SYLLABUS (BT-201)

ENGINEERING PHYSICS

UNIT 1:

Module 1: Wave nature of particles and the Schrodinger equation (8 lectures) Introduction to Quantum mechanics, Wave nature of Particles, operators ,Time-dependent and timeindependent Schrodinger equation for wavefunction, Application: Particle in a One dimensional Box, Born interpretation, Free-particle wavefunction and wave-packets, vg and vp relation Uncertainty principle.

UNIT 2:

Module 2: Wave optics (8 lectures) Huygens' principle, superposition of waves and interference of light by wave front splitting and amplitude splitting; Young's double slit experiment, Newton's rings, Michelson interferometer, MachZehnder interferometer.

Farunhofer diffraction from a single slit and a circular aperture, the Rayleigh criterion for limit of resolution and its application to vision; Diffraction gratings and their resolving power.

UNIT 3:

Module 3: Introduction to solids (8 lectures) Free electron theory of metals, Fermi level of Intrinsic and extrinsic, density of states, Bloch's theorem for particles in a periodic potential, Kronig-Penney model(no derivation) and origin of energy bands. V-I characteristics of PN junction, Zener diode, Solar Cell, Hall Effec .

UNIT 4:

Module 4: Lasers (8 lectures) Einstein's theory of matter radiation interaction and A and B coefficients; amplification of light by population inversion, different types of lasers: gas lasers (He-Ne, CO_2), solid-state lasers(ruby, Neodymium),Properties of laser beams: mono-chromaticity, coherence, directionality and brightness, laser speckles, applications of lasers in science, engineering and medicine. Introduction to Optical fiber, acceptance angle and cone, Numerical aperture, V number, attenuation.

UNIT 5:

Module 5: Electrostatics in vacuum (8 lectures) Calculation of electric field and electrostatic potential for a charge distribution; Electric displacement, Basic Introduction to Dielectrics, Gradient, Divergence and curl,Stokes' theorem, Gauss Theorem, Continuity equation for current densities; Maxwell's equation in vacuum and non-conducting medium; Poynting vector.

Unit -> 1.

Quantum Mechanics.

Wave nature of Particle :- According to einsdiene the energy of light is Concentrated into Small region, this represent the Smallest quantity of energy known as Photones. is an energy Pardicle.

- The nature of light having wave nature as well as Particle nature is known as dual nature and a Property is known as Wave Particle dualidy.

De - Broglie waves :- A moving matter Particle is Surrounded by a wave whose wavelength depend upon the mass are known as matter wave and de - Broglie wave

*. Wavelength Of de - Broglie Waves :- Consider a Photone whose energy is.

$$E = h\nu = \frac{hc}{\lambda} \longrightarrow h = 6.62 \times 10^{-34} \text{ J Sec.}$$

If mass of a particle is converted into an energy the energy is given by einstine mass - energy relation.

$$E = mc^2 \quad \text{—— (2)}$$

from (1) and (2)

$$mc^2 = \frac{hc}{\lambda}$$

$$\lambda = \frac{h}{mc} \qquad P = mv = mc$$

$$\boxed{\lambda = \frac{h}{P}} \text{ or } \boxed{\lambda = \frac{h}{mv}}$$

This wavelength is called De-Broglie wave length.

Different forms of De-Broglie wavelength

i) Kinetic energy.

$$E = \frac{1}{2} mv^2 = \frac{1}{2} \frac{mv^2 \times m}{m}$$

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

$$P = \sqrt{2mE}$$

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

The kinetic energy of a material of mass (m) moving with a velocity v is given as.

(2) According to kinetic theory the average kinetic energy of material particle is given by.

$$E = \frac{1}{2} mv^2 = \frac{3}{2} kT \quad \text{—— (1)}$$

$$\lambda = \frac{h}{\sqrt{2mE}} \quad \text{—— (2)}$$

from eqn (1) and (2)

$$\lambda = \frac{h}{\sqrt{2m \times \frac{3}{2} kT}} = \frac{h}{\sqrt{3mkT}}$$

Where, $k = 1.38 \times 10^{-23}$ J/K Boltzmann Constant, T = absolute temperature.

(3) Suppose an electron accelerate through a potential difference of V volt.

work done by gain in kinetic energy electric field.

$$eV = \frac{1}{2} mv^2, \; V = \frac{\omega}{q}$$

$\omega = qV \quad , \omega = eV$

Where es e is electronic charge of 1.6×10^{-19}

$$m\,2eV = mv^2 \times m$$
$$2meV = m^2 v^2$$
$$mv = \sqrt{2meV}$$

for e^-, $m = 9.1 \times 10^{-31}$ kg
$e = 1.6 \times 10^{-19}$ C
$h = 6.626 \times 10^{-34}$
$\lambda = \frac{12.27}{\sqrt{V}}$ Å

*. **Wave function and Operators :-** The wave functions is a quantity whose variation makes ups the matter waves So the Amplitude of the matter waves is discribe by wave function Consists of relation and imagenary parts.

$\Psi = A + iB$, Conjugate Ψ is

$$\Psi^* = A - iB$$

$|\Psi|^2 \rightarrow$ at a particular phase and at particular time is proportional to the B probability of finding the particle that time it is known as probability density.

$$|\Psi|^2 = \Psi \Psi^*$$

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$$\psi = Ae^{-i/\hbar (Et - Px)}$$

these is the phase equation for a pure particle.

Nessary Condition for a wave function.

- It must be Continous and Single value every where.
- $\frac{\partial\psi}{\partial x}, \frac{\partial\psi}{\partial y}, \frac{\partial\psi}{\partial z}$ must be Continous and Single value everywhere
- ψ must be normalised which means ψ must go to a as $x = \pm\infty$ in order that $y = \pm\infty$, $z = \pm\infty$

$\int|\psi|^2 dv$ must be finite Constant.

Energy and momentum Operator.

In quantum Phsics the State of the System is discribed by the wave function and the observable all represented by operator wave function Satisfy requirements for vector and Operator act on the wave function as linear transformation.

let us Partially different eqn.

$$\psi = Ae^{-\frac{i}{\hbar}(Et - Px)} \quad \text{—— (1)}$$

t we get

$$\partial\psi = \frac{-iE}{\hbar} Ae^{-i/\hbar(Et - Px)}$$

$$\frac{\partial\psi}{\partial t} = \frac{-iE}{\hbar}\psi$$

$$E\psi = i\hbar\frac{\partial\psi}{\partial t} \quad [i^2 = -1]$$

hence energy Operator

$$E = i\hbar\frac{\partial}{\partial t}$$

Now Partially diff. eq (1) wrt x we get

$$\frac{\partial\psi}{\partial x} = \frac{iP}{\hbar} Ae^{-i/\hbar(Et - Px)}$$

$$\frac{\partial\psi}{\partial x} = \frac{iP}{\hbar}\psi$$

$$P\psi = \frac{\hbar}{i}\frac{\partial\psi}{\partial x}$$

$$\left[P = \frac{\hbar}{i}\frac{\partial}{\partial x}\right] \text{ momendum Operator.}$$

A Operator tells us what operation to carry out on the quantity that follows it.

ψ is said to be eigen function of the operator $\frac{\partial}{\partial t}$ and E is the corresponding energy eigen value.

Schrodinger's wave equation :-

It is the different equation of the de-broglie wave associated with particles and discribe the motion of particles.

As total energy

$$E = KE + PE$$
$$E = \frac{p^2}{2m} + V$$

Total energy in the form of wave function ψ will be.

$$E\psi = \left[\frac{p^2}{2m}\right]\psi + V\psi \quad \text{--- (1)}$$

as we know that energy operator.

$$E = \hbar i \frac{d}{dt}$$

Momentum Operators

$$P = \frac{\hbar}{i}\frac{d}{dx}$$

By putting the value of E and P in eqn (1) we get.

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

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

This is Schrodinger's time dependent wave equation in 1D.

In 3-D

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

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

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

By putting by value of P in eqn (i) we get.

$$E\psi = \frac{-\hbar^2}{2m}\frac{\partial^2\psi}{\partial x^2} + V\psi$$

$$\frac{\hbar^2}{2m}\frac{\partial^2\psi}{\partial x^2} + [E-V]\psi = 0$$

this is Schrodinger's time Independent wave equation.

for free Particle $V=0$ then Schrodinger's wave function for a free Particles.

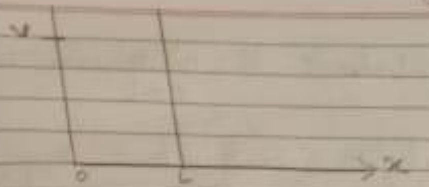
$$\frac{\hbar^2}{2m}\frac{\partial^2\psi}{\partial x^2} + E\psi = 0$$

Application Particle in a one dimensional box.

Consider a particle moving inside a box along x direction. the particle is bouncing b/w the walls of the box. L is the width of the box the potential energy V of the particle is infinite on both sides of the box.

$V=0$ for $0<x<l$

$V=\infty$ for $x \le 0$ & $x \ge L$ (boundary conditional)



within the box the Schrodinger's Equation becomes.

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

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

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

The general solution of this equations is

$$\psi = A\sin kx + B\cos kx$$

using boundary condition.

$\psi = 0$ at $x = 0$

$0 = A\sin 0 + B$

$B = 0$

$\psi = 0$ at $x = L$, $0 = A\sin kL$ $A \neq 0$

$\sin n\pi = \sin kL$

$k = \frac{n\pi}{L}$

wave function $\rightarrow \psi = A\sin\frac{n\pi x}{L}$

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Eigen Value :- $E = \frac{n^2 \pi^2 \hbar^2}{8mL}$ $n = 1, 2, 3 \ldots$

The Particle Cannot have any arbitary energy but can have only Certain discrete energy Corresponding to $n = 1, 2, 3$ each permited energy is Called eigen value of the Particle the wave function of ψ Corresponding to each eigen value are Called eigen functions

Eigen function.

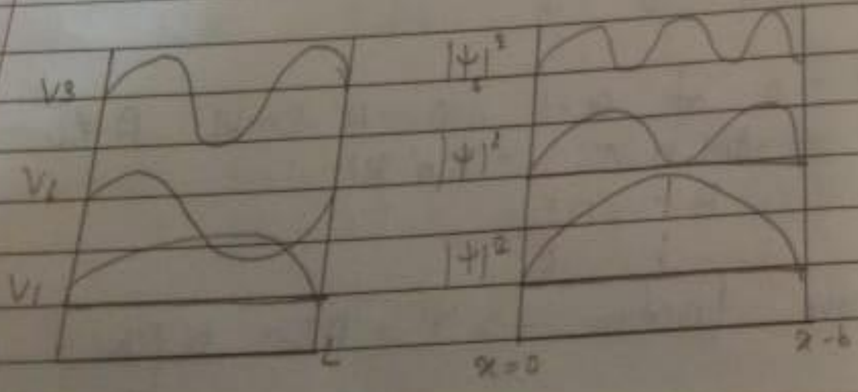
$$\int_{-\infty}^{+\infty} |\psi_n(x)|^2 \, dx = 1$$

$$\int_0^L |\psi_n|^2 \, dx = A^2 \int_0^L \sin^2\left(\frac{n\pi x}{L}\right) dx = 1$$

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

$$\frac{A^2}{2} [L] = 1, \quad A = \sqrt{\frac{2}{L}}$$

$$\psi_n = \sqrt{\frac{2}{L}} \sin \frac{n\pi x}{L}$$



Born interpretations :- It states that the probability density of finding the particle at a given point is proportional to the square of the magnitude of the particle wave function at that point.

$$P(x, y, z) = |\psi(x, y, z, t_0)|^2$$

Where $P(x, y, z)$ is the probability density function.

