\Rightarrow \theta = 0.$$

Principal Max is observed for those secondary wavelets which travel normally to the slit. Known as Principal Max.

Minima:

The Intensity will be min when

$$\sin\alpha = 0$$

$$\alpha = \frac{\pi e \sin\theta}{\lambda} = \pm m\pi$$

$$e\sin\theta = \pm m\lambda \qquad m = 1, 2, 3, 4 \ldots$$

$$m \neq 0$$

Secondary Maxima:

$$\frac{dI}{d\alpha} = \frac{d}{d\alpha}\left[A^2\left(\frac{\sin\alpha}{\alpha}\right)^2\right] = 0$$

$$A^2 \, 2\frac{\sin\alpha}{\alpha} \cdot \frac{[\alpha\cos\alpha - \sin\alpha]}{\alpha^2} = 0$$

Either $\sin\alpha = 0$ or Principal max.

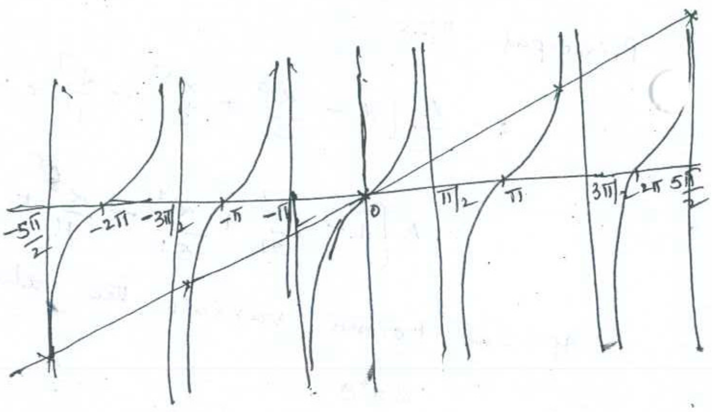
$$\alpha\cos\alpha - \sin\alpha = 0$$

Roots. $\alpha = \tan\alpha$.

$y = \alpha$

$y = \tan\alpha$.

Points of intersection of two curves give the values of α which satisfy eq (4).



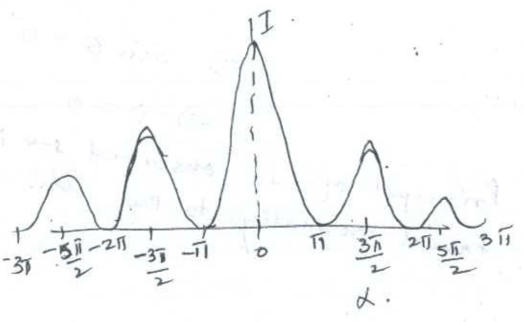
Points of intersection

$$\alpha = 0, \pm\frac{3\pi}{2}, \pm\frac{5\pi}{2}, \pm\frac{7\pi}{2} \text{ (approx)}$$

$I_0 = A^2$ Principal Max

$I_1 = \frac{A^2}{22}$ (approx)

$I_2 = \frac{A^2}{62}$ (approx)



114

End- Semester Examination, PHL -101 (W, X, Y, Z and N sections)
Department of Physics, Visvesvaraya National Institute of Technology, Nagpur.

Duration and Marks: 3 hrs (9.00 – 12.00), 60 marks 24th April 2019

Section- I

Answer any EIGHT questions (8 x 2.5 marks = 20 marks).

1(a) The lifetime of a nucleus in an excited state is 10^{-12} s. Calculate the probable uncertainty in energy (eV) and frequency (Hz) of a γ-ray photon emitted by it. CO1

1(b) Explain the existence of modified and unmodified component in Compton's scattering experiment. CO1

1(c) Evaluate the void space (%) in face centred cubic system. CO2

1(d) Derive Bragg's law of X-ray diffraction. CO2

1(e) For Cu at 1000 K (i) find the energy at which the probability that a conduction electron state is occupied is 90% (ii) Calculate the density of states for the evaluated energy. Fermi energy of Cu is 7.06 eV. CO3

1(f) A sample of pure Ge has intrinsic charge carrier density of $2.5 \times 10^{19}/m^3$ at 300 K. It is doped with donor concentration of 1 in every 10^6 atoms. Calculate the resistivity of doped Ge. Electron and hole mobilities are 0.38 m^2/V-s and 0.18 m^2/V-s and Ge atom concentration is 4.8×10^{28} atoms/m^3. CO3

1(g) The magnetic field in a cyclotron that is accelerating protons is 1.5 T. The maximum radius of the cyclotron is 0.35 m. (i) Calculate the maximum velocity attained by protons? and (ii) How many times per second should the potential across the dees must be reversed? CO4

1(h) A potential difference of 1600 volts is established between two parallel plates, which are 4 cm apart. An electron is released from negative plate, and at the same instance that a proton is released from a positive plate. (i) How far from the positive plate will they pass each other? and (ii) How do their velocities compare when they strike the opposite plate? CO4

1(i) A lens whose focal length is 40 cm forms a Fraunhofer diffraction pattern of the slit 0.3 mm wide. Calculate the distance of the first dark band and the next bright band from the axis. Wavelength of the light used is 5890 Å. CO5

1(j) In a Newton's rings experiment account for the following:
(i)if a plain polished mirror is used instead of glass plate. CO5
(ii)if little water drop is introduced between glass plate and plano-convex lens.

Section – II

Answer any FOUR questions (4 x 10 marks = 40 marks) CO1

2(a) Plot the graph between stopping potential (V_S) and frequency (ν). Indicate $W$and ν_o clearly. **(4)**
Estimate the ideal slope values from V_S $vs.\nu$ (with units) for metals A and B. Assume threshold frequencies of 5890 Å and 5896 Å for A and B respectively.

2(b) Show that Planck's law reduces to Wien's law in short wavelength limit and Rayleigh- Jean's law in the long wavelength limit. Planck's law: $U(\lambda, T) = \frac{8\pi hc}{\lambda^5}\left[\frac{1}{e^{\frac{hc}{\lambda k_B T}}-1}\right]$. **(4)**

2(c) Plot (i) $|\Psi^2|$ *vs.* width of 1- dimensional box of infinite potential well for 3rd excited state and (ii) Ψ *vs.* width of the 1- dimensional box on infinite potential well for 1st excited state. **(2)**

CO 2

3(a) Draw (1 0 0), (1 2 3), (0 1 1) and ($\bar{1}$ 0 0) Miller index planes in a cubic lattice of axial-length 'a'. Indicate the origin and axes clearly. (4)

3(b) Draw Orthorhombic, Hexagonal and Monoclinic systems. Specify the axial lengths and angles (lattice parameters). (3)

3(c) Derive a relation between inter-planar spacing (d) and Miller indices (h k l) of planes for a cubic crystal. (3)

CO 3

4(a) Derive expression for the carrier concentration in a p-type semiconductor at low temperature. (4)

4(b) Derive diode equation. Draw and explain the V-I characteristics of a diode on the basis of diode equation. (4)

4(c) Discuss the role of emitter, base and collector in a transistor. Can the functions of emitter and collector be interchanged? Explain. (2)

CO4

5(a) Derive an expression for e/m of an electron using crossed electric and magnetic fields in a cathode ray tube (with neat diagram). (4)

5(b) A proton has an initial velocity of 2.3×10^5 m/s in the X- direction. It enters in a uniform electric field of 1.5×10^4 N/C in a direction perpendicular to field lines. (i) Find the time taken for the proton to travel 0.05 m in the X- direction. (ii) Find the vertical displacement of the proton after it has travelled 0.05 m in X- direction and (iii) Determine the components of proton velocity after it has travelled 0.05 m in X- direction. (3)

5(c) A deuteron, an isotope of hydrogen, traverses in a circular path of radius 40 cm in a magnetic field of 1.5 T. (i) Find the speed of deuteron (mass of deuteron = 3.34×10^{-27} kg), (ii) Find the time required to make a half revolution and (iii) Through what potential difference would the deuteron have to be accelerated to acquire this velocity? (3)

CO 5

6(a) What is an anti-reflecting thin film? What are necessary conditions required in designing anti-reflection coating? (4)

6(b) Newton's rings are formed in reflected light of 5895Å with a liquid between plain glass plate and plano-convex lens. The diameter of the 5^{th} ring is 0.3 cm and radius of curvature of the plano-convex lens is 1 m. Calculate the refractive index of the liquid when the ring is (i) bright and (ii) dark. (4)

6(c) Show that fringes are equidistant in wedge shaped thin film. (2)

Mass of electron:	9.1×10^{-31} kg	Charge of the electron:	1.6×10^{-19} C
Planck's constant:	6.6×10^{-34} J-sec	Boltzmann constant:	8.61×10^{-5} eV/K

029300

Sr. No. :

Visvesvaraya National Institute of Technology, Nagpur - 440 010

विश्वेश्वरय्या राष्ट्रीय प्रौद्योगिकी संस्थान, नागपूर – 440 010

Answer Book (28 Pages)

Date of Exam : 24/4/19

Enrollment No. : N035

Name : P. Siril Reddy

Course Title : Physics

Branch : Chemical Engineering

Course Code : PHL-101

Examination for the Year 20............... (Tick ✓ the Applicable)

July - Nov Sem	
Jan - May Sem	
Summer Term	
End Sem	✓
Re - Exam	

Additional answer books used Yes/No

Sr. No. of Additional Answer Book
Signature of Invigilator
Department Seal

Q.No.	(a)	(b)	(c)	(d)	(e)	Marks
1	—	0.5	2.5	—		5.5
2	f —	g —	h 2.5	i —	j —	
~~3~~ 2	—		0			0
~~4~~ 3	3	3	—			6
~~5~~ 4	—		2			2
~~6~~ 5	3	3	2	—		8
~~7~~ 6	—					—
8						
9						
10						
Marks Obtained						21.5 (22)
Marks in Words	Twenty ~~only~~ two					
Name of Examiner						
Signature of Examiner						

To be filled in by Examiner only

INSTRUCTION TO THE CANDIDATES

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3. Number your answer according to the questions.
4. Hand over the answer book to the Invigilator, before you leave the examination hall finally.
5. Use of Red Ink/Red Pencil is not allowed. Red color is reserved for examiner.
6. **ONLY BLUE/ BLACK INK ARE ALLOWED FOR WRITING ANSWERS IN ANSWER BOOK. USE OF PENCIL ONLY FOR DIAGRAMS IS ALLOWED.**

WARNING

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Sr. No. : 029270

Visvesvaraya National Institute of Technology, Nagpur - 440 010

विश्वेश्वरय्या राष्ट्रीय प्रौद्योगिकी संस्थान, नागपूर – 440 010

Answer Book (28 Pages)

N027

Date of Exam : 24/4/19

Enrollment No. : BT18CIV089

Name : Gouri Naik

Course Title : Physics

Branch : Civil

Course Code : PHL - 101

Examination for the Year 2018-19..... (Tick ✓ the Applicable)

July - Nov Sem	
Jan - May Sem	✓
Summer Term	
End Sem	✓
Re - Exam	

Additional answer books used Yes/No

Sr. No. of Additional Answer Book

Signature of Invigilator

Orooe 24/4/19

Department Seal

Visvesvaraya National Institute of Technology, Department of Physics, Nagpur-440010

Q.No.	(a)	(b)	(c)	(d)	(e)	Marks
1	—	—	2.5	2.5	2	10
2	f0	92	40	i	j	
~~3~~ 2	4	4	0	—	—	8
~~4~~ 3	3	—	—	—	—	3
~~5~~ 4	—	—	—	—	—	—
~~6~~ 5	4	3	2	—	—	9
6	4	—	—	—	—	4
8						
9						
10						
Marks Obtained						34
Marks in Words	Thirty four					
Name of Examiner						
Signature of Examiner	Orooe					

To be filled in by Examiner only

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II[nd] Sessional Examination, PHL -101 (W, X, Y, Z and N sections)

Department of Physics, Visvesvaraya National Institute of Technology, Nagpur.

Duration: 1 hr (9.00 - 10.00 am) 20th March 2019
Total marks: 15 Marks.

Section- I

Answer any **FIVE** questions. Each question carry **TWO** marks **(5 x 2 marks = 10 marks).**

(1) Plot the graph of Fermi level (E_F) $vs.$ Temperature (T) for p and n- type semiconductors. Indicate E_C, E_V, E_A and E_D levels clearly. Assume the effective mass of hole (m_h^*) is equal to effective mass of electron (m_e^*). **(2)** CO

(2) Derive expression for Fermi energy level (E_F) in n-type semiconductor. CO 3 **(2)**

(3) Draw energy band diagram of **(a)** unbiased and **(b)** biased (common base mode, active region) p-n-p transistor. **(2)** CO

(4) Derive expression for barrier potential (V_o) of p-n junction at equilibrium in terms of acceptor (N_A) and donor (N_D) atoms concentration. **(2)** CO

(5) Plot the graph between Hall voltage (V_H) $vs.$ Applied magnetic field (B) for p- and n- type semiconductors. Assume constant current and thickness. **(2)** CO 3

(6) The conductivity $\sigma(T)$ of an intrinsic semiconductor varies with temperature as $e^{-4350}/_{T}$. Determine the probability of an electron to be thermally excited into the conduction band in this material at 300 K. **(2)** CO 3

(7) Draw neat energy band diagram of Silicon (Si) as a function of inter-atomic distance. **(2)** CO 2

Section- II (Compulsory Question: 5 Marks)

(8) **(a)** Plot the neat graphs of: **(a)** Density of states $vs.$ Energy for electrons in metal and **(b)** group velocity (v_g) $vs.$ k $(in\ the\ range{:}\ -\frac{\pi}{a}\ to\ \frac{\pi}{a})$ for an electron in a periodic potential. **(3)** CO

(b) The resistivity (ρ) and Hall coefficient (R_H) of doped silicon sample is found to be 8.9 x 10^{-3} Ω –m and 3.06 x 10^{-4} m^3/C. Assuming single carrier contribution by each atom, evaluate majority charge carrier concentration and mobility of majority charge carriers (*with appropriate units*). **(2)** CO 3

****

Mass of electron:	9.1 x 10^{-31} kg	Charge of the electron:	1.6 x 10^{-19} C
Planck's constant:	6.6 x10^{-34} J-sec	Boltzmann constant:	8.61 x 10^{-5} eV/K

Sr. No. 013493

Visvesvaraya National Institute of Technology, Nagpur - 440 010

विश्वेश्वरय्या राष्ट्रीय प्रौद्योगिकी संस्थान, नागपुर – 440 010

Answer Book (16 Pages)

Date of Exam : 20/03/2019

Enrollment No. : N 0 3 5

Name : P. Siril Reddy

Course Title : Physics

Branch : Chemical Engineering

Course Code : PHL-101

Examination for the Year 20.............. (Tick ✓ the Applicable)

July - Nov Sem	
Jan - May Sem	✓
Summer Term	
Sessional - I	
Sessional - II	✓

Additional answer books used Yes/No

Sr. No. of Additional Answer Book

Signature of Invigilator

Droose 20/3/19

Department Seal

Visvesvaraya National Institute of Technology Department of Physics 440010

Q.No.	(a)	(b)	(c)	(d)	(e)	Marks
1						—
2						—
3						1.5
4						—
5						1
6						—
7						2
8						3
9						
10						
					Total Marks	7.5

Name of Examiner

Signature of Examiner Droose

To be filled in by Examiner only

INSTRUCTION TO THE CANDIDATES

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Sr. No. : 013451

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विश्वेश्वरय्या राष्ट्रीय प्रौद्योगिकी संस्थान, नागपुर – 440 010

Answer Book (16 Pages)

Date of Exam : 20-3-19

Enrollment No. : N010

Name : Dhanshree Dhakite

Course Title : Physics

Branch : Mining

Course Code : PHL-101

Examination for the Year 20 18-19 ...... (Tick ✓ the Applicable)

July - Nov Sem	
Jan - May Sem	✓
Summer Term	
Sessional - I	
Sessional - II	✓

Additional answer books used Yes/No

Sr. No. of Additional Answer Book
Signature of Invigilator
Department Seal
Visvesvaraya National Institute of Technology, Nagpur-440010 Department of Physics

Q.No.	(a)	(b)	(c)	(d)	(e)	Marks
1						00
2						00
3						2
4						-
5						01
6						02
7						2
8						1.5
9						
10						
					Total Marks	8.5

Name of Examiner: Owais

Signature of Examiner

To be filled in by Examiner only

Dixite.

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Sr. No.: 037988

Visvesvaraya National Institute of Technology, Nagpur - 440 010

विश्वेश्वरय्या राष्ट्रीय प्रौद्योगिकी संस्थान, नागपूर – 440 010

Answer Book (16 Pages)

Date of Exam: 14th February 2019

Enrollment No.: N 0 1 6

Name: NIKHIL KUMAR

Course Title: PHYSICS

Branch: C.S.E

Course Code: PHL-101

Examination for the Year 2019.......... (Tick ✓ the Applicable)

July - Nov Sem	
Jan - May Sem	✓
Summer Term	
Sessional - I	✓
Sessional - II	

Additional answer books used Yes/No

Sr. No. of Additional Answer Book

Signature of Invigilator

Department of Physics Visvesvaraya National Institute of Technology Nagpur-440010

Oroosz 14/2/19

Department Seal

Q.No.	(a)	(b)	(c)	(d)	(e)	Marks
1						—
2						—
3						1
4						—
5						2
6						0
7						—
8						5
9						
10						
Marks Obtained						08
Marks in Words	Eight only					
Name of Examiner						
Signature of Examiner	Oroosz					

To be filled in by Examiner only

Nikhil kumar

INSTRUCTION TO THE CANDIDATES

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037984
Sr. No. :

Visvesvaraya National Institute of Technology, Nagpur - 440 010

विश्वेश्वरय्या राष्ट्रीय प्रौद्योगिकी संस्थान, नागपूर – 440 010

Answer Book (16 Pages)

Date of Exam : 14/02/2019

Enrollment No. : BT18MIN048/N014

Name : Ajit Nikam.

Course Title : Physics.

Branch : Mining Eng..

Course Code :

Examination for the Year 20.............. (Tick ✓ the Applicable)

July - Nov Sem	
Jan - May Sem	✓
Summer Term	
Sessional - I	✓
Sessional - II	

Additional answer books used Yes/No

Sr. No. of Additional Answer Book
Signature of Invigilator Oroor 14/2/19
Department Seal

Visvesvaraya National Institute of Technology, Nagpur-440010 Department of Physics

Q.No.	(a)	(b)	(c)	(d)	(e)	Marks
1						—
2						1.5
3						1
4						—
5						2
6						2
7						2
8						5
9						
10						
Marks Obtained						13.5
Marks in Words	Thirteen point five.					
Name of Examiner						
Signature of Examiner	Oroor					

To be filled in by Examiner only

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PHP 101 Physics Practical **[0:0:2, Credit : 1]**

Objectives :

1. The Objective of this course is to make the students gain practical knowledge to co-relate with the theoretical studies.
2. To achieve perfectness in experimental skills and the study of practical applications will bring more confidence and ability to develop and fabricate engineering and technical equipments.
3. Design of circuits using new technology and latest components and to develop practical applications of engineering materials and use of principle in the right way to implement the modern technology.

List of the Experiments :

1. To study the characteristics of Photocell and to determine the work function of the cathode material.
2. To calibrate an electromagnet and to study the dependence of Hall voltage on magnetic field and current through the sample.
3. To study the I/P, O/P and transfer characteristics and to determine 'α' of transistor in common base mode.
4. To study the forward and reverse characteristics of semiconductor diode.
5. To determine the bandgap in a semiconductor using reverse biased p-n junction diode.
6. To determine e/m for an electron by Thomson's method.
7. To calibrate an audio frequency oscillator and to determine the unknown frequency and phase of RC network by using single trace CRO.
8. To determine the radius of curvature of a plano- convex lens using Newton's Rings.
9. To determine the wavelength of sodium vapour lamp by plane transmission grating.

Reference Books:

1. Experiments in Engineering Physics by M.N. Avadhanulu and P.G. Kshirsagar

PHP-101 : Course Outcomes

Student will be able to:

CO1: Demonstrate experimental skills, analyze and interpret the results obtained.

CO2: Acquire written communication skill to write reports of experiments performed in the lab.

CO3: Understand basic concepts of Physics and develop oral communication skills.

CO4: Enhance understanding of concepts in physics by performing practicals.

CO5: Function effectively as an individual and as a member of a team.

CO-PO Matrix

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	2	---	---	3	---	---	---	---	---	1	---	---
CO2	---	---	---	---	---	---	---	---	---	3	---	---
CO3	3	---	---	2	---	---	---	---	---	2	---	---
CO4	3	---	---	3	---	---	---	---	---	1	---	---
CO5	-	---	---	---	---	---	---	---	3	1	---	---

INSTRUCTION MANUAL

AIM OF THE EXPERIMENT

To study the characteristics of a Photocell and to determine the work function of the cathode material

Aim: To study the characteristics of a Photocell and to determine the work function of the cathode material

Apparatus: Photocell, regulated DC power supply, sodium lamp source, digital voltmeter, digital millivoltmeter, ballistic galvanometer, tapping key

Formula:

$$\Phi = hc/\lambda - eV_s$$

Where

Φ is work function of cathode material

h is Planck's constant

c is velocity of light

λ is wavelength of incident radiation

V_s is stopping potential

Diagram:

Fig.1 Lamp and scale arrangement

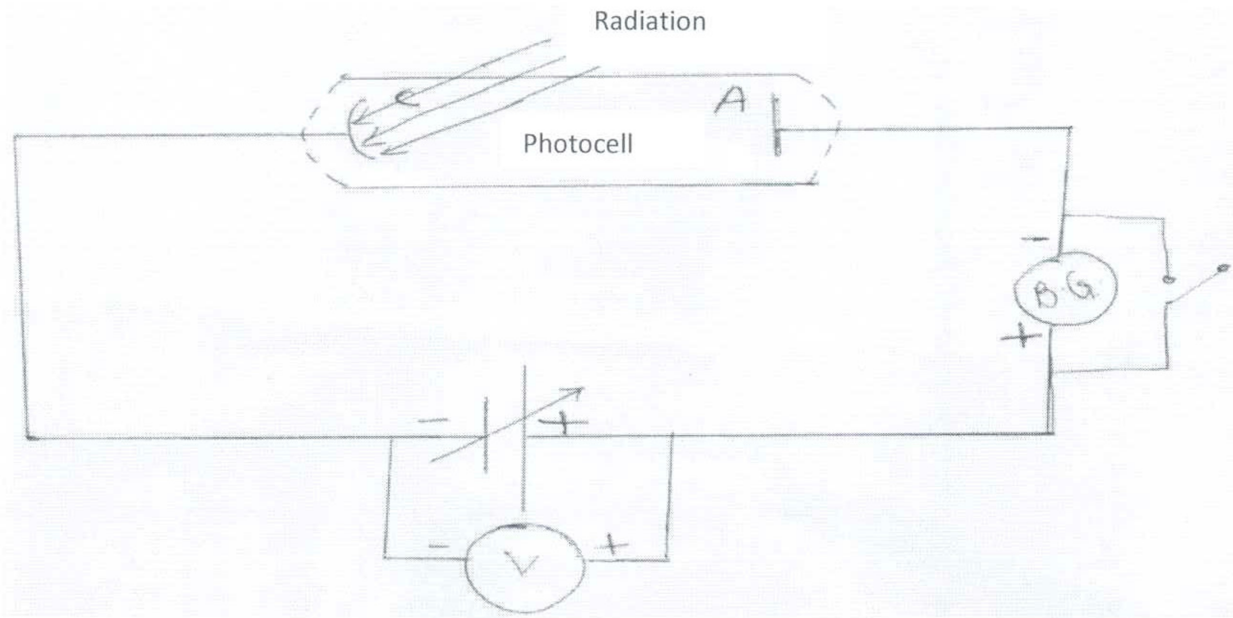


Fig.2 I-V Characteristics of a Photocell

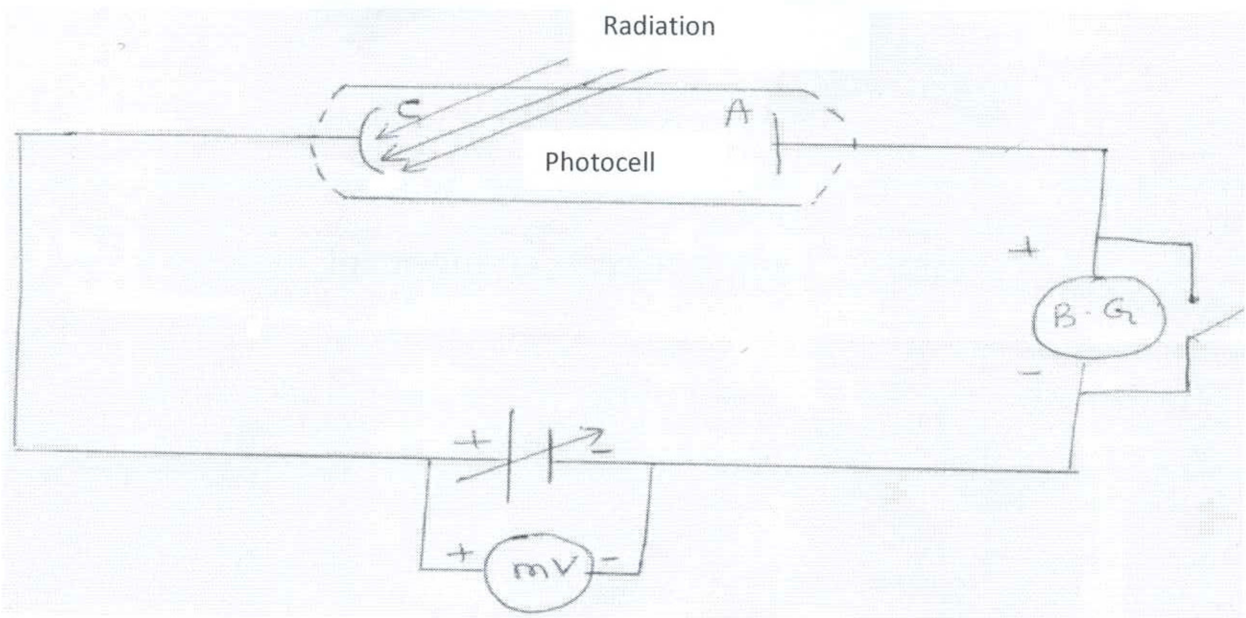


Fig.3 Stopping Potential

Theory:

i) The emission of electrons from a photosensitive material due to incidence of monochromatic radiation on it, is known as photoelectric effect. The emitted electrons are called as photoelectrons and current due to these photoelectrons is called as photoelectric current.

ii) Some minimum amount of energy is required by electrons to escape from a particular metal surface and is called as the work function (W) for that metal. The work function can be expressed in terms of frequency as

$$W = h\omega_o \text{ ....(1)}$$

where h is the Planck's constant

ω_o is the threshold frequency

According to Einstein, the Photoelectric effect should obey the equation,

$$h\omega = KE_{max} + W \text{ ....(2)}$$

On simplifying the above two equations, we get

$$KE_{max} = h\omega - h\omega_o$$

$$= h(\omega - \omega_o)$$

i)Thus the Photoelectric effect is an instantaneous phenomenon. There is no time delay between the incidence of light and emission of photoelectrons.

ii)The number of photoelectrons emitted is proportional to the intensity of incident light. Also, the energy of emitted photoelectrons is independent of the intensity of incident light.

iii)The energy of emitted photoelectrons is directly proportional to the frequency of incident light.

The photoelectric effect can be classified into following three types:

1. Photo-emissive effect: when the surface of certain metals is exposed to a peculiar light, they emit electrons. This is known as photo-emissive effect.
2. Photo-conductive effect: certain materials, like germanium and cadmium sulfide, when exposed to light, exhibit a change in resistance. This effect is known as photo-conductive effect.
3. Photo-voltaic effect: when the boundary surface between two surfaces in close contact is exposed to light radiation, a potential difference is developed across the boundary. This is known as photo-voltaic effect.

Procedure:

A) To Study I-V characteristics

1) Make connections as shown in the circuit diagram for I V Characteristics

2) Adjust the deflection on the scale to 0.

3) Keep the photocell as far as possible from the lamp source.

4) Switch on the power supply and apply 6V to the photocell.

5) Now bring the photocell closer to the lamp source slowly till the deflection on the scale is approximately 20cm. (full scale deflection). This fixes the position of the photocell.

6) Now decrease the voltage in steps of 1V noting the deflection each time. Now decrease the voltage by 0.2 V from 1V onwards till 0V each time noting the deflection.

7) Tapping key is used intermittently to minimize the deflection.

8) Find out the corresponding values of current using the calibration factor.

9) Plot the graph between current(Y axis) and voltage(X axis).

B) For Stopping Potential

1) Make connections as shown in the circuit diagram for stopping potential

2) Take the photocell closer to the source till the deflection reaches to 6 to 8 cm when the power supply is switched off.

3) Increase the voltage with the help of fine voltage knob in steps of 50 mV till the deflection reduces to 0 cm noting the deflection each time.

4) The potential corresponding to 0 deflections is the stopping potential.

5) Plot the graph between current(Y axis) and voltage(X axis).

Observation Table:

A) For I-V Characteristics

Sr. No.	Voltage(V)	Deflection cm	Current (nA)
1.	6		
2.	5		
3.	4		
4.	3		
5.	2		
6.	1		
7.	0.8		
8.	0.6		
9.	0.4		
10.	0.2		
11.	0		

B) For Stopping Potential

Sr. No.	Voltage(mV)	Deflection (cm)	Current (nA)
1.	0		
2.	50		
3.	100		
4.	150		
5.	200		
6.	250		
7.	280		
8.	310		
9.	340		
10.	370		
11.	400		
12.	430		

Calculations :

$$\Phi = hc/\lambda - eV_s$$

Result : The graph is plotted between plate current and voltage. The work function of the cathode material is found to be ....

Precautions : **1**. Avoid excessive deflection on the scale since BG is a sensitive and delicate instrument.

2.The photocell should be placed in proper alignment so that the cathode receives proper radiation.

INSTRUCTION MANUAL

AIM OF THE EXPERIMENT

To calibrate an electromagnet. To study the dependence of Hall voltage on magnetic field and current and to determine the Hall coefficient and carrier concentration.

Aim: To calibrate an electromagnet. To study the dependence of Hall voltage on magnetic field and current and to determine the Hall coefficient and carrier concentration.