Normalization $\int_{-\infty}^{+\infty} |\psi|^2 \, dv = 1$

Expectation Value :- To Correlate experiment and theory we define the expectation value of any parameter.

$$\langle x \rangle = \frac{\int_{-\infty}^{+\infty} x |\psi|^2 \, dx}{\int_{-\infty}^{+\infty} |\psi|^2 \, dx}$$

$$= \frac{\int_{-\infty}^{+\infty} \psi^* x \psi \, dx}{\int \psi^* \psi \, dx}$$

Uncertainity Principle :- It is impossible to determine exact position and momentum of a particle Simultaneously.

Position and momentum uncertainity relation.

$$\Delta x \cdot \Delta p \geq \hbar \text{ or } \Delta x \cdot \Delta p \geq \frac{h}{4\pi}$$

Energy and time uncertainity Principle.

$$\Delta E \cdot \Delta t \geq \hbar \text{ or } \Delta E \cdot \Delta t \geq \frac{h}{4\pi}$$

Heisenberg uncertainity Principle.

Proof :- Let us Consider two waves of angular frequency ω_1 and ω_2 and Propagation Constant k_1 and k_2 travelling along a Single direction.

$$\psi_1 = A \sin(\omega t - k_1 x) \quad \text{—(1)}$$
$$\psi_2 = A \sin(\omega_2 t - k_2 x) \quad \text{—(2)}$$

~~$\psi_1 = A \sin$~~

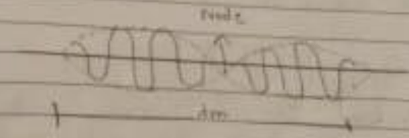
By the Principle of Superposition.

$$\psi = \psi_1 + \psi_2$$

$$= 2A \sin(\omega t - kx) \cos\left[\frac{\Delta \omega t}{2} - \frac{\Delta k x}{2}\right] \quad \text{—(3)}$$

Where, $\omega_1 - \omega_2 \; \Delta\omega$, $\Delta k = k_1 - k_2$

$$\omega = \frac{\omega_1 + \omega_2}{2}, \quad k = \frac{k_1 + k_2}{2}$$



Now a node is formed when $\cos\left[\frac{\delta\omega t}{2} - \frac{\delta k x}{2}\right]$ is Zero.

$$= \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}$$

This is x_1 and x_2 represent the Position of two Successive nodes, then at any instant we get.

$$\frac{\delta\omega t}{2} - \frac{\delta k x_1}{2} = \frac{(2n+1)}{2}\frac{\pi}{2} \quad \text{—(4)}$$

$$\frac{\delta\omega t}{2} - \frac{\delta k x_2}{2} = \left(\frac{2n+3}{2}\right)\frac{\pi}{2} \quad \text{—(5)}$$

Subtracting (5) and (4) we get

$$\frac{\delta k}{2}(x_2 - x_1) = \pi$$

Error in measurement Of the Position of the Particle.

$$\Delta x = \frac{\Delta}{\Delta k} = \frac{\Delta}{\Delta\left[\frac{2\pi}{\lambda m}\right]} = \frac{1}{\Delta\left[\frac{2\pi P}{h}\right]} = \frac{\hbar}{\Delta P}$$

$= \Delta x \cdot \Delta P = \hbar$

$= \Delta x \cdot \Delta P \geq \hbar$

Wave Packet :- A wave Packet Consist of a group and if farmed by the Superposition of a number of were an and around the Secter wave length.

Let a wave Packet be farmed by the Superposition of waves.

$$y_1 = a \sin(\omega t - k_1 x)$$
$$y_2 = a \sin(\omega t - k_2 x)$$

Its displacement equation

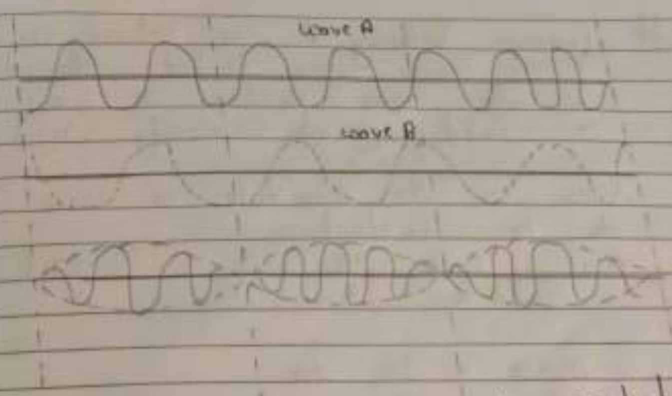
$$y = 2a \cos\left[\frac{\Delta\omega t}{2} - \frac{\Delta k\, x}{2}\right] \sin[\omega t - kx]$$

Then,
$$\Delta\omega = \omega_1 - \omega_2$$
$$\Delta k = k_1 - k_2$$
$$\omega = \frac{\omega_1 + \omega_2}{2}$$
$$k = \frac{k_1 + k_2}{2}$$

The amplitude of wave Packet is

$$A = 2a \cos\left[\frac{\Delta\omega t}{2} - \frac{\Delta k\, x}{2}\right]$$

Phase $= (\omega t - kx)$



wave packet.

Phase Velocity and group Velocity :

The Velocity of Value is Called Phase velocity it is denoted by V_P.

Since Phase of wave Packet $(\omega t - kx)$ is Constant i.e. $\omega t - kx$ = Constant.

$$\omega dt - k dx = 0$$

Hence V_P,

$$V_P = \frac{dx}{dt} = \frac{\omega}{k} = \frac{2\pi\nu}{\frac{2\pi}{\lambda}} = \nu\lambda$$

Group Velocity :- The Velocity with the wave Packet obtained due to the uper-position of wave traveling is Called group Velocity (V_g)

Since for the amplitude of wave Packet to be Constant.

i.e, $\frac{\Delta\omega t}{2} - \frac{\Delta k}{2} = x =$ Constant.

$$\frac{\Delta\omega t}{2} = \frac{\Delta k}{2} dx$$

Hence, group Velocity

$$V_g = \frac{dx}{dt} = \frac{\Delta\omega/2}{\Delta\omega/2} = \frac{\Delta\omega}{\Delta k}$$

$$V_g = \lim_{\omega_1 \to \omega_2} \frac{\Delta\omega}{\Delta k} = \frac{d\omega}{dk}.$$

m. Imp.

Relation between V_p and V_g.

wave velocity $V_g = \frac{d\omega}{dk}$

$$V_g = \frac{d(kV_p)}{dk}$$

$$= V_p + \frac{k\,dV_p}{dk}$$

$$= V_p + \left(\frac{2\pi}{\lambda}\right)\frac{dV_p}{d(2\pi/\lambda)}$$

$$\left[V_g = V_p - \lambda\frac{d \cdot V_p}{d\lambda}\right]$$

(1) for non-dispersive medium

$\frac{dV_p}{d\lambda} = 0$ $(\therefore V_g = V_p)$

(2) for dispersive medium.

$\frac{dV_p}{d\lambda}$ is Positive $\therefore (V_g < V_p)$

$\frac{dV_p}{d\lambda}$ is Negative $\therefore (V_g > V_p)$

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unit :- 1
Physcs

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June - 2023

(1)(a) State and Prove hisenberg uncertainity Principal.

(b) Derive time dependent and time independent Schrodingers wave equation.

Que (2) Define wave function and State its properties. Derive energy and momentum Operator.

Dec. 2023

(1)(a) State and Prove uncertainity Principle

(b) Discuss the energy and momentum operator.

(c) Derive the time dependent Schrodiger wave equation.

(2) Prove that for One dimensional motion of a Particle in a box $\psi = A \sin \frac{n\pi x}{L}$.

Nov. 2022

(1)(a) Explain the hisenberg uncertaindy Principle

~~(b) Discuss the energy and momentum Oper~~

(b) Discuse the relation b/w Phase velocity and group velocity.

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(2)(a) Obtain the time independent Schredinger wave equation.

(3) Write Short note on Physical Significant of wave function.

June - 2022.

(1)(a) Discuss the Physical Significant of wave function

(b) Discuss the energy eigen values and wave function of a Particle moving in 1 dimensional box.

(2) Obtain the time dependent S.w.d

(3) Explain the uncertainity Principle.

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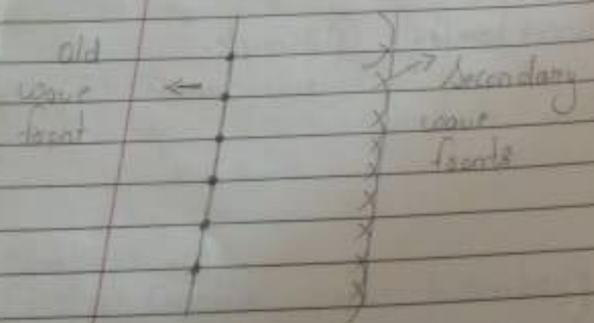
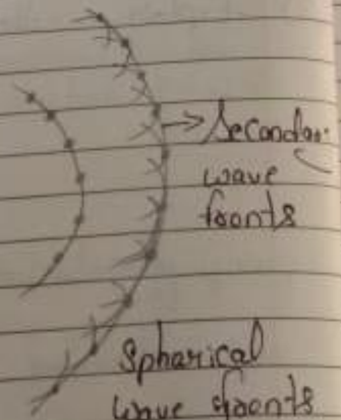
Unit :- 2
Wave Optics

Huygen's Principle :- In wave optics a wave front is the locus of Point characteristics by Propagation of Position of Same Phase that is a Propagation of a line in one to Occurs in 2-D or a Surface of a wave in (3D.)

According to the Principle, every Point on a Propagating wavefront gets a new Source of Separate Special Secondary wave front.



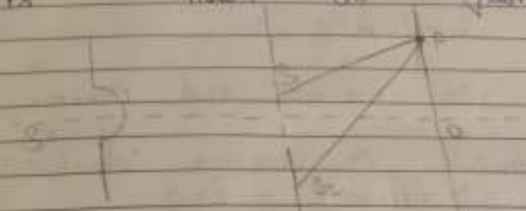
Plane wave front.



Spharical wave fronts

Superposition of waves :-

(1) **Path difference :-** The distance differents between optical Path of two rays, which are in Constant Phase difference with each other reuniting at a Particular Point is known as Path.



Path difference $= S_2P - S_1P$

The Principle of Super Position of waves is the resultant displacement is equal to the same of the in Indivated displacement of the two waves.

$$y = y_1 + y_2$$

where.

$$y_1 = a \sin \omega t$$

$$y_2 = a_2 \sin(\omega t - s)$$

The resultant indensity I at P, is Proposional to the equal do the resultant amplitude

Where. $A = a_1^2 + a_2^2 + 2 a_1 a_2 \cos\theta$

Topic :- Interference.

Condition of maxima and minima

The Indensity is maxima when (cos θ = 1) & Phase difference = 2nπ

$I_{max} = (a_1 + a_2)^2$

(2) The Indensity is minima when (cos θ = -1) & phase difference = (2n + 1) λ

$I_{min} = (a_1 - a_2)^2$

(3) Does On the Screen there is the variation in the indensity of the light being the beam alternet maxima and minima this is Called interference Pattern.

★ Interference of light :-

The non-uniform distribution of light indensity due to Superposition of two waves is Called interference.