Apparatus: Electromagnet, Constant current power supply, micro voltmeter, milliammeter, gauss meter, Hall probe etc

Formula:

$$R_H = V_H t / i.B_x$$

$$n = 1/R_H .e$$

Where

V_H is Hall voltage,

t is thickness of sample

i is the current passing through the sample

B_x is applied magnetic field

n is carrier concentration

e is electronic charge

Diagram:

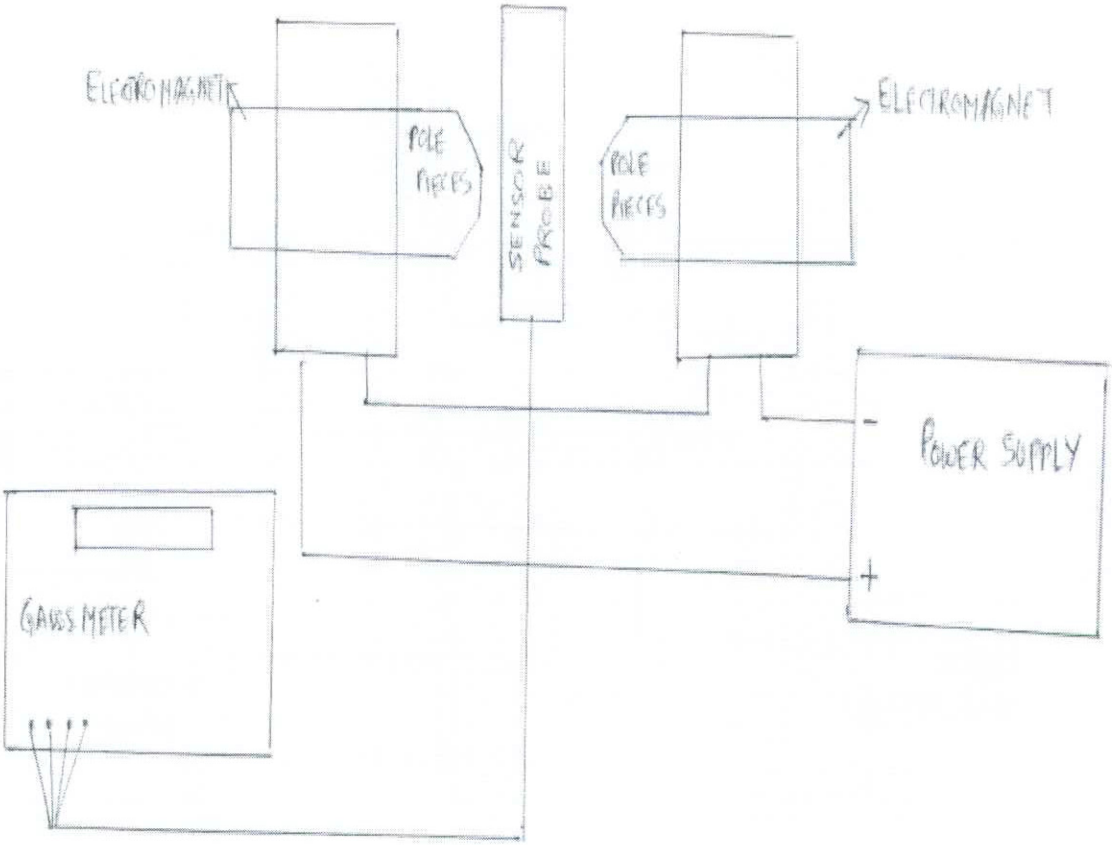


Fig. 1 Calibration of Electromagnet

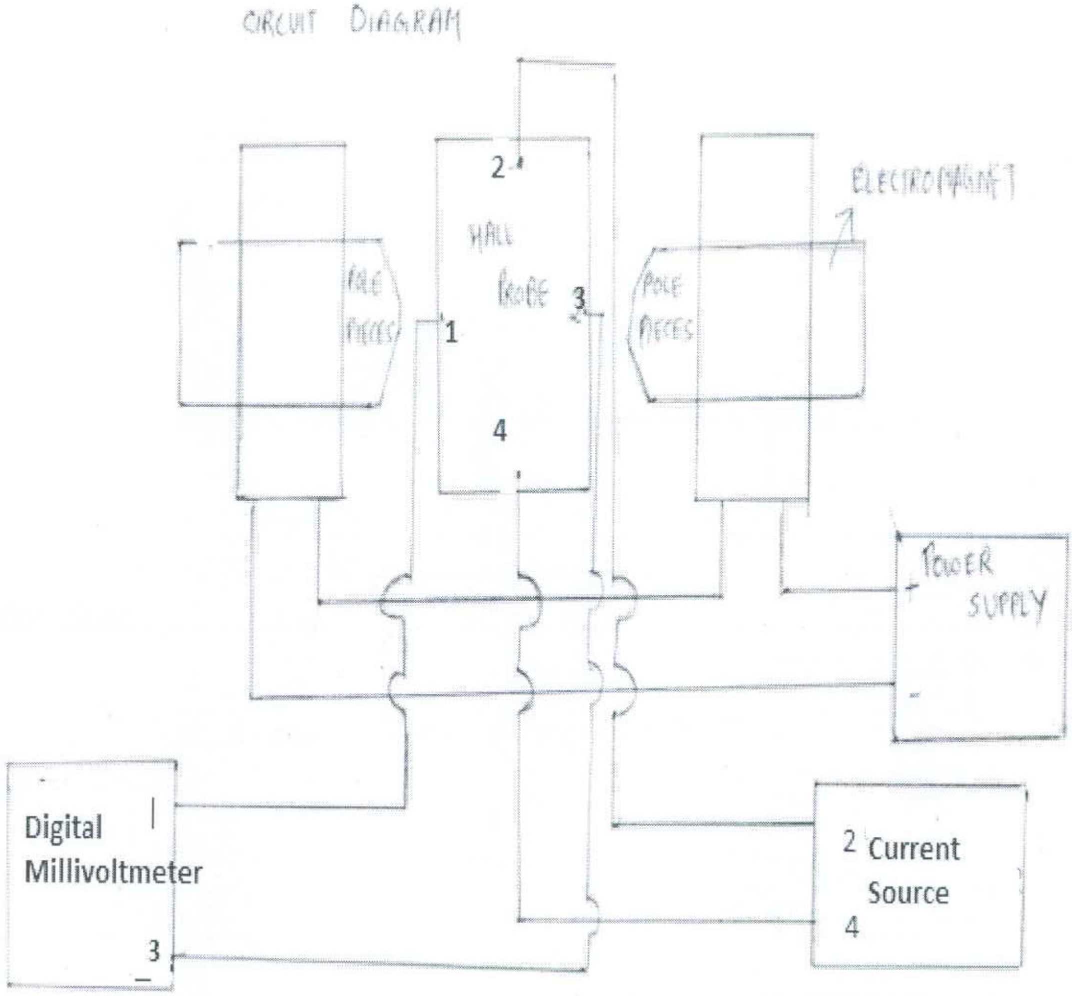
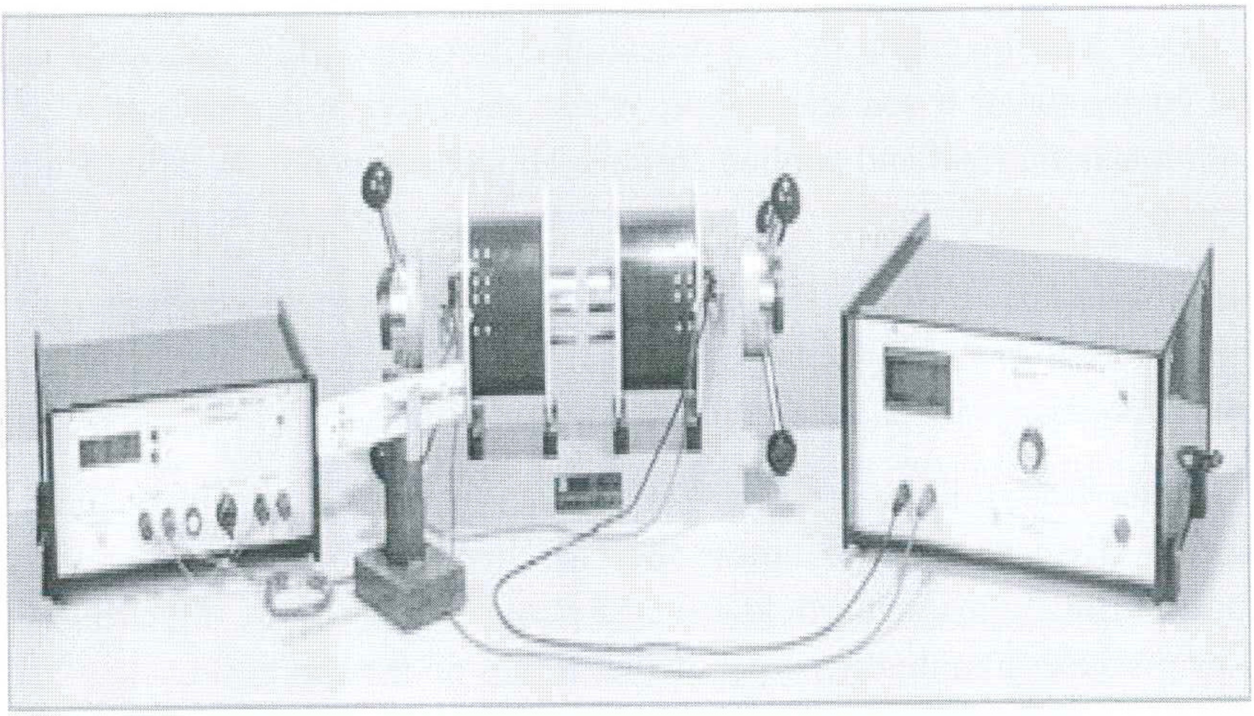


Fig.2 For the Measurement of Hall Voltage



Hall Effect Set Up

Theory:

i) When a current carrying conductor or a semiconductor is placed in a perpendicular magnetic field, a potential difference will be generated in the conductor or a semiconductor, whose direction is perpendicular to both magnetic field and applied current. This phenomenon is called Hall Effect.

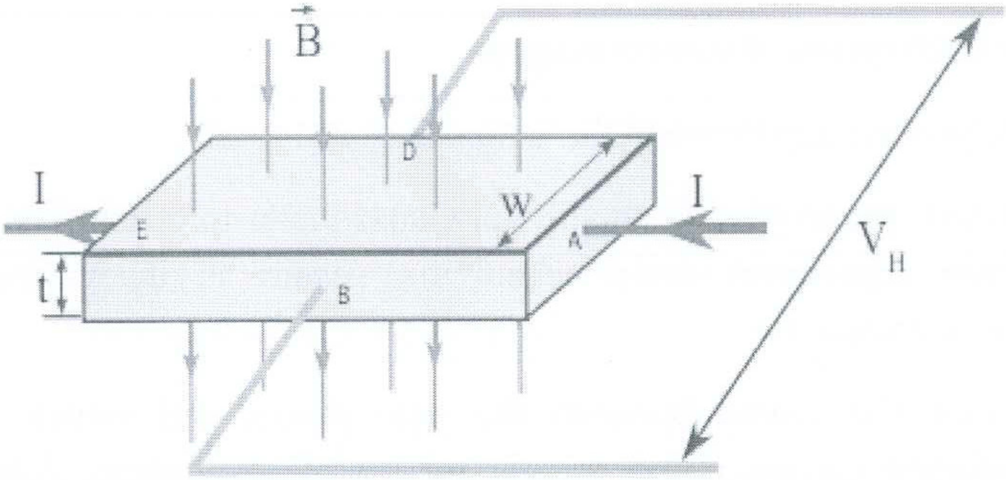
ii) In solid state physics, Hall Effect is an important tool to characterize the materials especially semiconductors. It directly determines both the sign and density of charge carriers in a given sample.

iii) Apart from this we are aware of the fact that a static magnetic field has no effect on charges unless they are in a motion. And when the charges flow, a magnetic field directed perpendicular to the direction of flow produces a mutually perpendicular forces on the charges.

iv)When this happens, electrons and holes will be separated by opposite forces. This will in turn produce and electric filed (E_h) which depends upon the cross product of the magnetic intensity , H, and the current density J. This is manifested by the equation given below

$$E_h = R.\ J \times H$$

where R is called as the Hall Coefficient



Hall voltage is developed perpendicular to both applied magnetic field and current

Let us consider a bar of semiconductor, having dimension, x,y and z. Let J is directed along x direction and H is along the z direction, then E_h will be along the y direction as shown in the figure given above.

From the above discussion we can write

$$R = \frac{V_h / y}{JH}$$

$$= \frac{V_h / z}{IH}$$

Where I=Jyz

V_h is the Hall voltage appearing between the two surfaces perpendicular to y .

Procedure :

A) For calibration of electromagnet

1. Adjust the gap between the pole pieces at 1.5 cm.
2. Adjust the reading of the digital Gauss meter to 0 with the help of Zero adjustment knob when the sensor is away from the electromagnet.
3. Insert the sensor between the pole pieces and switch on the constant current power supply for the electromagnet. Adjust the current through the electromagnet to 0.5 A.
4. Increase the current through the electromagnet in steps of 0.5 A upto 4A. Read the magnetic field in each case.
5. Plot the graph between the current along the X axis and magnetic field along the Y axis. This is the calibration curve for the electromagnet

B) For measurement of Hall voltage (dependence of V_H on magnetic field).

1. Insert the Hall probe such that the area of cross section of the probe is normal to the magnetic field.
2. Connect current leads to the constant current source as shown in the diagram.
3. Connect the Hall voltage terminals to the digital millivoltmeter (input terminal)
4. Adjust the current through the Hall probe to 1mA. Increase the current through the electromagnet from 0 in steps 0.5 A upto 4A. Measure the Hall voltage each time.

5. Repeat step 4 by changing the current through the sample to 2mA and 3 mA.

Observation Tables:

1. For calibration of electromagnet

Sr. No.	Current through electromagnet(A) I_E	Magnetic induction(Wb/m^2) B
1.	0	
2.	0.5	
3.	1.0	
4.	1.5	
5.	2.0	
6.	2.5	
7.	3.0	

2. For measurement of Hall voltage

Sr. No.	Current through electromagnet(A) I_E	Magnetic induction(Wb/m^2) B	Hall voltage in mV		
			Current through sample		
			i=1mA	i=2mA	i=3mA
	0.5				
	1.0				
	1.5				
	2.0				
	2.5				
	3.0				

3. For measurement of Hall voltage

Sr. No.	Current through sample(mA)	Hall voltage in mV		
		I_E = 1 A **B =**	**I_E = 2A** **B =**	**I_E = 3A** **B =**
1.	1 mA			
2.	2 mA			
3.	3 mA			
4.	4mA			
5.	5mA			

Calculations :

Result : The hall coefficient of the given semiconductor sample is found to be……………………..

Precautions :

1.The current through the Hall probe should not exceed the specified value.

2.The gap between the pole pieces should be kept constant throughout the experiment.

3. Do not switch ON or OFF the constant current power supply for electromagnet unless it is brought to a minimum value.

INSTRUCTION MANUAL

AIM OF THE EXPERIMENT

To calibrate the frequency of oscillator. To determine the frequency of AC mains. To determine the phase of RC network.

Aim:

- To calibrate the frequency of oscillator
- To determine the frequency of AC mains.
- To determine the phase of RC network.

Apparatus:

CRO, RC network, audio oscillator, step down transformer, patch chords etc

Formula:

A. For calibration of frequency of oscillator

$$T = t * x$$

$$f = 1/T$$

Where

T is time period

x is spread of sine wave

t is time base setting

f is frequency

B. For determination of unknown frequency

$$f_x T_x = f_y T_y$$

where

f_x is frequency applied to X i/p of CRO

f_y is frequency applied to Y i/p of CRO

T_x is number of horizontal tangencies

T_y is number of vertical tangencies

C. For determination of phase

$$\phi_x = \sin^{-1}(X_{int} / X_{max})$$

$$\phi_y = \sin^{-1}(Y_{int} / Y_{max})$$

$$\phi_t = \tan^{-1}(1/2\pi fRC)$$

Where

ϕ_x is measured phase angle of RC combination

ϕ_y is measured phase angle of RC combination

ϕ_t is calculated phase angle of RC combination

f is the frequency of the sine wave.