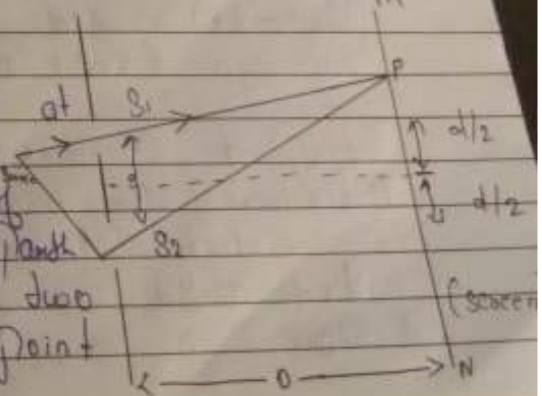
At the point where the resultant indensity of light is maximum interference is Sit to be Constructive at the point were resultant Indensity is minimum the interference Set to be Construction.

★ Topic :- Young double Slit experiment

Suppose S_1 and S_2 are two fin a Small distance D. a part a source as Souce a monocromatic light of wavelength λ.

MA is a Screen at a distance D from the Slip.

Consider a point P at a distance y from O the Centre of a Screen the Pandh difference between two waves at the point



P is equal the to $S_2p - S_1p$

now $(S_2p)^2 - (S_1p)^2$ is equall to

$$(S_2p)^2 - (S_1p)^2 =$$

$$= \left[D^2 + \left(y + \frac{d}{2}\right)^2\right] - \left[D^2 + \left(y - \frac{d}{2}\right)^2\right]^2$$

$$\because a^2 - b^2 = (a+b)(a-b)$$

$$= (S_2p + S_1p)(S_2p - S_1p) = \left[D^2 + \left(d + \frac{y}{2}\right)^2\right]^2$$

$$- \left[D^2 + \left(d - \frac{y}{2}\right)^2\right]^2$$

$$= D^2 + \left[d + \frac{y}{2}\right]^2 - D^2 - \left[d - \frac{y}{2}\right]^2$$

$$= d^2 + \frac{y^2}{4} + yd - d^2 + yd - \frac{y^2}{4}$$

$$= 2yd$$

$$(S_2P - S_1P) = \frac{2yd}{(S_2P + S_1P)}$$

The Point P lies to Very Close to D there for $(S_1p = S_2p = D)$

$$\frac{2yd}{2D} = \frac{yd}{D} \qquad \left\{\frac{S_2P + S_1P = D + D}{2D}\right\}$$

For Constructive interference (bright fringes)

Path difference $\frac{dy}{D} = nd$

$$y = \frac{nDd}{d}$$ first bright fringes

$x = 0$ and $y = 0$ at point O

than $n = 1$, $n = 2$

$$y_1 = \frac{Dd}{d}, \quad y_2 = \frac{2Dd}{d}$$

$$y_2 - y_1 = \frac{dD}{d} = \beta$$

For Constructive (dark fringes) interference

Path difference $\frac{dy}{D} = (2n-1)\frac{d}{2}$

$$y = \frac{(2n-1)Dd}{2d}$$

than $n = 1$, $n = 2$ $\quad y_1 = \frac{(1)Dd}{2d} = \frac{Dd}{2d}$

$$y_2 = \frac{3Dd}{2d}$$

Question :- Newton's Ring.

Two Types

(1) By the division of wavefront

(2) By the division of amplitude

(1) Division of wavefront :-

The Incident wavefront is divided into two parts By the Phenomina of reflection, retreaction. The two parts of wavefront travles unequall distance and reunite do produce interference fringe.

Example :- young's double Slit experiment.

(2) By the division of amplitude :-

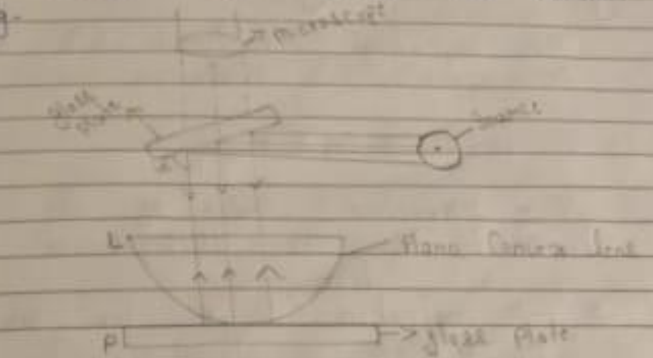
The amplitude of the incident light is divided into two parts either by parallel reflection are or reflection these live wave with divided amplitude trace travelling distance and produces.

Example :- meal Son interference.

Newton's Ring :
formation of Newton's Ring.

When a plano - Convex lens of large radice of Curvature its placed with in Contact with a plane gass and air plane of increasing thickness from the is foom between

the upper surface of the plate and the light is allow in the monochromatic than alternet brigth and dark heat and backe with these sandle dark a form this beams are known as Newton ring.



Experiment arrangement :- A plano Convex lens of large radius of Curvature is placed on a plane glass place such that both of them is heaving a point of Contact light from a monochromatic source fall on a glass plate in Clind at a angle of 45 In the incident a beam the light reflected front glass plate falle normally on the air film on Closed b/w air film. light rays reflected upward from the glass film

Theory :- Newton's Ring.

The impreding effective path difference is equall to the :

$$2\mu t \cos r + \frac{\lambda}{2}$$

μ = refractive index of the year

$t \rightarrow t$ is the thickness of air film

$r \rightarrow$ inclination rays for air $\mu = 1$ at $r = 0$

then path difference is equal to

$$= 2t + \frac{\lambda}{2}$$

Case-1 for maxima (bright friranges) the equal to the

$$2t + \frac{\lambda}{2} = n\lambda$$

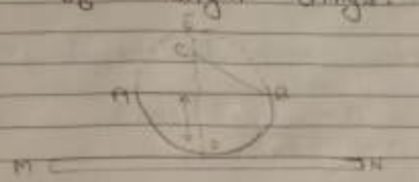
$n\lambda = 1, 2, 3$ and show of

Case 2 for dark fringes (minima) the path difference is equall to.

$$2(n+1)\frac{\lambda}{2} = 2t + \frac{\lambda}{2}$$

$\lambda = 1, 2, 3, 4$

Diameter of bright rings.



Let ADBC be the lens is on the glass plate MN, the point of contact is D. Let R be the radius of curvature of the curved surface of the lens. Let r be the radius of Newton's Ring and t is the thickness. from the geometrical property of circle.

$$AD \times DB = OD \times DE$$

$$r \times r = t(2R - t)$$

$$r^2 = 2Rt - t^2$$

t neglected (very small)

$$r^2 = 2Rt$$

$$2t = \frac{r^2}{R}$$

By using the condition of bright rings path diff.

$$(2n-1)\frac{\lambda}{2}$$

$$\rightarrow \frac{r^2}{R} = (2n-1)\frac{\lambda}{2}$$

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$$r\sqrt{(2n-1)\frac{1}{2}R}$$

(1) Diameter of the bright ring $D = 2r$

$$D = \sqrt{2\lambda R(2n-1)}$$

$$D \propto \sqrt{(2n-1)}$$

D is directly proportional to square root of whole number.

(2) Diameter of the dark rings.

$$\frac{r^2}{R} = n\lambda$$

$$r = \sqrt{n\lambda R}$$

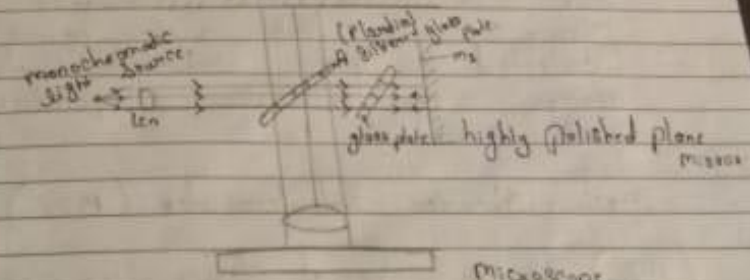
diameter is directly proportional to square root of whole number.

Michelson Interferometer :- Michelson interferometer Instrument in which the funomia of intereferometer is used to make prisize measurement of wave length refractive index and destance.

*. Principle :- In michelson itaferometer a beam a ligth from an extranal source is divided into two parts equall intensity by

Parsal reflection refraction.

- this beam travels into usually perpendicular and come together after reflection from plane mirror this beam over leap and each other interference



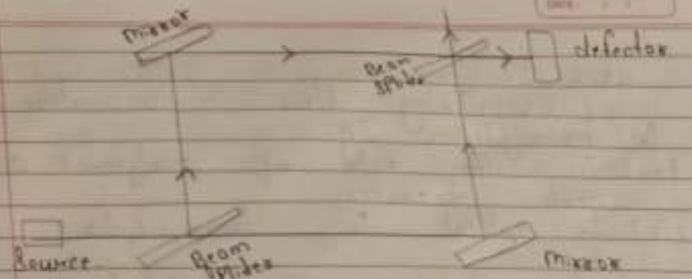
Construction :- It consist of two highly polised mirrors m_1 and m_2. m_2 plane glass plate are parallel to each other. the glass plate a is partity silver so that the light coming from the source is equally reflected and refracted by the lens 2 max the beam parallel.

Working :- light from a monochromatic source after passing through the lens 2 mage the beam parallel and flase all the plate A the partiely and flase all the plate A the partialy silver glass plate a in which one half of the incident beam is reflected towards the mirror M_1 and other half is refractive towards the mirror M_2 this two beams (reflected and refracted) travel along to usually perpendicularly path and.

Mach-Zehender Interferometer (MZI)

(MZI) is a special device for demostrated interference by division of amplitude (MZI) is use to measur the relative phase ship variation from two collimated beams drives by spliding light single source.

Construction :- It consist of a source of collimated beams, two beam spliters two mirrors and two detectors.



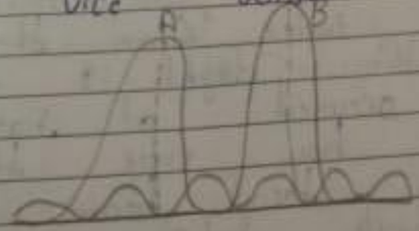
Working :-
The beam spliter is a piece of glass with a dialectric of mattle coting on the front surface. light from the source strike from the front has a 50% chances of beaing reflected and 50% chances of beam refractive a 180° plates shift occurs for reflection since the medium behind the mirror has higher refractive index than the medium in which the light is travelling no phasship occured at rarer surface reflection how ever than a photon approches the beam spiliter from the back sides.

. if first and the glass and has 50% chances of reflecting of the electric coting and the reflect does not induce a phase changes.

uses :-
(i) visallising flow in ui dermal.
(ii) monolydic IC.
(iii) In the field of analymics and neat transfer
(iv) In opdical dolly Communication

Rayleigh's Coidedion of resolution.

The ability of an opdical instrument do resoluted the image of two near instrument do resoluted the images They propose two spectal ions of equal intensity a set do be resoluted if the principle maxima of the diffreedion petern due do one falsè on the first secondary minimum of the defledion pattern due do other and vice verse.



application do vision :-

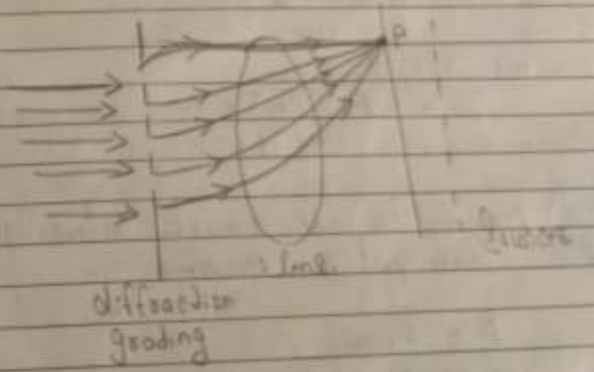
eye is an Organ which act is a instrument in the human of optical system the obilidy of an eye do distinguish Small details an objects

is called angular resolution when two points sources are resolut from each other they are separated by adhelet the radius of airy disk.