R is resistance in RC combination

C is capacitance in RC combination

Circuit Diagram:

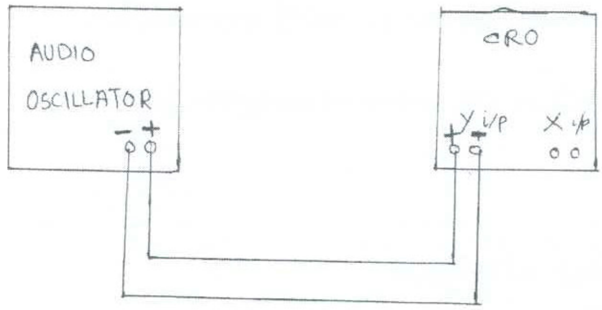


Fig.1 CIRCUIT DIAGRAM FOR CALIBRATION OF AUDIO OSCILLATOR

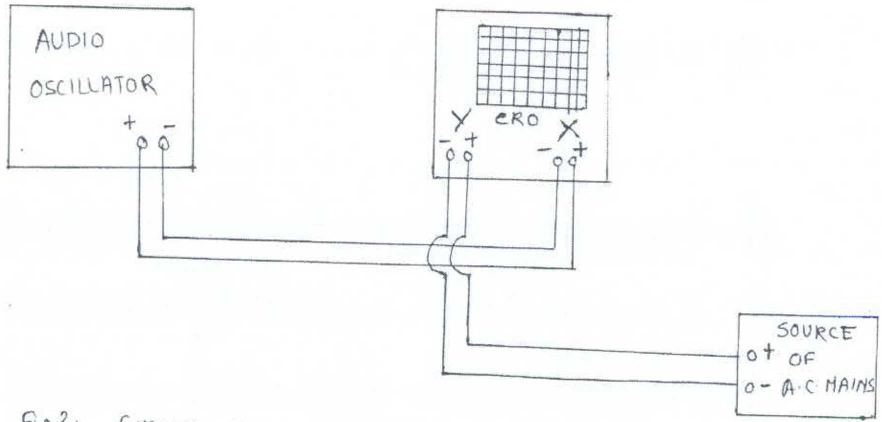


Fig2. CIRCUIT DIAGRAM FOR DETERMINATION OF FREQUENCY OF A.C. MAINS

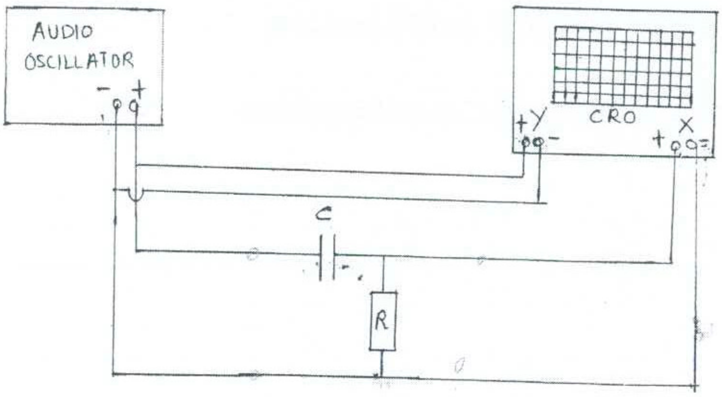
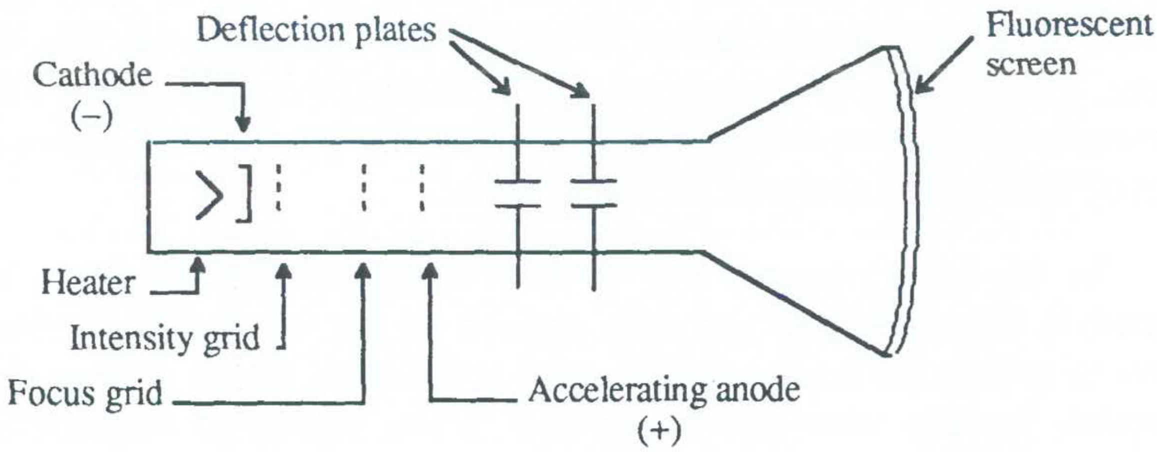


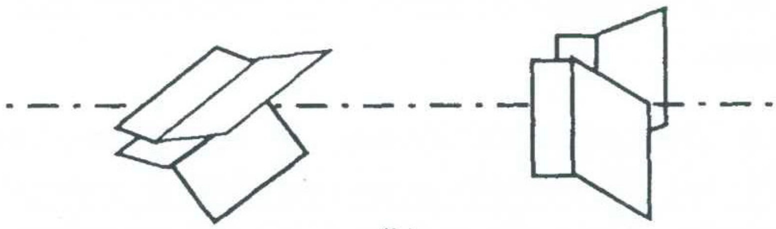
Fig 3. CIRCUIT DIAGRAM FOR DETERMINATION OF PHASE

Theory:

The cathode-ray oscilloscope (CRO) is a common laboratory instrument that provides accurate time and aplitude measurements of voltage signals over a wide range of frequencies. Its reliability, stability, and ease of operation make it suitable as a general purpose laboratory instrument. The heart of the CRO is a cathode-ray tube shown schematically in Fig. 4.



(a)



(b)

Fig.4 a) Cathode Ray tube Schematic Diagram and b) details of deflection plate

The cathode ray is a beam of electrons which are emitted by the heated cathode (negative electrode) and accelerated toward the fluorescent screen. The assembly of the cathode, intensity grid, focus grid, and accelerating anode (positive electrode) is called an *electron gun*. Its purpose is to generate the electron beam and control its intensity and focus. Between the electron gun and the fluorescent screen are two pair of metal plates - one oriented to provide horizontal deflection of the beam and one pair oriented ot give vertical deflection to the beam. These plates are thus referred to as the *horizontal* and *vertical deflection plates*. The combination of these two deflections allows the beam to reach any portion of the fluorescent screen. Wherever the electron beam hits the screen, the phosphor is excited and light is emitted from that point. This conversion of electron energy into light allows us to write with points or lines of light on an otherwise darkened screen.

In the most common use of the oscilloscope the signal to be studied is first amplified and then applied to the vertical (deflection) plates to deflect the beam vertically and at the same time a voltage that increases linearly with time is applied to the horizontal (deflection) plates thus causing the beam to be deflected horizontally at a uniform (constant> rate. The signal applied to the vertical plates is thus displayed on the screen as a function of time. The horizontal axis serves as a uniform time scale.

The linear deflection or sweep of the beam horizontally is accomplished by use of a *sweep generator* that is incorporated in the oscilloscope circuitry. The voltage output of such a generator is that of a saw tooth wave as shown in Fig. 5. Application of one cycle of this voltage difference, which increases linearly with time, to the horizontal plates causes the beam to be deflected linearly with time across the tube face. When the voltage suddenly falls to zero, as at points (a) (b) (c), etc...., the end of each sweep - the beam flies back to its initial position.

The horizontal deflection of the beam is repeated periodically, the frequency of this periodicity is adjustable by external controls.

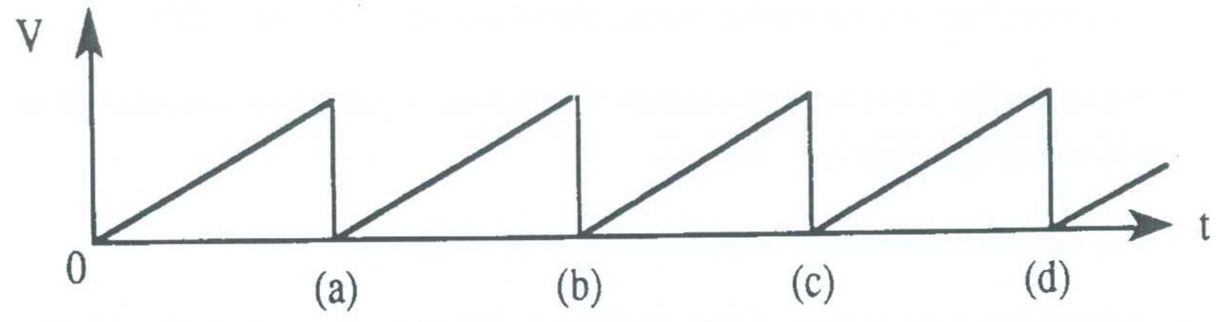


Fig 5. Voltage difference between horizontal plates as a function of time

CRO controls

The controls available on most oscilloscopes provide a wide range of operating conditions and thus make the instrument especially versatile. Since many of these controls are common to most oscilloscopes a brief description of them is as follows:

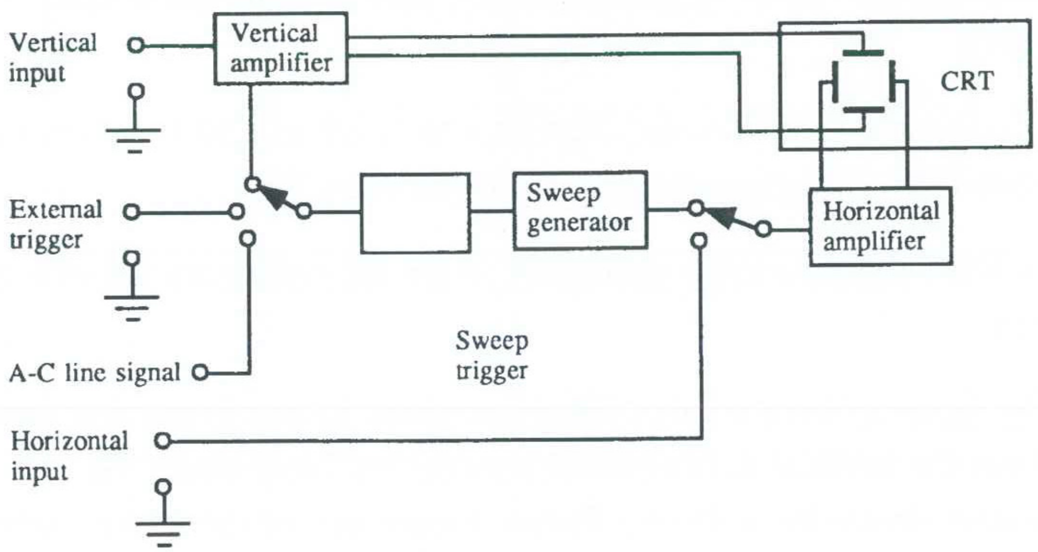


Fig.6 Block diagram of a typical oscilloscope

Procedure:

A. For calibration of audio frequency oscillator

1. Connect the output of the audio oscillator to Y i/p of CRO.

2. Release the XY knob so that the time base signal gets connected to the X i/p of the CRO.

3. Adjust the sine wave pattern along the base line

4. Adjust the frequency of the audio oscillator to the value at which you want to calibrate the oscillator.

5. Find out the spread of the sine wave. Note down the time/div setting from the display screen of the CRO and the frequency from the audio oscillator.

Repeat the same procedure for different frequencies

B. For determination of frequency of AC mains

1. Press the XY knob so that time base gets disconnected from X I/P of CRO.

2. Connect the O/P of audio oscillator to X I/P of CRO and the O/P of the step down transformer to the Y I/P of the CRO.

3. Increase the frequency gradually to get the stationary pattern on the screen.

4. The figures obtained are called Lissajous figure. From this figure, find out the vertical & horizontal tangencies. Note down the frequency from the audio oscillator. Frequency of the audio oscillator should be changed from 25 Hz to 300Hz.

C. For determination of Phase

1. Connect the O/P of audio oscillator to X I/P of CRO.

2. Connect the O/P of audio oscillator also to the I/P terminal of the RC combination.

3. Connect the two terminals of the resistance to Y I/P of CRO. An ellipse is displayed on the screen of the CRO. The ellipse has to be positioned so that it is situated symmetrically around the centre of the screen.

4. Note down X_{int} , X_{max}, Y_{int} and Y_{max}.

5. Note down values of R & C and f.

6. Calculate the experimental and theoretical values of phase angle.

Observation Table :

A. For the calibration of audio frequency oscillator

Sr. No.	Audio Oscillator frequency f (kHz)	Time base setting(s/cm)	Spread of sine wave (cm)	Time period (s)	Measured frequency (kHz)

B. For frequency determination

Sr. No.	Horizontal frequency f_x	Horizontal tangency	Vertical tangency	Vertical frequency f_y

C. For phase determination

Sr. No.	Frequency kHz	X_{int} cm	X_{max} cm	Y_{int} cm	Y_{max} cm	ϕ_x	ϕ_y	ϕ_t

Calculations:

Results:

1. Frequency of audio Oscillator is calibrated

2. Frequency of A.C. mains is found to be ………………..Hz

3. Theoretical and observed values of phase of RC network are in agreement.

Precautions:

1. The trigger mode should always be at auto level.

2. The variable knob should be kept at cal position.

INSTRUCTION MANUAL

AIM OF THE EXPERIMENT

To determine the charge to mass ratio (e/m) for an electron by Thomson's method.

Aim: To determine the charge to mass ratio (e/m) for an electron by Thomson's method.

Apparatus: Cathode Ray Tube, (CRT), power supply for CRT, wooden frame, deflection magnetometer, wooden bench, bar magnets, stop watch etc.

Formula:

$$e/m = V\,py\,(l + p/2)/t\,A^2$$

$$B = B_0\,(T_0^{\,2} / T^2)\,\mathrm{Sin}\,\varphi$$

Where e – charge of an electron

m – mass of an electr

V – voltage applied to deflection plates for deflecting the beam by fixed distance x

Y – displacement of the spot

t – separation between the deflecting plates

p – length of deflecting plates

l - distance between the end of deflecting plates and screen

B – magnetic induction

B_0 – horizontal component of earth's magnetic field

T – Time period of oscillation of deflection magnetometer needle in the presence of two bar magnets.

T_0 – period of oscillation of deflection magnetometer needle in the presence of earth's magnetic field.

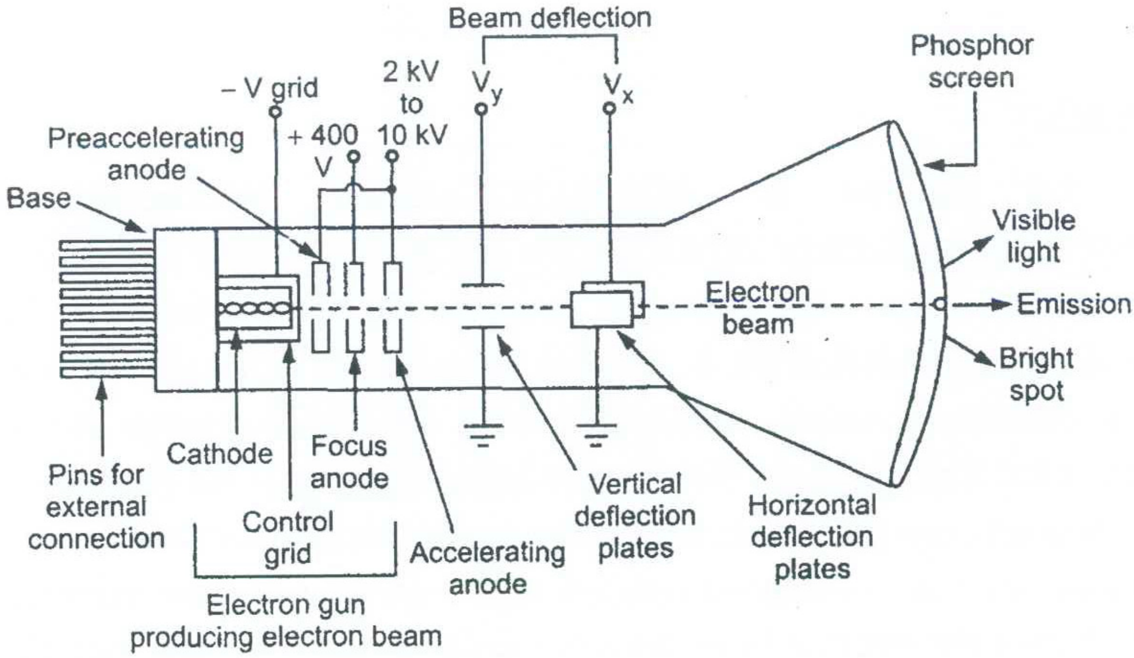
Φ – inclination of the magnetic needle to the earth's magnetic field

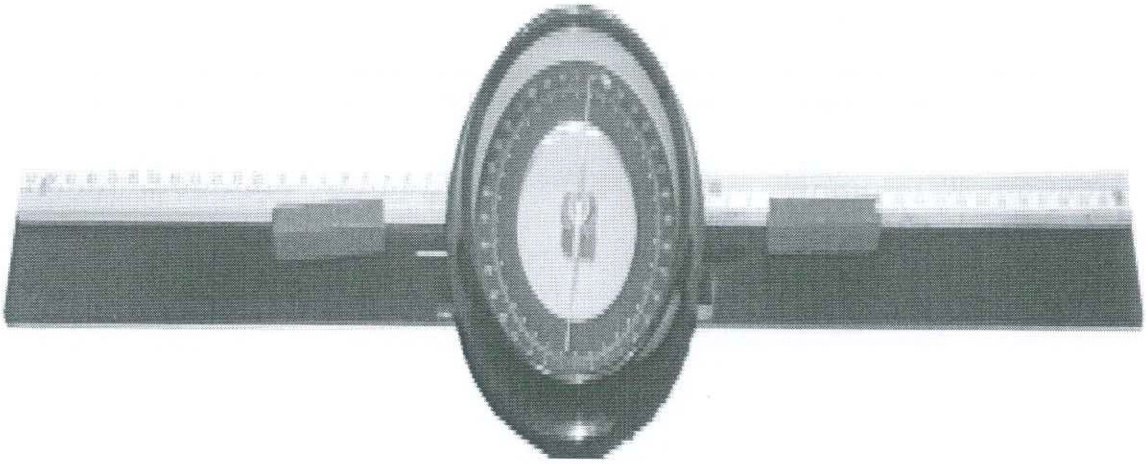
A – area under the curve plotted between x and [B (L- x)]

x - is the distance of the screen from the aperture

L – distance of electron gun exit to the screen.

Diagram :





Theory:

An electron is deflected in electric and magnetic fields. However the deflection depends upon charge ‘e’, mass ‘m’ and velocity ‘v’ of the electron. By arranging crossed electric and magnetic fields, the electrostatic deflection is counter balanced by magnetic deflection. This condition enables one to determine the specific charge to mass ratio ‘e/m’.The magnetic field is produced using two bar magnets. The bar magnets are placed perpendicular to the earths magnetic field. The cathode ray tube is aligned parallel to the earths magnetic meridian in which case the electron beam travels parallel to the magnetic meridian.

A charged particle moving in a magnetic field experiences a force known as the Lorentz force, which in vector notation is given by

$F = q(v \times B)$ ....(1)

where q is the charge on the particle,

v is the vector velocity,

B is the vector magnetic field.

This vector cross product equation is a shorthand way of saying the following:

(a)The force is perpendicular to both the velocity of the particle v and the direction of the magnetic field B. The direction of the force on a positive charge is given by a right-hand rule: F is in the direction of your thumb if the fingers of your right hand curl from v to B through the smaller angle. F is into the page in the sketch below if the charge is positive and out of the page if the charge is negative.

(b) The magnitude of the force varies as the sine of the angle, θ, between the direction of motion and the direction of the field. (c) The magnitude of the force is proportional to q, v, and B. Hence, $F = qvB \sin\theta$ ....(2)

In measuring the charge to mass ratio e/me in this experiment, the apparatus is arranged so that the force will be perpendicular to v and B. Then the charged particle will move in a curved path in a plane perpendicular to B. The velocity will change direction but not magnitude. In this case $\theta = 90°$ and from Equation (2)

$$F = qvB \quad \text{.............................(3)}$$

Recall from mechanics that a mass which experiences a constant force perpendicular to its velocity will move in a circle such that the force is directed toward its center.

From Newton's Second Law for uniform circular motion

$$F_{radial} \sum = mv\ 2\ R \quad \text{.................... (4)}$$

where R is the radius of the circular motion.

In the situation where the only net force is the Lorentz force given by Equation (3), $qvB = mv\ 2\ R$ .... (5)

This expression can be simplified to give the charge to mass ratio as

$$q\ m = v\ RB \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

In the case of the electron, q = e and m = mass of the electron

Procedure :

1.Fix the wooden frame and bench together . Place the deflection magnetometer on the bench such that 90^0 - 90^0 diameter of its circular scale is parallel to the straight line which lies along the central line parallel to the length of the bench. Orient the whole combination to a position so that aluminum pointer coincides with 0^0 - 0^0 marks. This position is the position of the magnetic meridian and should remain undistributed throughout the experiment.

2. Place the CRT in place of the bench and switch on the power supply. Focus the spot and adjust the intensity. Note down the position of the spot.

3. Place two bar magnets on the wooden frame , equidistance from CRT axis and with their length perpendicular to it, with unlike poles towards the tube. By doing this , magnetic field is set and electrons are subjected to a magnetic field perpendicular to their path. So the luminous spot is shifted along y axis. Adjust the distance of the bar magnets to get sufficient deflection of the spot. Note down the position of the spot. Calculate the spot displacement y.

4. Nullify the deflection of the spot with an electric field between Y plates . This is achieved by applying potential difference across the pair with the help of deflection knob. Then bring the spot to original place and note down the potential difference required for it. After applying potential difference, if the deflection of the spot increases then the reverse position of the switch should be used.

5. Switch off the power supply after ensuring that all the control knobs are at zero setting.

6. Replace the CRT by the wooden bench , place the deflection magnetometer on the bench with 90^0 - 90^0 of it coinciding with the line along which electrons were traveling when CRT was in it position, 0^0 - 0^0 diameter of the magnetometer should coincide with the first line on the graph paper which corresponds to the center.

7. Set the magnetometer needle in the oscillation by bringing the third magnet near the magnetometer and withdrawing it. Note the time for 5 oscillations with the help of stop watch for two times to minimize the personal error. Now note the angle made by the needle to earth's magnetic field when it is at rest.

8. Repeat the above procedure after changing the position of the deflection magnetometer such that the 0^0 - 0^0 diameter of it coincides with second line on the graph paper which represents the distance of the screen from the aperture.

9. Now note the time taken for 3-5 oscillations in the presence of earths magnetic field which is T_0 .

Observation Table:

Table 1

Original position of the spot	……………………………..(cm)
Displaced Position of the spot	……………………………(cm)
Displacement of the spot	……………………………(cm)
Voltage required to bring the spot back	…………………………(V)

Table 2

Sr. No.	X (m)	Φ			Time for n oscillations/ Number of oscillations (sec)			Time period T = t/n	B (wb/m^2)	(L- x) (m)	[B(L- x)] (wb/m)
		Φ_1	Φ_2	Φ_m	t_1	t_2	t_m				
1.	0										
2.	2										
3.	4										
4.	6										
5.	8										
6.	10										
7.	12										

Calculations:

Result: The charge to mass ratio (e/m) for an electron is found to be______.

Standard value = 1.74 C/kg

Percentage error=………………… %

Precautions :

- While determining the magnetic meridian , no magnetic material should be kept nearby.
- The wooden bench should remain in the magnetic meridian throughout the experiment the experiment.
- Stop watch readings be taken accurately.

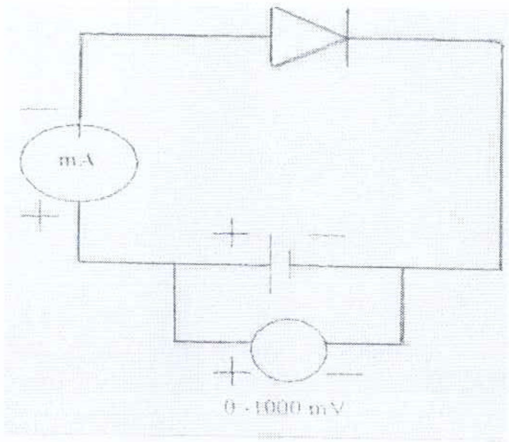
Instruction Manual

To plot the V-I characteristics of a P-N junction diode and to find the cut in voltage.

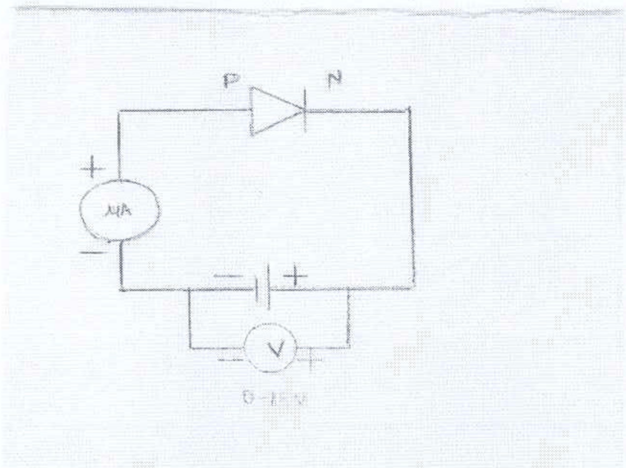
Aim: To plot the V-I characteristics of a P-N junction diode and to find the cut in voltage

Apparatus: Diode, Voltmeter, milliammeter, patch cords, microammeter, millivoltmeter etc.

Circuit diagram:



Circuit diagram for forward bias



Circuit diagram for reverse bias

Theory

- A PN-junction is formed when an N-type material is fused together with a P-type material creating a semiconductor diode.
- When the N-type semiconductor and P-type semiconductor materials are first joined together a very large density gradient exists between both sides of the PN junction.
- The result is that some of the free electrons from the donor impurity atoms begin to migrate across this newly formed junction to fill up the holes in the P-type material producing negative ions.
- This process continues back and forth until the number of electrons which have crossed the junction have a large enough electrical charge to repel or prevent any more charge carriers from crossing over the junction.
- Eventually a state of equilibrium (electrically neutral situation) will occur producing a "potential barrier" zone around the area of the junction as the donor atoms repel the holes and the acceptor atoms repel the electrons.
- Since no free charge carriers can rest in a position where there is a potential barrier, the regions on either side of the junction now become completely depleted of any more free carriers in comparison to the N and P type materials further away from the junction. This area around the **PN Junction** is now called the **Depletion Layer**.
- A suitable positive voltage (forward bias) applied between the two ends of the PN junction can supply the free electrons and holes with the extra energy. The external voltage required to overcome this potential barrier that now exists is very much dependent upon the type of semiconductor material used and its actual temperature. Typically, at room temperature the voltage across the depletion layer for silicon is about 0.6 – 0.7 volts and for germanium is about 0.3 – 0.35 volts.
- There are two operating regions and three possible "biasing" conditions for the standard **Junction Diode** and these are:

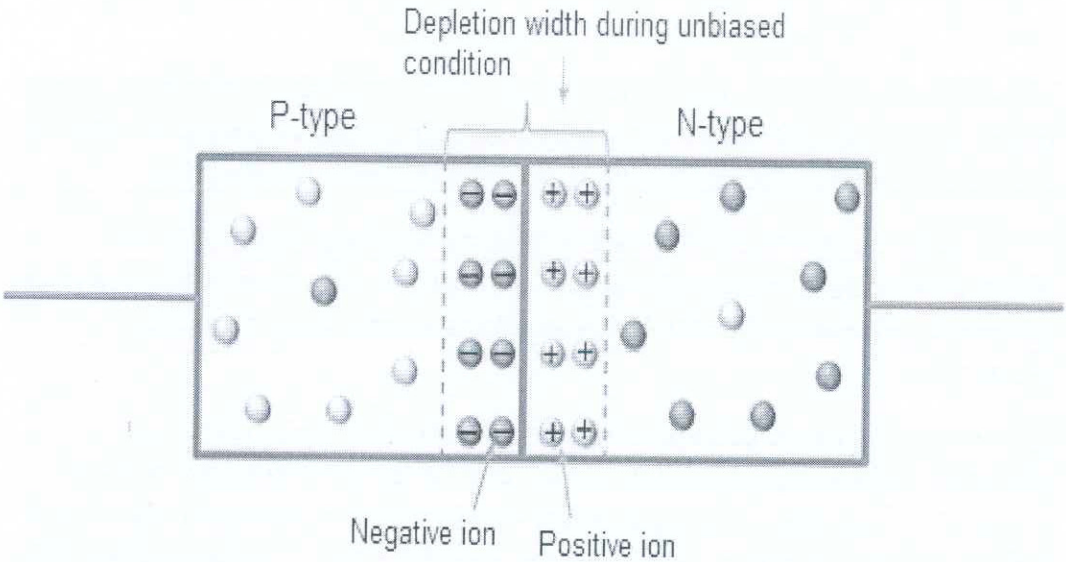
  1) Zero Bias – No external voltage potential is applied to the PN junction diode.

  2) Forward Bias

  3)Reverse Bias

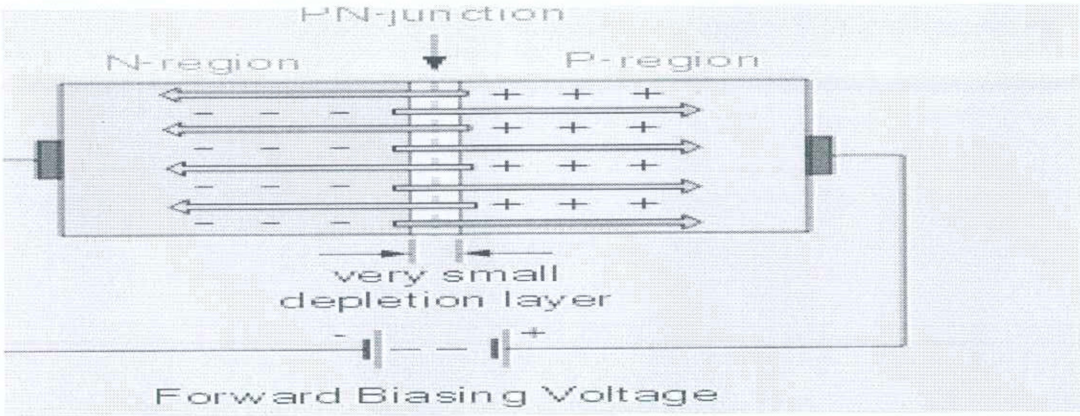
Zero Biased Condition

- In this case, no external voltage is applied to the P-N junction diode; and therefore, the electrons diffuse to the P-side and simultaneously holes diffuse towards the N-side through the junction, and then combine with each other.
- Due to this an electric field is generated by these charge carriers. The electric field opposes further diffusion of charged carriers so that there is no movement in the middle region. This region is known as depletion width or space charge.



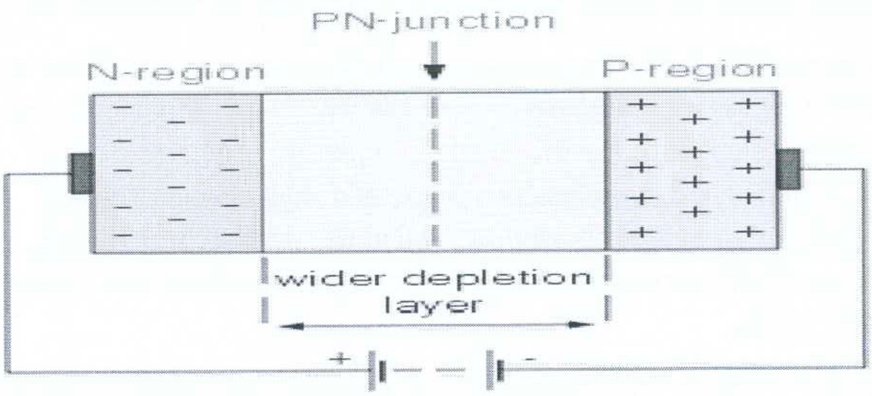
Forward Bias

- In the forward bias condition, the negative terminal of the battery is connected to the N-type material and the positive terminal of battery is connected to the P-Type material. This connection is also called as giving positive voltage.
- Electrons from the N-region cross the junction and enters the P-region. Due to the attractive force that is generated in the P-region the electrons are attracted and move towards the positive terminal.
- Simultaneously the holes are attracted to the negative terminal of the battery. By the movement of electrons and holes current flows. In this condition, the width of the depletion region decreases due to the reduction in the number of positive and negative ions.