Resolution
angular vision formule $Q = \frac{1.22\lambda}{D}$ radian
D diameter eye

* The size of eye people changes during day and night because d.

Diffection grading :- a diffection is an arrangement equivalent do equall N (No) of equal with and separated an by equall one another by equall opa spaces.



Let e of and d width of each spaces between the spaces then (e+d) is called the element and the (e+d) is called the grading.

It first and the glass and has a 50% chances of reflecting of the electric cotting and the reflection does not induce a phase change.

Uses :-

Intensity distribution for N slit.

$$I = \frac{A_0^2 \sin^2 \alpha}{\alpha^2} \frac{\sin^2 N\beta}{\sin^2 \beta}$$

(Generalised Expression)

Principal Maxima :-
Intensity would be maximum

$\sin \beta = 0$

$\beta = n\pi$

$n = 0, 1, 2, 3 \ldots$

$$I_P = \frac{A_0^2 \sin^2 \alpha N}{\alpha^2}$$

this maxima are most intens in a called Principal maxima.

$\beta = \pm n\pi$

$$\frac{\pi(e+d) \sin \theta}{\lambda} = \pm n\pi$$

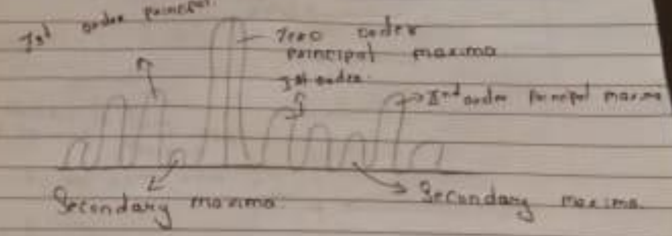
$(e+d) \sin \theta = \pm n\pi$

$n = 0, 1, 2, 3, \ldots$

this is known as grading element.

$n = 0$

it is called zero-order maxima.



Resolving power of diffracting grading.

The resolving power of a diffraction grading represent its ability to form separ spectral lines for wavelength very close together it is given by $\lambda / d\lambda$ where $d\lambda$ is the smallest wavelength difference just resolved at wavelength λ.

(1) Derivation :- Let a parallel beam of light of wavelength λ and $\lambda + d\lambda$ be incident normally on a diffraction grading.
Let nth Principal maxima of wavelength λ be formed in the direction θ.

$(e+d) \sin \theta = n\lambda$

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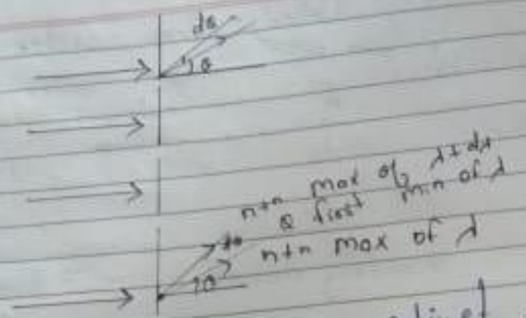


Let the first minima adjust and due the mixima be formed in the direction $\alpha + d\theta$.

than,

$$N(e+d)\sin\theta = m\lambda \quad \text{—— (i)}$$

Where N is the total no. of ruling on the grading the first mining adjustand due the and principal maxima in the direction increasing than.

$$m = nN + 1$$

$$\Rightarrow N \times (e+d)\sin(\alpha + d\theta) = \left(\frac{nN}{N} + 1\right)\lambda \quad \text{—— (ii)}$$

$$(e+d)\sin(\alpha + d\alpha) = \left(\frac{nN+1}{N}\right)\lambda \quad \text{—— (iii)}$$

According to raylength (ul area the wavelength λ and $\lambda + d\lambda$ a just resolved by the maxima grading when the wavelength $\alpha + d\alpha$.

Then,

$$(e+d)\sin(\alpha + d\alpha) = n(\lambda + d\lambda) \quad \text{—— (iv)}$$

Comparing (3) & (4)

$$\left[\frac{nN+1}{N}\right]\lambda = n(\lambda + d\lambda)$$

$$\frac{nN+1}{nN} = \frac{\lambda + d\lambda}{\lambda}$$

$$\frac{nN}{nN} + \frac{1}{nN} = \frac{\lambda}{\lambda} + \frac{d\lambda}{\lambda} \Rightarrow 1 + \frac{1}{nN} = \frac{d\lambda}{\lambda} + 1$$

$$\frac{1}{nN} = \frac{d\lambda}{\lambda} \Rightarrow \frac{\lambda}{nN} = d\lambda \Rightarrow \frac{\lambda}{d\lambda} = nN$$

Resolving Power.

for Sentral maxima resolving power $= 0$.

$$n = 0$$

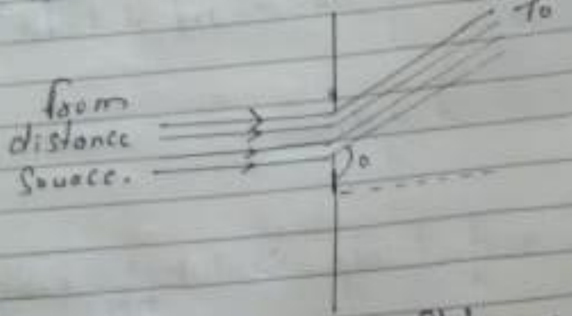
$$\frac{\lambda}{d\lambda} = 0$$

Resolving Power. Diffraction :-

The Spreading Out of light wave into the geomtoical Sadow when it passes through a narrow opening is known as the differaction the intensity distribution on the screen is known as the diffraction pattern.

Diffraction

In this diffraction the source of light from the diffracting and operature.



at a single slit intensity $I = \frac{I_0 \sin^2 \alpha}{\alpha^2}$

Position of central maxima.
$\alpha = 0$

$\lim_{\alpha \to 0} \frac{\sin^2}{\alpha} = 1.$

hence intensity $I = I_0 \left[\frac{\sin^2 \alpha}{\alpha^2} \right] = I_0$

at a circular operature
the path difference $\Rightarrow d \sin \theta$
for minima $\Rightarrow d \sin \theta = n\lambda$
for maxima $\Rightarrow d \sin \theta = (2n-1)\frac{\lambda}{2}$

UNIT-3

Free Electron theory of metals

Classical free electron theory is based on the following postulates:

1. A solid metal is composed of atoms and the atoms have nucleus, around which there are revolving electrons.

2. In a metal the valance electrons of atoms are free to move throughout the volume of the metal like gas molecules of a perfect gas in a container

3. The free electrons move in a random directions and collide with either positive ions fixed to the lattice or other free electrons and collisions are elastic in nature i.e. there is no loss of energy.

4. The movement of free electrons obeys the classical kinetic theory of gasses. The mean K.E. of a free electron is equal to that of gas molecule $\left(\frac{3}{2}KT\right)$.

5. The electron velocities in a metal obey Maxwell-Boltzman distribution of velocities.

6. The free electrons move in a uniform potential field due to ions fixed in the lattice

7. When an electric field is applied to the metal the free electrons are accelerated. The accelerated electrons move in opposite direction of the applied.

8. The electric conduction is due to the free electrons only.

ROOT MEAN SQUARE (R.M.S.) VELOCITY:

Let $\bar{C}$ be the r.m.s velocity of the free electron. then the

$$Kinetic\ energy = \frac{1}{2}m\bar{C}^2$$

But according to the classical free electron theory the mean

$$\text{Kinetic Energy} = \left(\frac{3}{2}KT\right).$$

$$\frac{1}{2}m\bar{c}^2 = \frac{3}{2}KT$$

$$\Rightarrow \boxed{\bar{c} = \sqrt{\frac{3KT}{m}}}$$

where $\bar{c}$ = root mean square velocity

MEAN FREE PATH (λ) AND MEAN COLLISION TIME (τ_C)

The average distance travelled by an electron between two successive collisions in the presence of applied filed is known as 'Mean free path (λ)'.

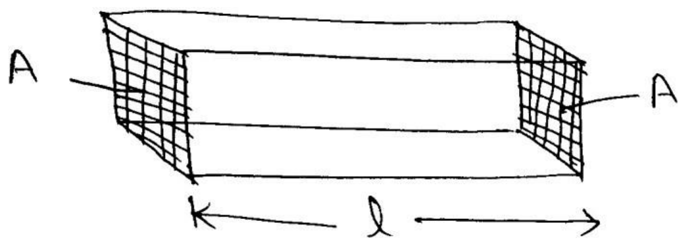
The time taken by an electron between two successive collisions is known as "Mean Collision Time(τ_C)" of the electron

$$\boxed{\tau_c = \frac{\lambda}{\bar{c}} = \lambda\sqrt{\frac{m}{3KT}}}$$

DRIFT VELOCITY (v_d):

It is the average velocity acquired by the free electrons of a metal in a particular direction during the application of the electric field.

ELECTRICAL CONDUCTVITY IN METALS:



Let us consider a conductor of length l and area of cross section A

The volume of the conductor $= Al$

If there are n number of electrons per unit volume of the metal

then the total number of electrons in the metal $= Aln$

If e is the charge of the electron then the total charge q due to all electrons in the conductor is given by $q = Aln.e$

Let t be the time taken by the electron to move from one end to other end then

$$\text{Current}\,(I) = \frac{charge}{time} = \frac{q}{t} = \frac{Alne}{t}$$

$$\text{But } \frac{l}{t} = v_d$$

m$I = Anev_d$

$$\Rightarrow v_d = \frac{I}{Ane} = \frac{J}{ne}$$

Where J = current density $= \frac{I}{A}$

In a metal the current density J is given by the equation

$J = nev_d$ ---------------- (1)

Where n = number of electrons per Unit volume, e = electron charge and v_d = drift velocity

If E is the applied electric field then the electric force acting on a free electron is given by

$F = eE$ .... (2)

From Newton's IInd law $F = ma$ --------------------------------- (3)

From (2) and (3) $ma = eE$

i.e. $a = \frac{eE}{m}$

but a = drift velocity/collision time = $\frac{v_d}{\tau_c}$

$$v_d = a\tau_c = \frac{eE}{m}\tau_c$$

$$\text{m } J = ne.\frac{eE}{m}\tau_c = \frac{ne^2E}{m}\tau_c \text{...}(4)$$

But from microscopic form of ohms law

$$J = \sigma E \text{...................................}(5)$$

On comparing Eq(4)&(5)

m Conductivity $\sigma = \frac{ne^2}{m}\tau_c$ or Re*sistivity*.p = $\frac{m}{ne^2\tau_c}$

Conductivity may also be expressed in terms of mobility (μ) which is defined as drift velocity per unit electric field

$$\mu = \frac{v_d}{E} = \frac{e}{m}\tau_c$$

From (4) $\boxed{\sigma = ne\mu}$

RELAXATION TIME(τ_r)

Under the influence of an external electric field free electrons attain a directional velocity of motion. If the field is switched off the velocity starts decreasing exponentially. Such a process that tends to restore equilibrium is called relaxation process.

If v_o is the velocity at $t = 0$ at which the field is switched off.