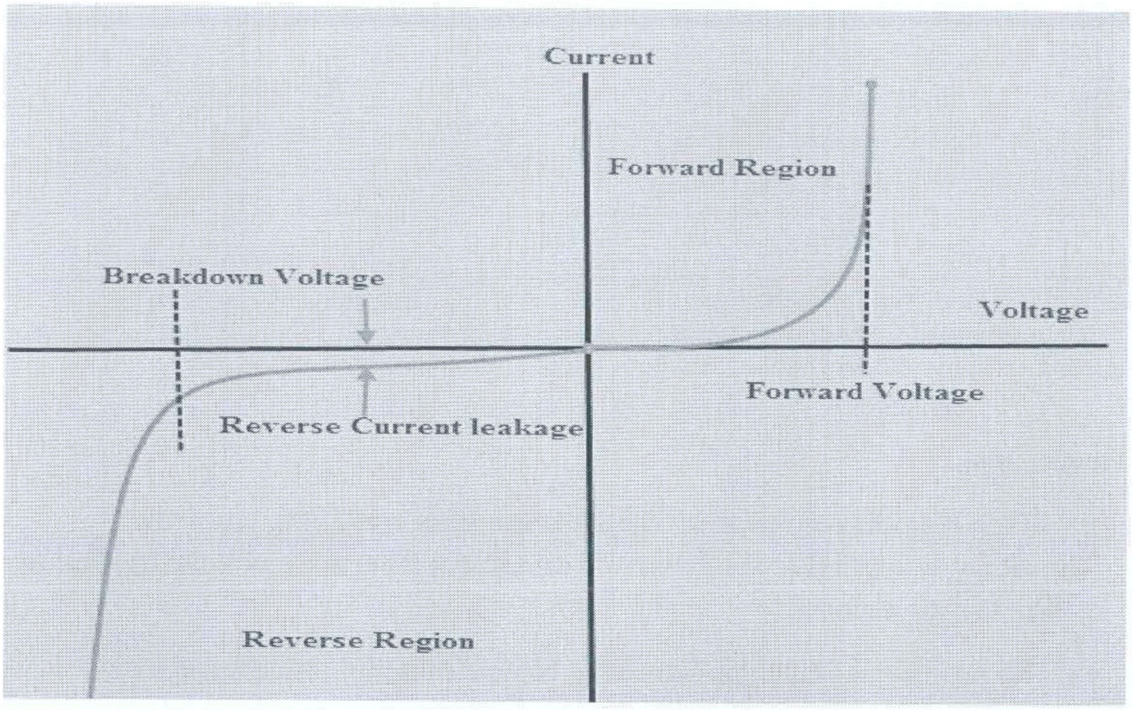


Reverse bias

- When a diode is connected in a **Reverse Bias** condition, a positive voltage is applied to the N-type material and a negative voltage applied to the P-type material.
- The positive voltage applied to the N-type material attracts electrons towards the positive electrode and away from the junction, while the holes in the P-type end are also attracted away from the junction towards the negative electrode.
- The net result is that the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path, almost an insulator and a high potential barrier is created across the junction thus preventing current from flowing through the semiconductor material.



V-I Characteristics of P-N junction Diode



The axes of the graph show both positive and negative values and so intersect at the center. The intersection has a value of zero for both current (the Y axis) and voltage (the X axis). The axes +I and +V (top right) show the current rising steeply after an initial zero current area. This is the forward conduction of the diode when the anode is positive and cathode negative. Initially no current flows until the applied voltage is at about the forward junction potential, after which current rises steeply showing that the forward resistance (I/V) of the diode is very low; a small increase in voltage giving a large increase in current.

The -V and -I axes show the reverse biased condition (bottom left). Here we see that although the voltage increases hardly any current flows. This small current is called the leakage current of the diode and is typically only a few micro-amps with germanium diodes and even less in silicon. If a high enough reverse voltage is applied however there is a point (called the reverse breakdown voltage) where the insulation of the depletion layer breaks down and a very high current suddenly flows.

In most diodes this breakdown is permanent and a diode subjected to this high reverse voltage will be destroyed. In Zener diodes however, this point is used to give the diode its special ability to stabilize the applied voltage: If the voltage increases at this point heavy current flows and reduces the voltage. The breakdown in a Zener diode is not destructive due to its special construction.

Procedure:

A. For forward bias

1. Connect the P-N Junction diode in forward bias.
2. In the forward bias mode Anode is connected to positive of the power supply and cathode is connected to the negative of the power supply.
3. For various values of forward voltage note down the corresponding values of the forward current.

B. Reverse bias

1. Connect the P-N junction diode in the reverse bias mode
2. In the reverse bias mode, the anode is connected to the negative of the power supply and the cathode is connected to the positive of the power supply.
3. For various values of reverse voltage note down the corresponding values of reverse current.

Observation table:

1) Forward Characteristics

S.No	Voltage (mV)	Current (mA)

2) Reverse Characteristics

S.No	Voltage (V)	Current (μA)

Result:

1)The VI characteristics of PN junction diode in Forward Bias is verified.

2 The VI characteristics of PN junction diode in Reverse Bias is verified.

3) The cut in voltage is found..........................

Precautions:

1. While doing the experiment do not exceed the ratings of the diode. This may lead to damage of the diode.

2. Connect voltmeter and milliammeter in correct polarities as shown in the circuit

diagram.

3. Do not switch ON the power supply unless you have checked the circuit connections as per the circuit diagram.

Instruction Manual

To determine the energy band gap of a semi-conductor

Aim: To determine the energy band gap of a semi-conductor

Apparatus: P-N Junction diode, water bath, DC supply, thermometer, microammeter (0-500 μA)

Formula: $\mathbf{Is = Ie^{-Eg/kT}}$

$\mathbf{E_g}$ = **1**000.m.k

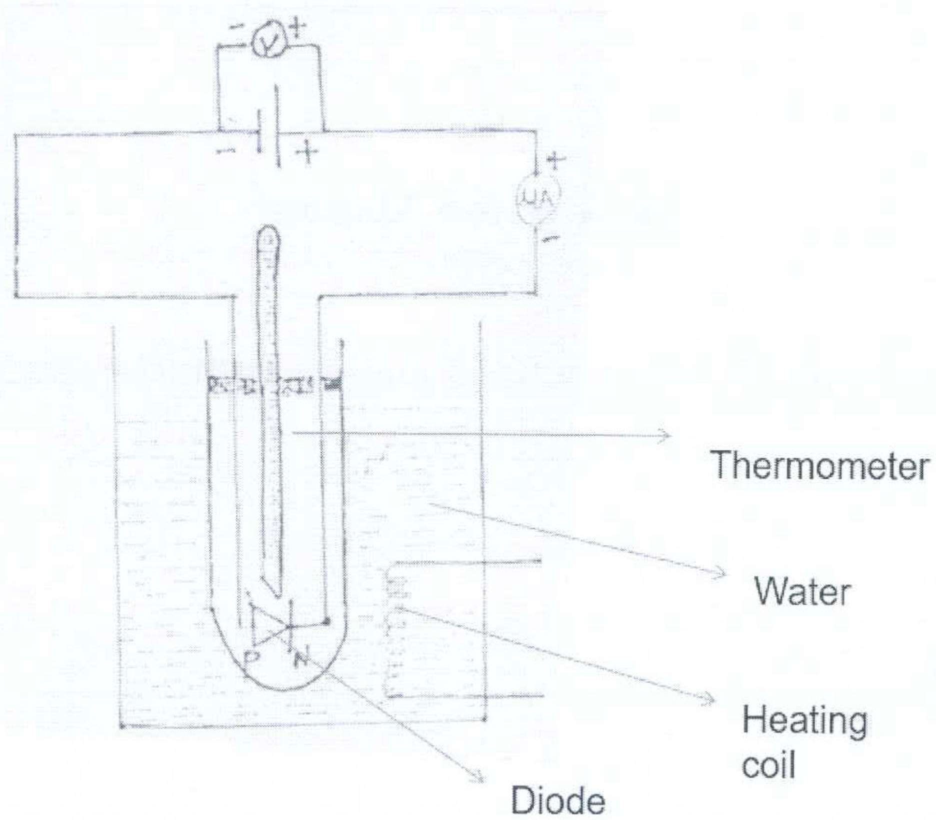
where

E_g is the energy band gap

m is the slope

k is the Boltzmann constant (8.675 X 10^{-5} ev)

Circuit Diagram



Theory

Valence band is the range in energy graph where all the **valence** electrons reside; whereas, **conduction band** is the range of energy contained by all the free electrons. The gap between those **bands** is known as forbidden energy gap.

Bands for Doped Semiconductors

The application of band theory to n-type and p-type semiconductors shows that extra levels have been added by the impurities. In n-type material there are electron energy levels near the top of the band gap so that they can be easily excited into the conduction band. In p-type material, extra holes in the band gap allow excitation of valence band electrons, leaving mobile holes in the valence band.

The energy gap, i.e., the gap between valance band and conduction band decides the conductivity of a material. The typical energy gaps of the semiconductors which are in the range 1 eV to 3 eV impart many useful properties to the semiconductors. The ability of the semiconductors to conduct due to electrons as well as holes.

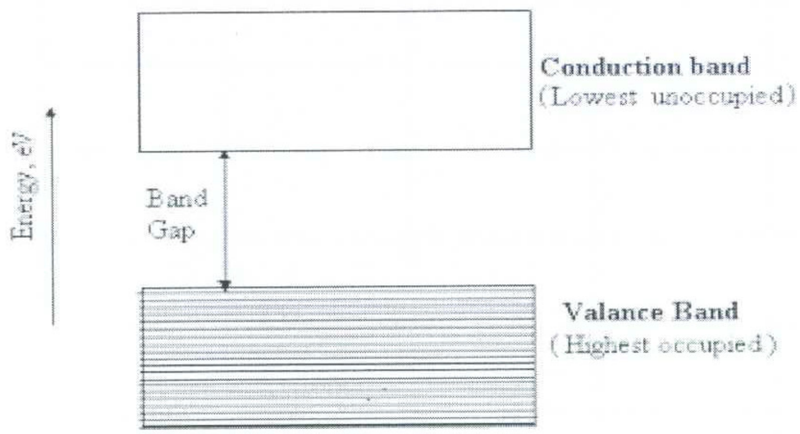


Figure 7.1: Concept of energy gap

Procedure:

- The Make connections as shown in the circuit diagram

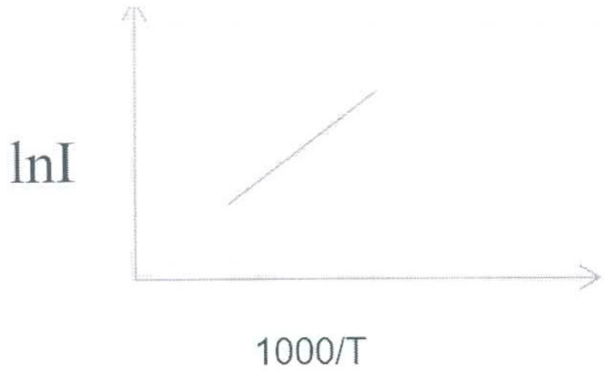
- First take room temperature reading and then start the heater.
- Raise the temperature to about 70^0 C. The bulb of the thermometer should be in contact with diode so that it records the accurate temperature.
- Switch off the heater when the temperature reaches 70^0 C.
- Apply 6V to the diode.
- While cooling, note the readings of the temperature and current with a step of 5 □C till the temperature falls down to 40 □C.
- Plot the graph between lnI along Y axis and 1000/T along X axis.

Observation Table

V= 6V

Sr. No.	T ^{0}C	T ^{0}K	I(μA)	lnI	1000/T
1	75				
2	70				
3	65				
4	60				
5	55				
6	45				
7	40				

Nature of graph



Calculations:

E_g =1000. m. k

Result: The energy band gap of p -n junction diode is found to be -------

Precautions:

1.The bulb of the thermometer should be in contact with diode.

2.The readings of the Voltmeter and milliammeter are to be taken with the heater off so that the temperature near the diode is in steady state.

Instruction Manual

To study input, output and transfer characteristics and determine value α of a given transistor in common base mode.

Aim: To study input, output and transfer characteristics and determine value **α** of a given transistor in common base mode.

Apparatus: n-p-n Transistor, regulated DC power supplies, a millivoltmeter (0-1000 mV), milliammeter (0-50 mA) connecting wires etc.

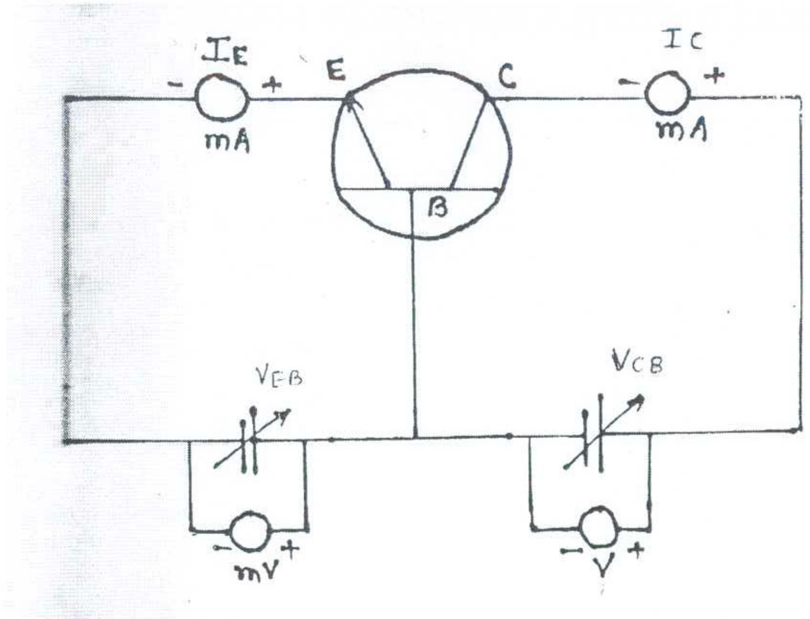
Formula:

$$\alpha = \frac{\Delta I_C}{\Delta I_E}$$ **By keeping VCB =constant**

where

αis the current amplification factor

Circuit Diagram



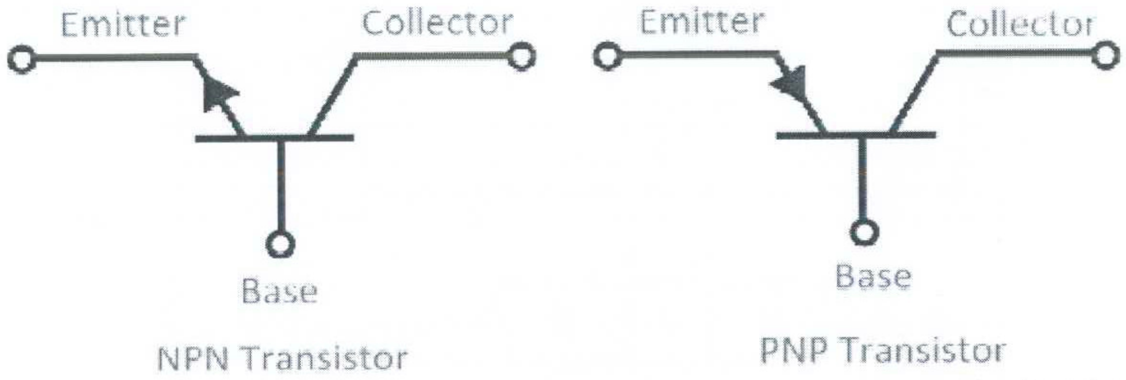
Theory

Definition: The transistor is a semiconductor device which transfers a weak signal from low resistance circuit to high resistance circuit. The words **trans** mean **transfer property** and **istor** mean **resistance property offered to the junctions.** In other words, it is a switching device which regulates and amplify the electrical signal likes voltage or current.