The velocity at any time is given by

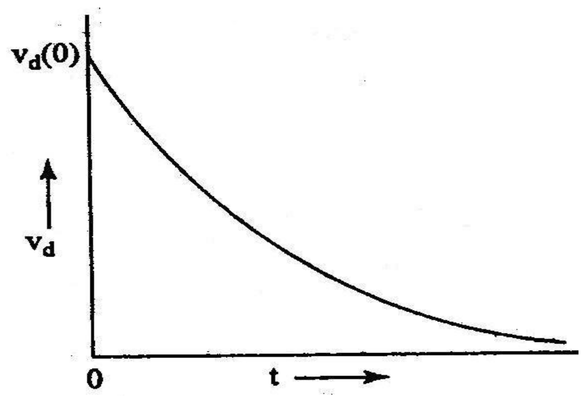
$$v = v_o e^{\frac{-t}{\tau_r}}$$

In the above expression τ_r = relaxation time

If $t = \tau_r$

$$v = v_o e^{\frac{-t}{\tau_r}} = v_o e^{-1} = \frac{v_o}{e}$$

mRelaxation time τ_r is defined as the time required for the electron to reduce its velocity to $\frac{1}{e}$ of its initial value. (OR) time taken for the drift velocity to decay $\frac{1}{e}$ of its initial value.



Failure of classical free electron theory:

1. The phenomena such as photo electric effect, Compton Effect and black body radiation could not be explained by classical free electron theory.
2. According to classical theory the value of specific heat of metals is given by 4.5R (R =Universal gas constant) where as the experimental value is nearly 3R(Dulong Petit law)
3. Electrical conductivity of semiconductor or insulator could not be explained by using this model.
4. According to classical free electron model $\frac{K}{\sigma T}$ is constant.(Widemann-franz law) as this not constant at low temperatures.
5. Ferromagnetism could not be explained by this theory
6. According to classical free electron theory,
   Resistivity

$$p = \frac{m}{ne^2\tau_c} = \frac{m}{ne^2}\sqrt{\frac{3KT}{m}}\frac{1}{\lambda} = \frac{\sqrt{3KTm}}{ne^2\lambda}$$

$$p = \sqrt{T}$$

But according to experiments $p \alpha T$

QUANTUM FREE ELECTRON THEORY:

Sommerfield applied quantum mechanics to explain conductivity phenomenon in metals. He has improved the Drude- Lorentz theory by quantizing the free electron energy and retaining the classical concept of force motion of electrons at random.

ASSUMPTIONS

1. The electrons are free to move with in the metal like gaseous molecules. They are confined to the metal due to surface potential.

2. The velocities of electrons obey Fermi-Dirac distribution because electrons are spin – half particles.

3. The electrons would go into different energy levels and obey Pauli's exclusion principle.

4. The motion of the electron is associated with a wave called matter wave, according to the deBroglie hypothesis.

5. The electrons can not have all energies but will have discrete energies according to the equation $E_{n}= \frac{n^2 h^2}{8ma^2}$ where a is the dimension of the metals.

Derive an expression for electrical conductivity by using quantum free electron theory

According to Quantum theory

$$p = mv = \hbar K \text{ ---- (1)}$$

$$\text{Where } \hbar = \frac{h}{2\pi},\ K = \frac{2\pi}{\lambda}$$

Differentiating equation (1) w.r.t to t

$$a = \frac{dv}{dt} = \frac{\hbar}{m}\frac{dK}{dt}$$

At equilibrium the lorentz force $F = -eE$ acting on the electron is equal and opposite to the product of mass and acceleration of the electron

i.e.

$$eE = ma$$

$$\Rightarrow m\frac{\hbar\, dK}{m\, dt} = eE$$

$$\Rightarrow dK = \frac{eE}{\hbar} dt \text{ ---(2)}$$

Integrating (2) between the limits 0 and t

$$\int_0 dK = \int_0^t \frac{eE}{\hbar} dt$$

$$K(t) - K(0) = \frac{eE}{\hbar} t$$

$$\Delta K = \frac{eE}{\hbar} t_c$$ where t_c =men collision time.

$$\text{But } J = ne\Delta v \text{ and } \Delta v = \hbar \frac{\Delta K}{m}$$

$$\Delta v = \hbar \frac{\Delta K}{m} = \frac{\hbar}{m}\frac{eE}{\hbar} t = \frac{eEt}{m}$$

$$\therefore J = \frac{ne^2Et}{m^*}$$

From microscopic form of Ohm's law

$$J = \sigma E$$

$$\therefore \sigma = \frac{ne^2 t}{m^*}$$

This is the expression for the electrical conductivity.

FERMI DIRAC DISTRIBUTION:

In quantum theory different electrons occupy different energy levels at O`K. Electrons obey Pauli's exclusion principle. As the electrons receive energy they are excited to higher levels which are unoccupied at O K. The occupation of electrons obeys Fermi-Dirac distribution law. The particles that obey Fermi-Dirac distribution law are called Fermions.

The Fermi-Dirac distribution function at a temperature T is given by

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

Where E_f = Fermi energy, $f(E)$ =the probability that a state of energy (E) is filled.

(I) At T=O K for $E > E_f$ $\quad E = \frac{n^2h^2}{8ma^2}$

$$f(E) = \frac{1}{e^{-\infty} + 1} = 1$$

This means that all the energy state below E_f are filled.

For $E > E_f$

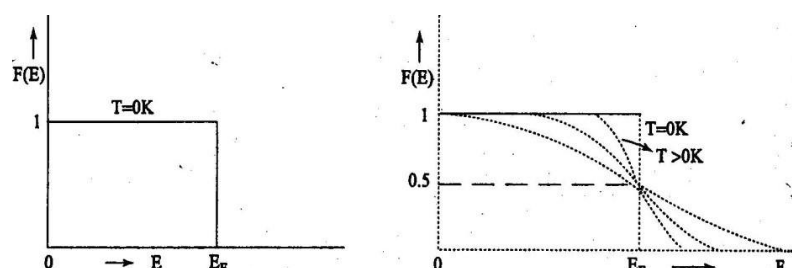
$f(E) = \frac{1}{e^{\infty} + 1} = 0$ Means that all the energy levels above E_f are empty.

From this we define Fermi level as it is the level at 0K below which all the levels are filled and above which all the levels are empty or it is the highest occupied state at 0K

(2) At T>0 and $E = E_f$

$$f(E) = \frac{1}{1+1} = \frac{1}{2}$$

Fermi level is the state at which the probability of electron occupation is ½ at any temperature.



(a) (b)

FERMI ENERGY:

The Fermi energy is a concept in quantum mechanics referring to the energy of the highest occupied quantum state in a system of Fermions at absolute zero temperature.

For the one dimensional infinite square well the energy of the particle is given by

$$E = \frac{n^2h^2}{8ma^2}$$

Suppose now instead of one particle in this box we haven particles in the box and that particles are fermions with spin ½ then only two particles can have the same energy.i.e. Two particles have the same energy of

$$E_1 = \frac{h^2}{8ma^2}$$

Two particles having energy

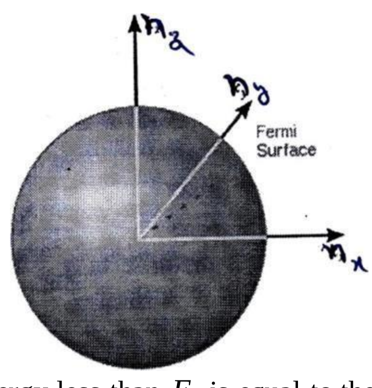
$$E_2 = \frac{4h^2}{8ma^2}$$

∴All the energy levels up to n=N/2 are occupied and all the higher levels are empty.

$$E_f = E_{N/2} = \frac{(N/2)^2 h^2}{8ma^2} = \frac{N^2h^2}{32ma^2}$$

$$\boxed{E_f = \frac{N^2h^2}{32ma^2}}$$

DENSITY OF STATES



The number of states with energy less than E_f is equal to the number of states that lie within a sphere of radius $|n_f|$ in a region of K–space where n_x, n_y and n_z are positive.

$$\text{m}\, N = 2\cdot\frac{1}{8}\cdot\frac{4}{3}\pi n_f^3$$

$$\text{m}\, N = 2\cdot\frac{1}{8}\cdot\frac{4}{3}\pi n_f^3 = \frac{3N}{\pi} \Rightarrow \boxed{n_f = \left(\frac{3N}{\pi}\right)^{\frac{1}{3}}}$$

So the Fermi energy

$$E_f = \frac{\hbar^2 \pi^2 n_f^2}{2ma^2} = \frac{\hbar^2 \pi^2}{2ma^2}\left(\frac{3N}{\pi}\right)^{\frac{2}{3}}$$

$$E_f = \frac{\hbar^2 \pi^2}{2m\,a^2}\left(\frac{3N}{\pi}\right)^{\frac{2}{3}} = \frac{\hbar^2 \pi^{\frac{4}{3}} (3N)^{\frac{2}{3}}}{2m\,(a^3)^{\frac{2}{3}}} = \frac{\hbar^2}{2m}\left(\frac{3N\pi^2}{a^3}\right)^{\frac{2}{3}} = \frac{\hbar^2}{2m}\left(\frac{3N\pi^2}{V}\right)^{\frac{2}{3}}$$

$$N^{\frac{2}{3}} = \frac{2m}{\hbar^2}\left(\frac{V}{3\pi^2}\right)^{\frac{2}{3}} E_f$$

$$\Rightarrow N = \left(\frac{2m}{\hbar^2}\right)^{\frac{3}{2}}\left(\frac{V}{3\pi^2}\right)E_f^{\frac{3}{2}}$$

Therefore density of states: $D(E) = \frac{dN}{dE} = \frac{3}{2}\left(\frac{2m}{\hbar^2}\right)^{\frac{3}{2}}\left(\frac{V}{3\pi^2}\right)E_f^{\frac{1}{2}}$

$$D(E) = \frac{V}{2\pi^2}\left(\frac{2m}{\hbar^2}\right)^{\frac{3}{2}} E_f^{\frac{1}{2}}$$

Therefore the total number of energy states per unit volume per unit energy range

$$Z(E) = \frac{D(E)}{V} = \frac{1}{2\pi^2}\left(\frac{2m}{\hbar^2}\right)^{\frac{3}{2}} E_f^{\frac{1}{2}} = \frac{1}{2\pi^2}\frac{(2m)^{\frac{3}{2}}}{h^3}\, 8\pi^3 E_f^{\frac{1}{2}}$$

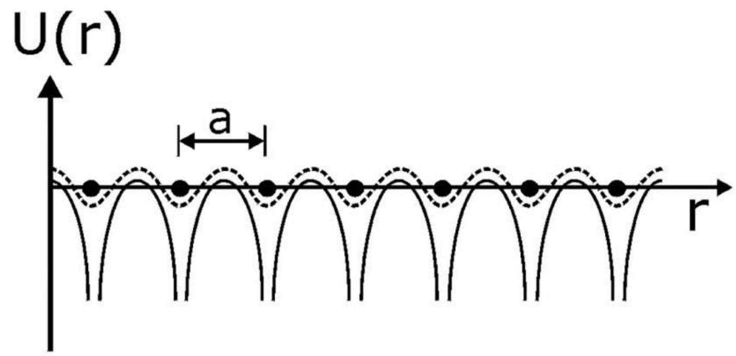
$$Z(E) = \frac{4\pi}{h^3}(2m)^{\frac{3}{2}} E_f^{\frac{1}{2}}$$

Therefore the number of energy states in the energy interval E and $E + dE$ are

$$\boxed{Z(E)dE = \frac{4\pi}{h^3}(2m)^{\frac{3}{2}} E_f^{\frac{1}{2}} dE}$$

BAND THEORY OF SOLIDS

BLOCH THEORM:



Metals and alloys are crystalline in nature. When the electron move into the periodic ion core, it enters into the periodic potential i.e. potential is minimum at the positive ion sites and maximum between the two ions.

The one dimensional Schrödinger wave for this case is

$$\frac{\partial^2\psi}{\partial x^2} + \frac{8\pi^2 m(E - V)}{h^2}\psi = 0$$

The periodic potential $V(x)$ may be defined as

$$V(x) = V(x + a)$$

Bloch has shown that the one dimensional solution of the form

$$\psi(x) = e^{ikx}.u_k(x) = e^{ika}.u_k(a)$$

Where $u_k(x) = u_k(x + a)$

$$\psi(x + a) = e^{ik(x+a)}.u_k(x + a)$$

$$= e^{ikx}e^{ika}.u_k(x + a)$$

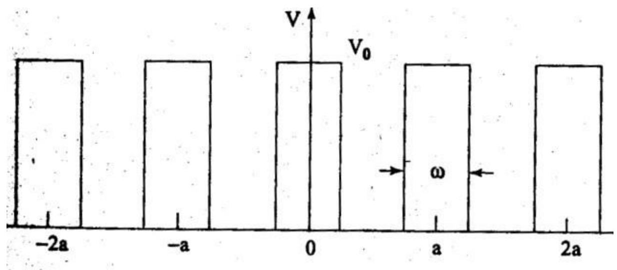
$$= e^{ika}e^{ikx}.u_k(x)$$

$$\boxed{\psi(x + a) = e^{ika}\psi(x)}$$

This is referred as Bloch condition.

KRONIG-PENNEY MODEL:

The free electrons in a metal move under a periodic potential due to regularly arranged positive ions. The nature of the energies of the electron is determined by solving Schrödinger wave equation. For simplicity, the periodic potential is taken in the form of regular o-ne dimensional array of square well potentials.



Within the wall the electron has potential energy

$V = 0, 0 < x < a$

Outside the wall the electron has the PE

$V = V_0, -b < x < 0$

m the Schrödinger wave equation for the two regions are

$$\frac{\partial^2\psi}{\partial x^2} + \frac{8\pi^2 mE}{h^2} = 0, 0 < x < a \text{ ----------(1)}$$

$$\frac{\partial^2\psi}{\partial x^2} + \frac{8\pi^2 m(E-V)\psi}{h^2} = 0, -b < x < 0 \text{------------(2)}$$

Let $\alpha^2 = \dfrac{8\pi^2 mE}{h^2}$

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

Then (1) and (2) becomes

$$\frac{\partial^2\psi}{\partial x^2} + \alpha^2\psi = 0, \text{ ....(3)}$$

$$\frac{\partial^2\psi}{\partial x^2} - \beta^2\psi = 0, \text{ ....(4)}$$

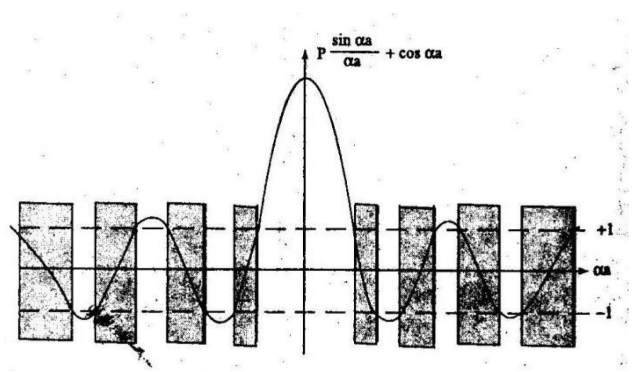
On solving equations (3) and (4) and by applying Bloch Theorem we get

$$\boxed{P\frac{\sin\alpha a}{\alpha a} + \cos\alpha a = \cos ka} \text{ ------------- (5)}$$

Where $P = \frac{mabV_0}{h^2}$

and $\alpha^2 = \frac{8\pi^2 mE}{h^2} \Rightarrow E = \frac{h^2\alpha^2}{8\pi^2 m}$

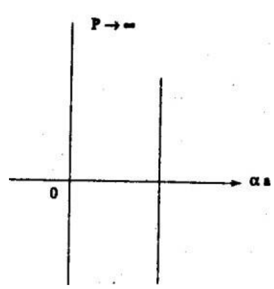
The nature of the equation is illustrated by the plot i.e. drawn between $P\frac{\sin\alpha a}{\alpha a} + \cos\alpha a$ and αa **and** at the same time the RHS having the value between +1 and -1



In the above graph only some of the range of αa **values are a**llowed indicating the a limiting range of energies are allowed. Allowed energy region is indicated by dark region and the forbidden region is indicated by dotted lines.

<u>Special cases:</u>

(i) If $P \to \infty$ the allowed band reduces to single energy level. This is the special case of electron trapped.



(ii) If $P \to 0$

$\cos\alpha a = \cos ka$

$k = \alpha$

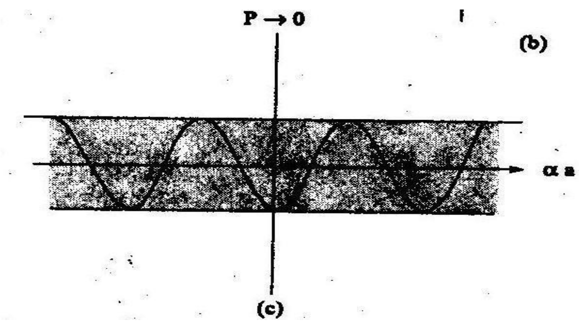
$k^2 = \alpha^2 = \frac{8\pi^2 mE}{h^2} \Rightarrow E = \frac{h^2k^2}{8\pi^2 m} = \frac{h^2}{8\pi^2 m}\frac{4\pi^2}{\lambda^2}$

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

Therefore Total energy =KE+PE

$\Rightarrow$Potential Energy $V = 0$

And this is the case of free electron.



Finally we conclude that

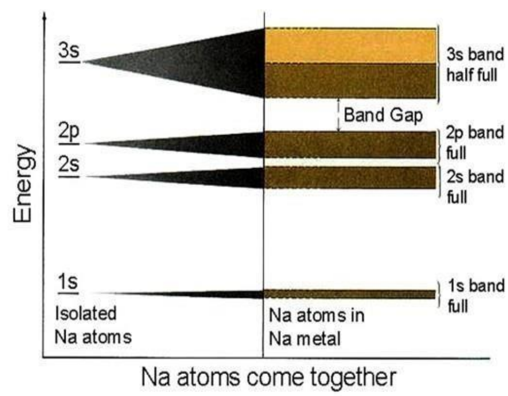
(i) Electrons in solids are permitted to be in allowed energy bands separated by forbidden energy gaps.

(ii) Allowed energy band width increases with αa

(iii) $P \rightarrow$ ⍰ is the case of electron trapped and

$P \rightarrow 0$ is the case of classical free particle

ORIGIN OF ENERGY BANDS:



In an isolated atom the electrons are tightly bound and have discrete sharp energy levels. When two identical atoms are brought closure the outermost orbit of these atoms overlaps and interacts. Then the energy levels corresponding to those atoms are split into two. If more atoms are brought together more levels are formed and for a solid of N atoms each of energy levels of an atom split into N levels of

Depends on the degree of overlap of electrons of adjacent atoms and is largest for outermost atomic electrons.

The electrons in the inner shells are strongly bound to their nucleus while the electrons in the outer most shells are not strongly bound to the nucleus. The electrons in the outermost shell are called valance electrons. The band formed by the energy levels containing the valance electrons is known as valence band.

Valence Band:

The band formed by the energy levels of valence electrons is called valence band. Or the band having highest occupied band energy. It may be partial or completely filled.

Conduction band:

This is the lowest unfilled energy band. This is empty or partially filled.

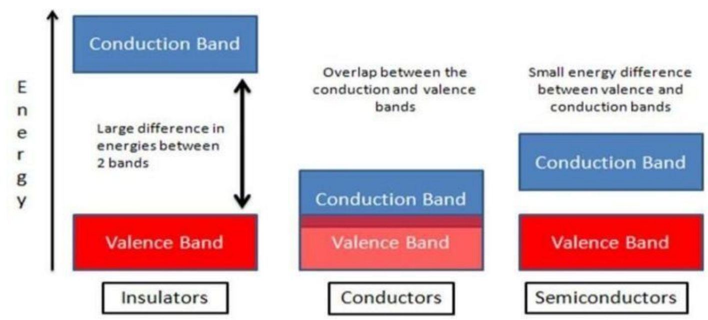
Forbidden Energy gap:

The conduction band and valence band are separated by a region or gap known as forbidden band. In this there is no electron exist.

CLASSIFICATION OF MATERIALS INTO CONDUCTORS, SEMICONDUCTORS AND INSULATORS:

INSULATOR:

In case of insulators the forbidden band is wide. Due to this free electrons cannot jump from valence band to conduction band. In insulators the energy gap between Valence and conduction band is of the order of 10eV.

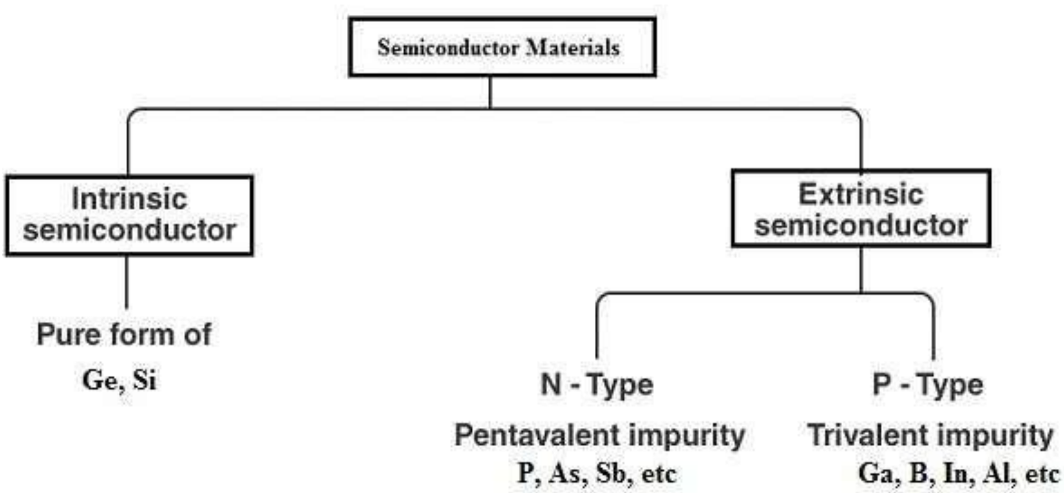


CONDUCTORS:

In case of conductors there is no forbidden band the valence band and conduction band overlap each other. Here plenty of electrons are available for electronic conduction.

SEMICONDUCTORS:

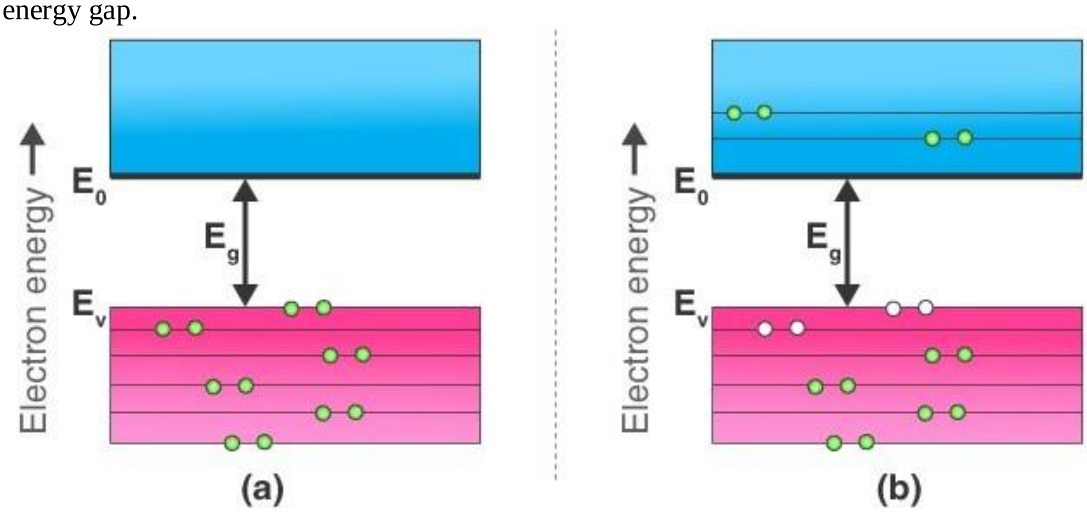
In semiconductors there is small forbidden band exist between valence band and conduction band. In semiconductors forbidden band gap is between 0.7 to 1.1 eV. For semiconductors the electrical properties lie between insulators and good conductors.