The transistor consists two PN diode connected back-to-back. It has three terminals namely emitter, base and collector. The base is the middle section which is made up of thin layers. The right part of the diode is called emitter diode and the left part is called collector-base diode. These names are given as per the common terminal of the transistor. The emitter-based junction of the transistor is connected to forward biased and the collector-base junction is connected in reverse bias which offers a high resistance.

Transistor Symbols

There are two types of transistors, namely NPN transistor and PNP transistor. The transistor which has two blocks of n type semiconductor material and one block of P-type semiconductor material is known as NPN transistor. Similarly, if the material has one layer of N-type material and two layers of P-type material then it is called PNP transistor. The symbol of NPN and PNP is shown in the figure below.



Doping means addition of impurity (called dopant) into a pure semiconductor (intrinsic semiconductor) in order to improve the semiconductor's electrical properties (hence it becomes impure semiconductor or extrinsic semiconductor)

- If the impurity added (dopant) is from 3rd group of periodic table we get p-type extrinsic semiconductor
- If the impurity added (dopant) is from 5th group of periodic tables we get n-type extrinsic semiconductor

We know that generally the transistor has three terminals – emitter (E), base (B) and collector. But in the circuit connections we need four terminals, two terminals for input and another two terminals for output. To overcome these problems, we use one terminal as common for both input and output actions.

Using this property, we construct the circuits and these structures are called transistor configurations. Generally, there are three different configurations of transistors and they are common base (CB) configuration, common collector (CC) configuration and common emitter (CE) configuration.

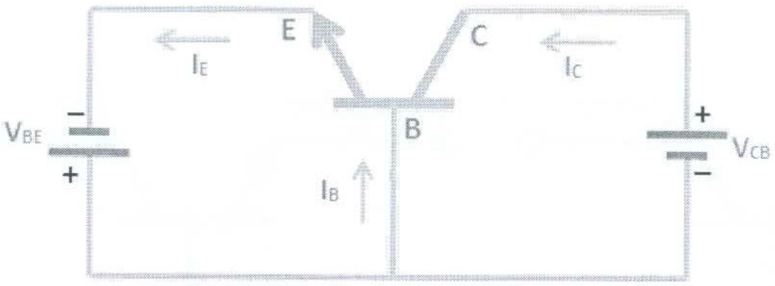
The behavior of these three different configurations of transistors with respect to gain is given below.

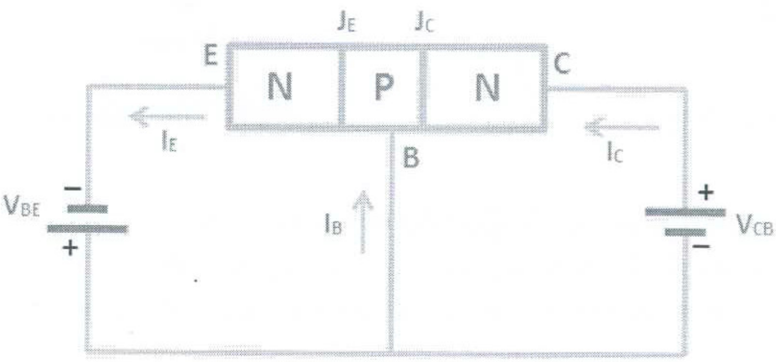
Common Base (CB) Configuration: no current gain but voltage gain

Common Collector (CC) Configuration: current gain but no voltage gain

Common Emitter (CE) Configuration: current gain and voltage gain

Working of transistor: The emitter base junction of transistor is forward bias whereas collector base is reverse bias.





Same biasing different mA position

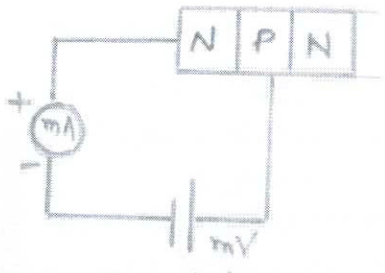


Fig 2(a)

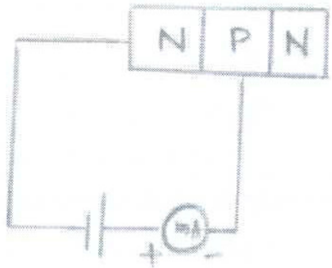


Fig (2b)

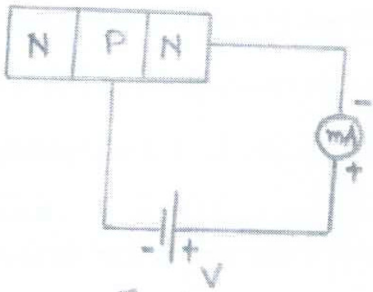


Fig 3

The function of emitter is to supply majority carriers to the base. Under which bias condition can that happen? It happens under forward bias.

Rule no 1: - Input junction or the emitter base junction is always forward biased.

We want the carriers in the base to reach the collector. Under which condition does that happen? It happens in reverse bias. Reverse bias prohibits majority charge carriers from crossing to the other side, but due to in built electric field it pulls the minority carriers on the other side

In a normal p-n junction current is in microamperes in reverse bias. In a transistor majority charge carriers are sent into base in large number. Although some of them recombine with holes in p-type base, the base is made thin tominimize recombination and so the large number of minority carriers which are injected by emitter' go over to the collector. So, the current is in mA not in microamps.

The proportion of electrons able to cross the base and reach the collector is a measure of the BJT efficiency. The heavy doping of the emitter region and light doping of the base region causes many more electrons to be injected from the emitter into the base than holes to be injected from the base into the emitter.

The common-base current gain is approximately the gain of current from emitter to collector in the forward-active region. This ratio usually has a value close to unity; between 0.98 and 0.998. It is less than unity due to recombination of charge carriers as they cross the base region. Alpha and beta are more precisely related by the following identities (NPN transistor).

Procedure:

A) for input and Transfer characteristics

1. Make the connection as shown in the circuit diagram.
2. Keep V_{CB} constant at different values such as 1V, 6V and 12V.
3. In the above conditions note I_C and I_E for increasing values of V_{BE}.
4. Plot a graph between I_E and V_{BE} and I_C vs I_E. From the graph of transfer characteristics (I_C vs I_E) the amplification factor α can be determined.

B) for the output characteristics

1. keep I_E constant at different values andvary V_{CB} and note the collector current.
2. Plot a graph between I_C vs V_{CB}.

Observation table for Input characteristics:

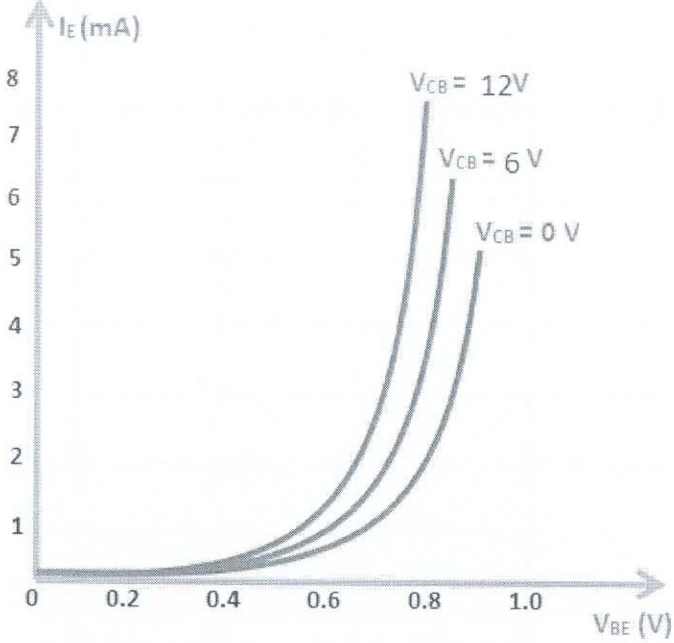
S.No.	V_{BE} (mv)	V_{CB} =1V		V_{CB} =6V		V_{CB} =12V	
		I_E(mA)	I_C(mA)	I_E(mA)	I_C(mA)	I_E(mA)	I_C(mA)
1.							
2.							
3.							
4.							
5.							
6.							
7							
8							

Observation table for output characteristics

S.No.	V_{CB} (V)	I_E =4mA $I_{C(mA)}$	I_E =8mA $I_{C(mA)}$	I_E =12mA $I_{C(mA)}$
1.				
2.				
3.				
4.				
5.				

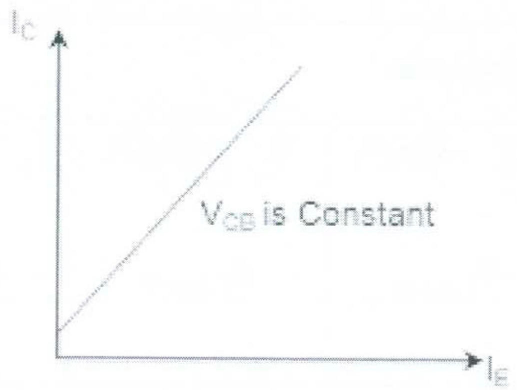
Nature of graph

Input characteristics

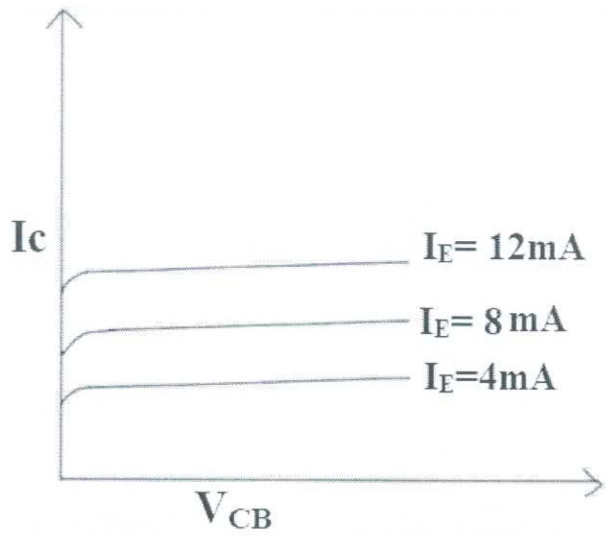


I/p characteristics CB configuration

Transfer characteristics



Output characteristics



Result:

The input, output and transfer characteristics of a transistor in common base mode have been studied and the value of α is found to be ....

Precautions:

1. All the connections should be tight.
2. All the voltage and current limit should be observed carefully.

Instruction Manual

To determine the radius of curvature of a Plano convex lens using Newton's Rings method

Aim: To determine the radius of curvature of a Plano convex lens using Newton's Rings method

Apparatus: Sodium vapour lamp, Plano convex lens, glass plate, travelling microscope etc.

Formula: $$R = \frac{D^2_{m+p} - D^2_{m}}{4p\,\lambda}$$

By graph R= Slope/4λ

where

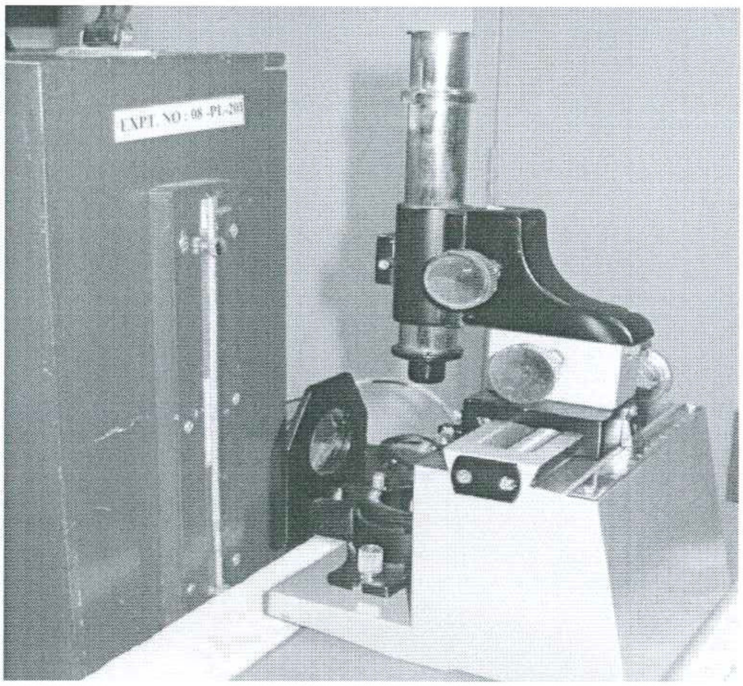
λ is the wavelength of the light used.

D_{m}, D_{m+p} are the diameters of m and (m+p) th dark rings respectively.

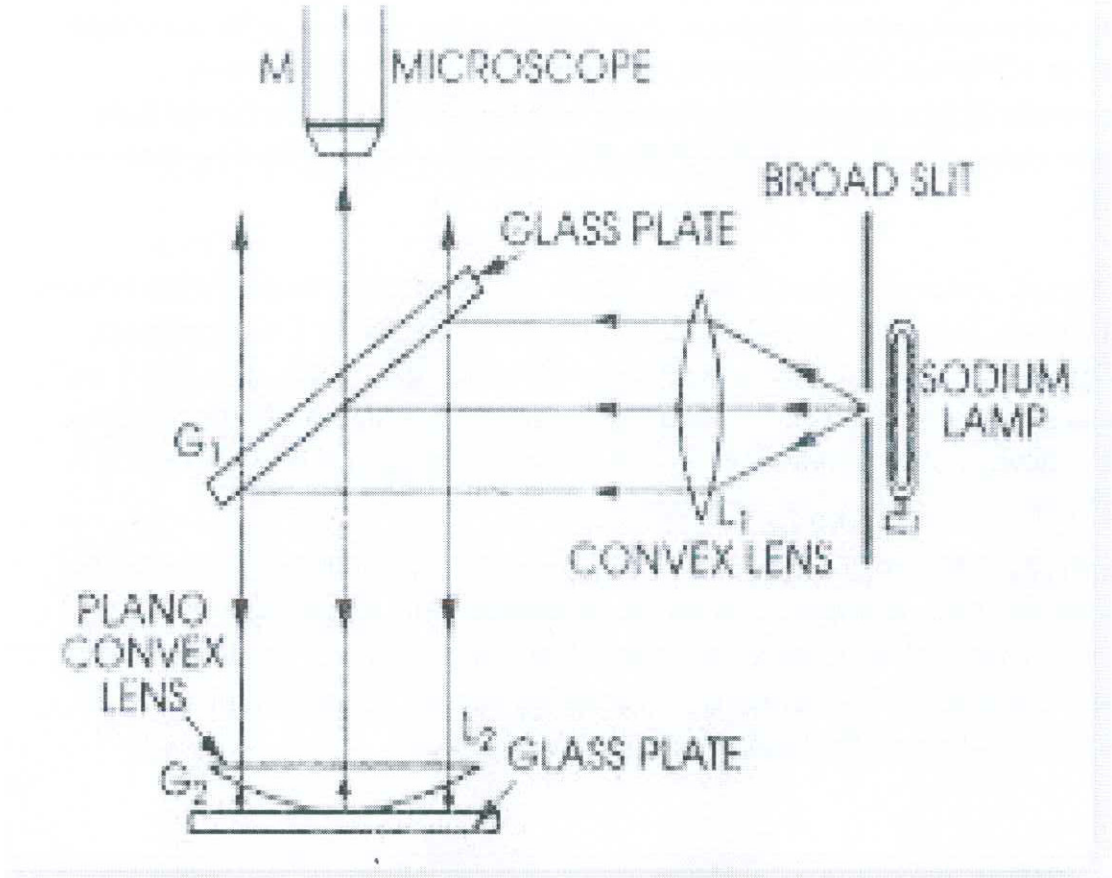
p is an integer (n= 2 or n=4or n=6 or n=8)

R is the radius of curvature of the Plano convex lens.

Experimental set up



Ray Diagram



Theory

Interference

Interference is the phenomenon of superimposition of two or more waves having same frequency emitted by coherent sources such that amplitude of resultant wave is equal to the sum of the amplitude of the individual waves. The amplitude of resultant wave can either be larger or smaller than of individual waves depending on whether the interference is constructive or destructive

Conditions for interference.

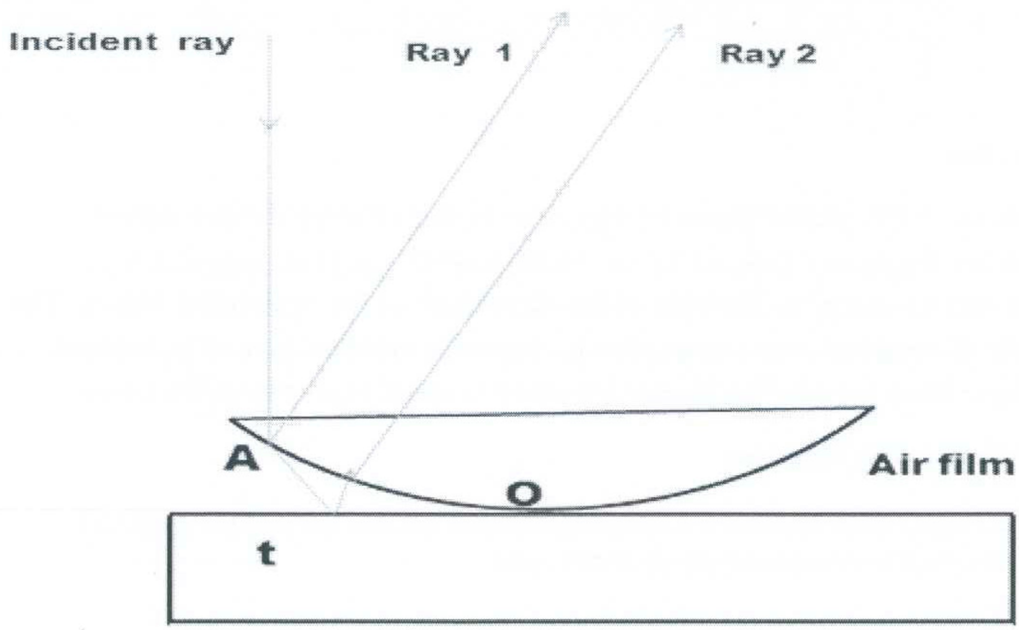
- The light sources must be coherent, which means they emit identical waves with a constant phase difference.
- The light should be monochromatic - they should be of a single wavelength.

How rings are Formed

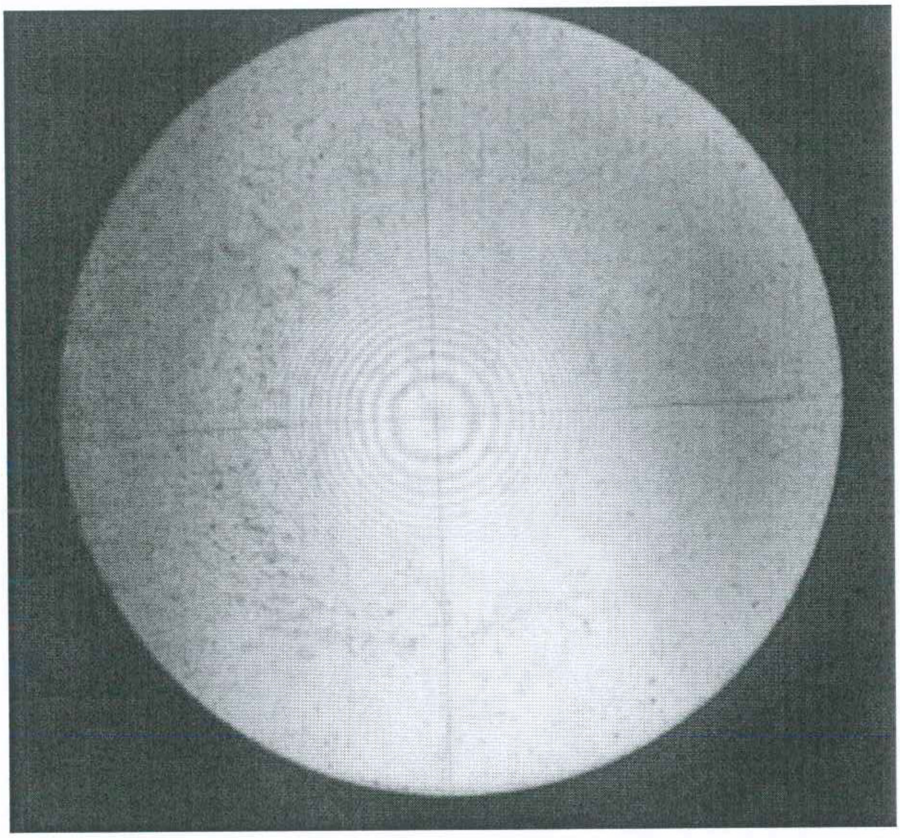
A thin air film is formed between the plate and the lens. The thickness of the air film varies from zero at the point of contact to some value t. If the lens plate system is illuminated with monochromatic light falling on it normally, concentric bright and dark interference rings are observed in reflected light. These circular fringes were discovered by Newton and are called Newton's rings.

A ray AB incident normally on the system gets partially reflected at the bottom curved surface of the lens (Ray 1) and part of the transmitted ray is partially reflected (Ray 2) from the top surface of the plane glass plate. The rays 1 and 2 are derived from the same incident ray by division of amplitude and therefore are coherent. Ray 2 undergoes a phase change of p upon reflection since it is reflected from air-to-glass boundary.

Central dark spot: At the point of contact of the lens with the glass plate the thickness of the air film is very small compared to the wavelength of light therefore the path difference introduced between the interfering waves is zero. Consequently, the interfering waves at the center are opposite in phase and interfere destructively. Thus, a dark spot is produced.



Circular fringes of equal thickness: Each maximum or minimum is a locus of constant film thickness. Since the locus of points having the same thickness fall on a circle having its centre at the point of contact, the fringes are circular.



Newton's rings pattern

Procedure:

- Adjust the travelling microscope so as to get circular fringes. The point of intersection of cross wires coincides with the centre of ring system.
- Designate the innermost and clearly seen ring as the first dark ring. Move the microscope to the left and make the vertical crosswire of it coincide with the 20th ring. Record the main scale and vernier scale reading of the microscope.
- Move the crosswire slowly such that the cross wire shifts on left hand side 18th, 16th, 14th etc. upto the 2nd ring, and every time taking the reading of the microscope.
- Then move the crosswire on right side of the central dark spot and coincide the crosswire with the 2nd ring on the right-hand side. Similarly repeat the same procedure for 4th, 6th, 8th …., upto the 20th dark ring, each time recording the reading of the microscope.

- Tabulate the reading in the given format.

Observation Table

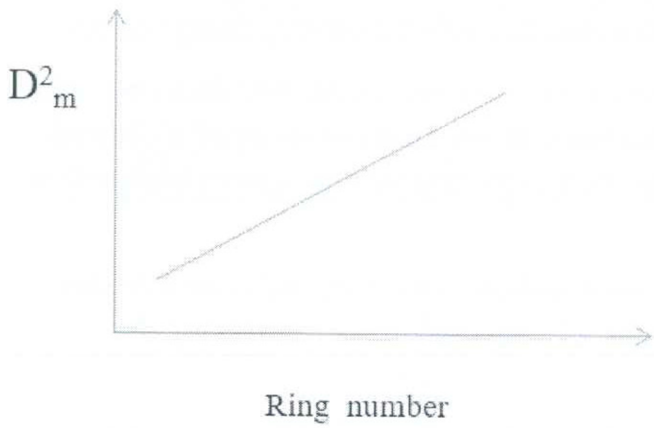
Least count of Traveling Microscope = mm

Ring No.	LH.S			RH.S			D_m	D_m^2	$D_{m+p}^2 - D_m^2$
	M.S.R	V.S.R	T.R	M.S.R	V.S.R	T.R			
20									
18									
16									
14									
.12									
.10									
8									
6									
4									
2									

Calculations: $$R = \frac{D^2_{m+p} - D^2_m}{4p\lambda}$$

By graph R=Slope/4λ

Plot a graph between number of rings along the x-axis and D^2_m along **the y-axis.**



Result: The radius of curvature of Plano convex lens is found to be……….

Graphically the value of radius of curvature of Plano Convex lens is------

Precautions:

1. Clear and distinct fringe pattern should be obtained.
2. Readings of main scale and vernier scale should be taken accurately
3. While taking readings the travelling microscope should be moved towards one side only so as to avoid back lash error

Instruction Manual

To determine wavelength of sodium light by using plane transmission grating.

Aim: To determine wavelength of sodium light by using plane transmission grating.

Apparatus: Sodium vapour lamp, grating, spectrometer, reading lens etc.

Formula: $(a+b)\sin\theta = n\lambda$

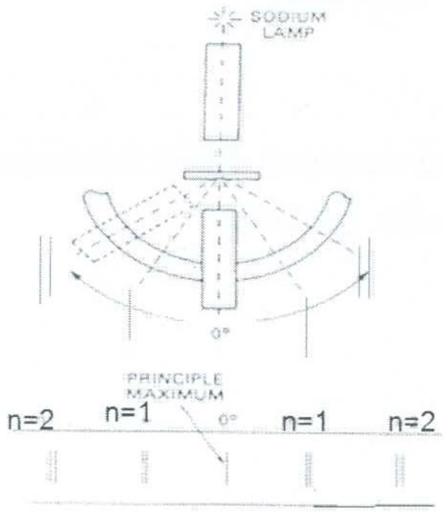
where $(a+b)$ is the grating element

θ is angle of diffraction

n is the order of diffraction

λ is the wavelength of sodium vapour lamp

Diagram:



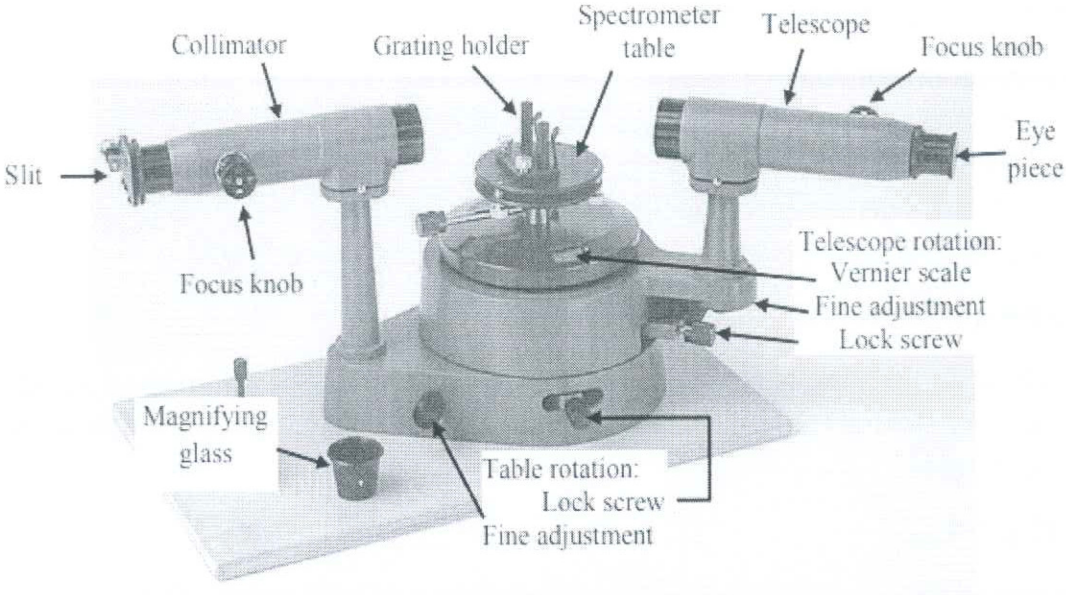


Fig. 2: Spectrometer and its components.

Theory:

The bending and spreading of light waves around sharp edges or corner or through small openings is called Diffraction of Light.

Diffraction effect depends upon the size of obstacle. Diffraction of light takes place if the size of obstacle is comparable to the wavelength of light.

Light waves are very small in wavelength, i.e. from 4 x 10-7 m to 7 x 10-7 m. If the size of opening or obstacle is near to this limit, only then we can observe the phenomenon of diffraction.

TYPES OF DIFFRACTION

Diffraction of light can be divided into two classes:

1)Fraunhofer diffraction.

2) Fresnel diffraction.

FRAUNHOFFER DIFFRACTION

In Fraunhoferdiffraction, Source and the screen are far away from each other.

Incident wave fronts on the diffracting obstacle are plane.
Diffracting obstacle give rise to wave fronts which are also plane.
Plane diffracting wave fronts are converged by means of a convex lens to produce diffraction pattern.

FRESNEL DIFFRACTION

In Fresnel diffraction,
Source and screen are not far away from each other.
Incident wave fronts are spherical.
Wave fronts leaving the obstacles are also spherical.
Convex lens is not needed to converge the spherical wave fronts

DIFFRACTION GRATING

A diffraction grating is an optical device consists of a glass or polished metal surface over which thousands of fine, equidistant, closely spaced parallel lines are been ruled.

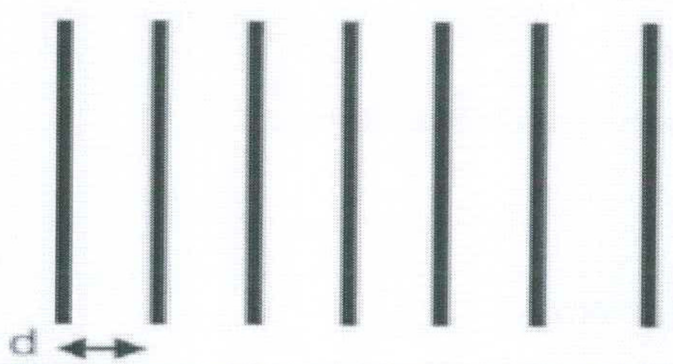
PRINCIPLE

Its working principle is based on the phenomenon of diffraction. The space between lines act as slits and these slits diffract the light waves there by producing a large number of beams which interfere in such away to produce spectra.

GRATING ELEMENT

Distance between two consecutive slits(lines) of a grating is called grating element. If 'a' is the separation between two slits and 'b' is the width of a slit, then grating element 'd' is given by;

d = a + b



Procedure:

For normal incidence

1. The spectrometer is adjusted for parallel rays
2. The width of the slit is properly adjusted and the image of the slit is obtained on the vertical crosswire. The telescope is locked in this position. The prism table is rotated and reading from the one of the windows is made exactly 0□ (360□). The reading in another window is 180□. The table is locked.
3. The telescope is now unlocked and rotated through 90□ and then fixed.
4. The grating is now mounted on the prism table and it is adjusted such that the reflected image of the slit coincides with the vertical crosswire.
5. The prism table is then rotated through 45□ in such a way that the light falls normally on the grating. The prism table is fixed in this position

For the angle of diffraction

1. The telescope is unlocked. It is brought in line with the collimator. The 0^{th} order image is observed.
2. The telescope is rotated so as to receive 2^{nd} order image on the L.H.S in the field of view. Readings on both the sides of the windows are noted.
3. Then the telescope is rotated and the 1^{st} order image is made coincident with the vertical crosswire. Reading is noted from both the windows.
4. The same procedure is repeated for the 1^{st} and 2^{nd} order on R.H.S.

Observation table:

Least count of spectrometer=

For direct reading

S.No.	W1			W2		
	MSR	VSR	TR	MSR	VSR	TR

For angle of diffraction

Order	LHS						RHS						2θ		θ
	W1			W2			W1			W1			W1	W2	
	M	V	T	M	V	T	M	V	T	M	V	T			
n=1															
n=2 Y1															
n=2 Y2															

Calculations:

$$(a+b)\sin\theta = n\lambda$$

Results: The wavelength of sodium light are tabulated below

Color	Wavelength		Std Value
	1st order	2nd order	
Yellow 1			5890 A°
Yellow 2			5896 A°

Precaution:

1. Prism table should be properly leveled.
2. Grating should be handled properly.
3. Prism table should not be disturbed throughout the experiment after adjusting the grating for normal incidence.