Intrinsic Semiconductors

The intrinsic semiconductors are the semiconductors are elemental semiconductors or also called as pure semiconductors. These semiconductors are made up of one kind of atoms only. The examples of intrinsic semiconductors are Silicon (Si) and Germanium (Ge).

At T=0 K the intrinsic semiconductor behaves as insulators. Because no electron exists in the conduction band. But at ordinary temperatures due to thermal agitations the covalent bonds are broken and some electrons move to conduction band. The Fermi energy level inside an intrinsic semiconductor lies in the middle of energy gap.



(a) Intrinsic Semiconductor at T = 0 Kelvin, behaves like an insulator (b) At t>0, four thermally generated electron pairs

Extrinsic Semiconductors

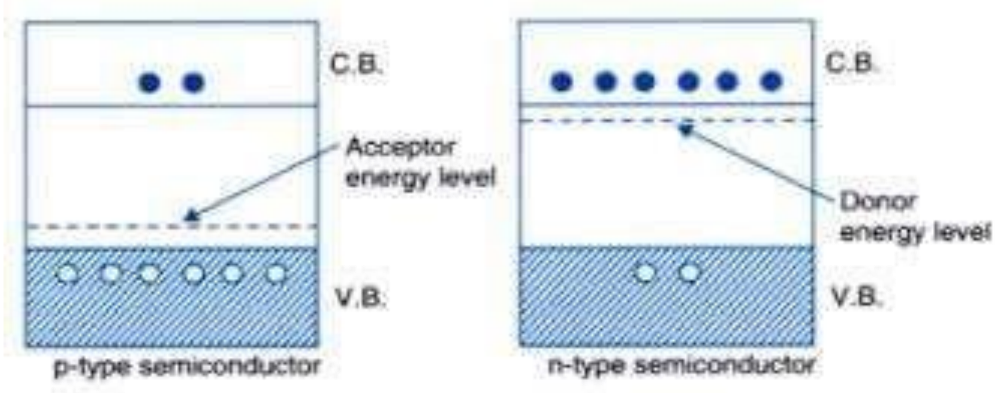
By doping suitable impurity in the intrinsic semiconductors. Thus obtained semiconductors are called as extrinsic semiconductors. Depending upon the type of impurity added the extrinsic semiconductors can be classified as N-type and P-type semiconductors.

N-type Semiconductors

When intrinsic semiconductors either Si or Ge are doped with pentavalent material, then the obtained semiconductor material is called N-type semiconductor. The Si or Ge are tetravalent materials hence the four electrons in the outer shell of these materials forms the covalent bond with another Si or Ge atoms to complete their octet. When a pentavalent impurity Like Arsenic (As) is added to the Si or Ge then the four out of five valance electrons are shared by the host atoms(Si or Ge) while the fifth electrons of the impurity is loosely bound to its parent atom. These loosely bound electrons give rise to donor levels. At ordinary temperature all the electrons of the donor level move to the conduction band.

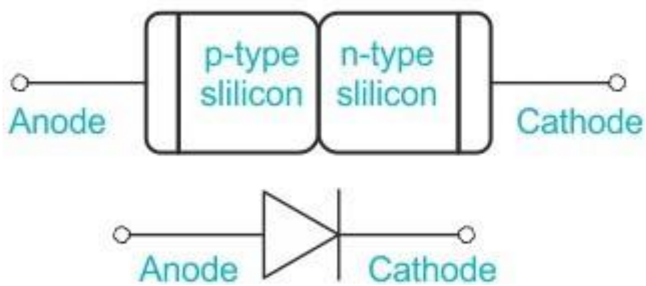
P-type Semiconductors

When intrinsic semiconductors either Si or Ge are doped with trivalent material, then the obtained semiconductor material is called P-type semiconductor. When a trivalent impurity Like Arsenic (Al) is added to the Si or Ge then the three valance electrons of impurity atom is shared by the host atoms (Si or Ge) and one of the electrons of host atom remain unshared. This result in the deficiency of an electron .Thus electron deficiency exists in valance band just above the conduction band and are called as acceptor levels.



PN Junction Diode

An interface or a boundary within a semiconductor device, between the P-type and the N-type semiconductor material, is called the PN junction.



Formation of PN Junction Diode

In a PN junction diode, an ionized donor is left behind on the N-side when an electron diffuses from the N-side to the P-side and a layer of positive charge develops on the N-side of the junction. When a hole moves from the P-side to the N-side, an ionized acceptor is left behind on the P-side, causing a layer of negative charges to accumulate on the P-side of the junction. The depletion area is defined as a region of positive and negative charge on each side of the junction. An electric field with a direction from a positive charge to a negative charge develops on either side of the junction.

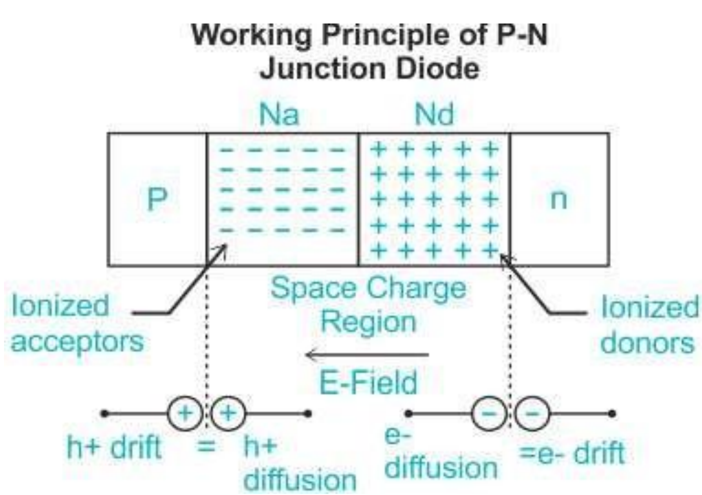


Fig- Construction Diagram of PN Junction Diode

The electric potential between P and N-regions changes when an external potential is supplied to the PN junction terminals. As a result, the flow of the majority of carriers is altered, allowing electrons and holes to diffuse through the PN junction.
The diode is thought to be in the forward bias state if the applied voltage reduces the width of the depletion layer, and reverse bias if the applied voltage increases the width of the depletion layer. The diode is said to be in the zero bias or unbias state if the breadth of the depletion layer remains unchanged.

VI Characteristics of PN Junction Diode

The relationship between the voltage across the junction and current through the circuit is known as the volt-ampere (VI) characteristics of a PN junction diode or semiconductor diode. Normally, voltage is measured along the x-axis, whereas the current is measured along the y-axis.

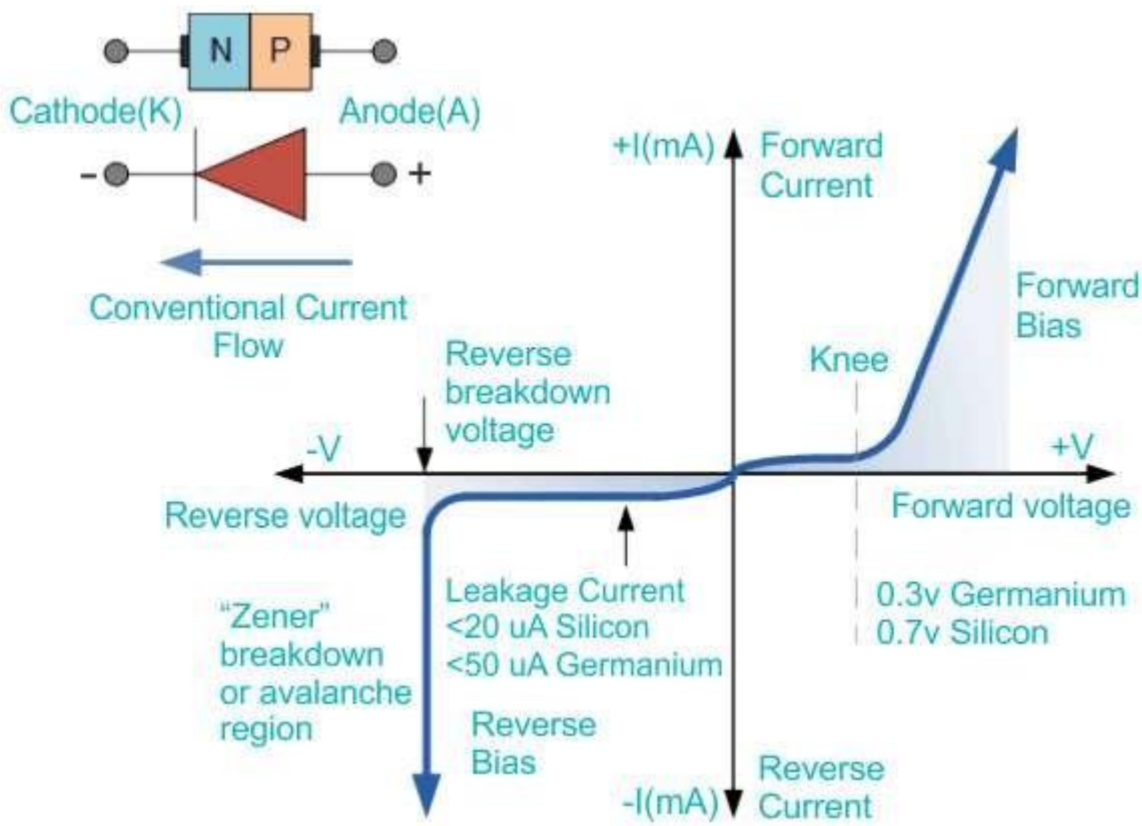


Fig- VI Characteristics of PN Junction Diode

The VI characteristics of PN junction diode can be explained in three cases:

- Zero bias or unbias
- Forward bias
- Reverse bias

Zero bias or unbias

No movement of holes or electrons occurs at zero bias state as no potential is applied externally which prevents the passage of electric current to flow in the diode.

Forward Bias

When the p-type is connected to the battery's positive terminal and the n-type to the negative terminal, then the P-N junction is said to be forward-biased.

Reverse Bias

When the p-type is connected to the battery's negative terminal and the n-type is connected to the positive side, the P-N junction is reverse biased.

Breakdown

In reverse biasing, when the applied potential is increased it leads to abrupt increase of reverse current this is called as breakdown. Two kind of mechanism are responsible for the abrupt current change

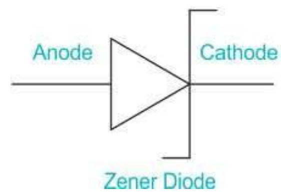
1. Avalanche breakdown This kind of break down occurs when the impurity concentration is lower. The increase in the reverse applied potential does not leads to increase in the current but increase in the potential results in the increase in the kinetic energy of electron, when electron acquires the kinetic energy of the order of the strength of covalent bond then this electron breaks the covalent bond of the atom resulting in the electron hole pair. Thus produced electrons get accelerated and break another covalent bond and the process continues in the generation of large number of current carriers and large current starts to flow across the junction. The avalanche breakdown results in the damage of diode.

2. Zener breakdown This kind of break down occurs when the impurity concentration is higher. The increase in the reverse applied potential does not leads to increase in the current but increase in the potential results in the widening of depletion layer. Thus a large electric field is set across junction, when the strength of internal field is of the order of the strength of covalent bond then this field breaks the covalent bond of the atoms resulting in the generation of large number of electron hole pairs and large current starts to flow across the junction. The zener breakdown does not damage the diode. When reverse potential is removed then the diode acquires its original state. The breakdown curve in this case is sharp near breakdown voltage.

S. No.	*Zener Breakdown*	*Avalanche Breakdown*
1.	This takes place in a very thin junction (the depletion layer is narrow).	This takes place in a thicker junction (the depletion layer is wide).
2.	This is observed in zener diodes at $V_z \sim 6$ V (or less).	This is observed in zener diodes at V_z greater than 6 V.
3.	In this, the carrier increase is the result of electric field strength (about 2×10^7 V/m).	In this, the carrier increase is the result of collisions.
4.	V-I characteristics with the zener breakdown is very sharp at V_z.	V-I characteristics with the avalanche breakdown is gradual near V_z.
5.	The breakdown voltage decreases with increase in temperature.	The breakdown voltage increases with increase in temperature.
6.	Zener breakdown does not result in the destruction of the diode.	Avalanche breakdown destroys the diode.

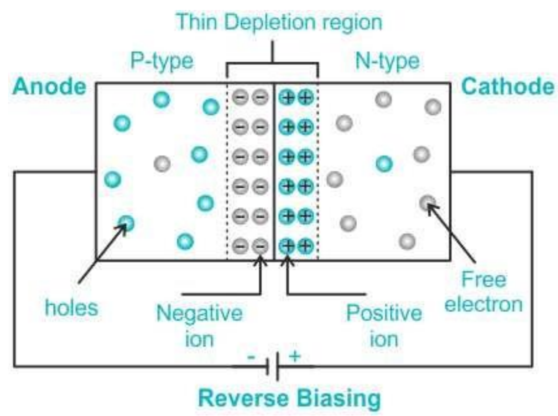
What is a Zener Diode?

A Zener diode can be defined as a heavily doped semiconductor device that is designed to operate the electric circuit in the reverse direction. It is also called a breakdown diode. It is a heavily doped semiconductor diode that is designed to operate the electric circuit in the reverse direction.



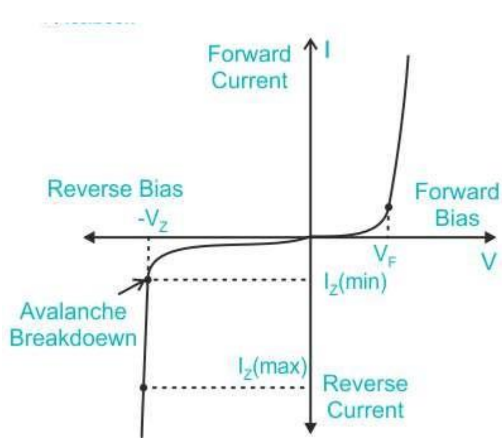
Working Principle of Zener Diode

The working principle is such that if the reverse bias voltage is less than the breakdown voltage, or if it is forward biased then it acts as an ordinary diode. This means that forward bias allows current to flow and reverse bias blocks the current from flowing. After this, the voltage surpasses the breakdown point in reverse bias, and the diode falls in the Zener region, where it gets conducted without getting damaged. Current in this region is known as avalanche current but for a Zener diode, it is also known as a Zener current.



Further, by controlling the amount of doping of the semiconductor material and by doing this the thickness of the depletion region in the PN junction and the breakdown voltage can be set to any value according to the need of the appliance.

V-I Characteristics of Zener Diode



The V-I characteristics of a Zener diode are divided into two parts which are mentioned as follows:

Forward Characteristics of Zener Diode

The first quadrant of the graph depicts the forward characteristics of a Zener diode, and from which we can understand that it is almost similar to the forward characteristics of any other normal PN junction diode.

Reverse Characteristics of Zener Diode

When a reverse voltage is applied to a Zener voltage, a small reverse saturation current which is I_oIo flows across the whole diode. This current is present due to thermally generated minority carriers present in the diode. As the reverse voltage starts to increase, at a certain value of reverse voltage the reverse current also starts to increase drastically and sharply. The breakdown in the diode has occurred. This voltage is known as breakdown voltage in zener diode or Zener voltage and is denoted by V_zVz.

Applications of Zener Diode

The uses of a Zener diode are mentioned as follows:

- **Zener Diode as Voltage Regulator**
- **Zener Diode in Over-Voltage Protection**
- **Zener Diode in Clipping Circuits**

3.13 HALL EFFECT

Definition. *When a metal or a semiconductor carrying a current I is placed in a transverse magnetic field B, a potential difference is produced in the direction normal to both the current and magnetic field directions. This phenomenon is called* ***Hall effect.***

Hall effect measurements showed that it is the negative charge carriers namely electrons that are responsible for electrical conduction in metals. It also showed that there exists two types of charge carriers in semiconductors.

Importance. The importance of Hall effect is that it helps to determine the :

(*i*) sign of charge carriers,

(*ii*) charge carriers concentration and

(*iii*) mobility of charge carriers if conductivity of the material is known.

Experimental Determination of Carrier Concentration and Mobility

Let us consider an *n*-type semiconductor in which the conduction is predominated by electrons. Suppose an electric current *j* flows in the positive *x*-direction and a magnetic field *B* is applied normal to this electric field in *z*-direction (Fig. 3.29). A force, called the Lorentz force is exerted on each electron which causes the electron paths to bend. As a result of this, the electrons accumulate on one side of the slab and are deficient on the other side.

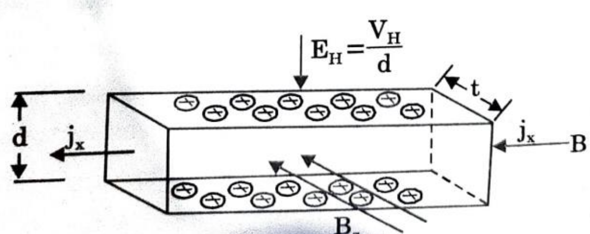


Fig. 3.29. Schematic view of an *n*-type semiconductor bar.

Thus, an electric field is created in the y-direction which is called the ***Hall field***. In equilibrium condition

Hall Force = Lorentz force

$$F_H = F_L$$

$$-qE_H = v_x B_z q$$

where v_x is the velocity of the electrons, and q the electronic charge ...(75)

$$\therefore \quad E_H = v_x B_z \qquad ...(76)$$

As current density $j_x = -Nv_x q$ $\left(\text{Putting } v_x = \frac{E_H}{B_z}\right)$

$$j_x = -\frac{NE_H q}{B_z}$$

$$N = -\frac{j_x B_z}{qE_H} = -\frac{j_x B_z}{q(V_H / d)} \qquad ...(77)$$

$$V_H = -\frac{j_x B_z d}{Nq} = -\frac{IB_z d}{NqA} \qquad ...(78)$$

[A = Area of cross-section of end face]

If t is the thickness of the semiconductor specimen, $A = dt$ and the above equation reduces to

$$V_H = -\frac{B_z I}{Nqt} \qquad ...(79)$$

Hall field per unit current density per unit magnetic induction is called **Hall coefficient** R_H. Thus,

$$R_H = \frac{E_H}{J_x B_z} = +\frac{V_H / d}{j_x B_z} = -\frac{B_z I}{j_x B_z d \cdot Nqt}$$

$$R_H = -\frac{1}{Nq} \qquad ...(80)$$

In terms of Hall coefficient, Hall voltage is given by

$$V_H = R_H \frac{BI}{t} \qquad ...(81)$$

The sign of the Hall coefficient R_H indicates whether electrons or holes predominate in the conduction process.

If R_H = negative, then electrons are the predominant charge carriers.

If R_H = positive, then holes are the predominant charge carriers.

The electron mobility is given as

$$\mu_n = \frac{\sigma}{N|q|}$$

Hence

$$\boxed{\mu_n = |R_H|\sigma} \qquad ...(82)$$

Thus, the magnitude of μ_n may also be determined if the conductivity σ has also been measured.

The net electric field E is the semiconductor is a vector sum of E_x (electric field component in x-direction) and E_H (Hall field). It acts at an angle θ_H to the x-axis. θ_H is called the **Hall angle.**

From Fig. 3.30.

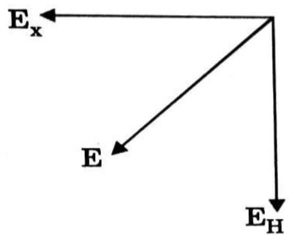


Fig. 3.30.

$$\tan\theta_H = \frac{E_H}{E_x} \qquad ...(83)$$

As
$$E_H = \frac{V_H}{d} = \frac{B_z / j_x}{N|q|} \qquad ...(84)$$

Also
$$E_x = \rho j_x \qquad ...(85)$$

$\therefore$
$$\boxed{\tan\theta_H = \frac{B_z}{N|q|\rho}} \qquad \left[\because \ \sigma = \frac{1}{\rho}\right]$$

$\therefore$
$$\tan\theta_H = \sigma R_H B_z$$

The product σR_H is designated as μ_n the mobility of electrons.

$\therefore$
$$\tan\theta_H = \mu_n B_z$$

$\therefore$
$$\boxed{\theta_H = \tan^{-1}(\mu_n B_z)} \qquad ...(86)$$

In the above discussions it is assumed that all carriers travel with a mean speed v_x. However this does not happen. As a result, the value of R_H gets modified. The appropriate value is

$$\boxed{R_H = \frac{3\pi}{8}\left(-\frac{1}{Nq}\right)} \qquad ...(87)$$

Accordingly,

$$\boxed{\mu_n = \left(\frac{8}{3\pi}\right)\sigma R_H} \qquad ...(88)$$

Applications:

1. Hall effect can be used for the measurement of the strength of magnetic field
2. It is used for the determination of carrier concentration of semiconductors
3. The sign of Hall coefficient tells about the predominant charge carriers in a semiconductor
4. Hall effect can be used for the amplification of weak signals

3.12 SOLAR CELL

The solar cell (or photovoltaic cell), is a device which converts light energy into electrical energy. This is an important photovoltaic device and is basically a *p-n* junction with a large surface area.

The high-efficiency solar cell was first developed by Chapin, Fuller and Pearson in 1954 using a diffused silicon *p-n* junction. Since then, solar cells have been developed and produced with polysilicon, CdTe and GaAs. In past four decades, a remarkable progress has been made.

Megawatt solar power generating plants have been built, solar cells are being combined with building materials, and are now the most important long-duration power supply for satellites and space vehicles. Over 95% of solar cells in production are silicon based.

A solar cell can deliver powers of the order of 1 kW/m^2. The schematic of the typical junction solar cell, with its top finger contacts, is shown in Fig. 3.27(*a*). The photovoltaic energy conversion process may best be expressed by the equivalent circuit shown in Fig. 3.37(*b*). An ideal diode is connected in parallel with a constant current (or voltage) source, which represents the photovoltaic energy generated, and with a load resistor.

(A) Basic Characteristics

The solar cell as shown in Fig. 3.27(*a*) consists of a shallow *p-n* junction formed by diffusion or epitaxy, on the surface a front ohmic contact stripe and fingers, and a back ohmic contact which covers the entire back surface. Fig. 3.27(*b*) represents the simplest equivalent circuit of the cell and contains the constant current source I_{ph}, the load current I, and the reverse saturation current of the diode I_s.

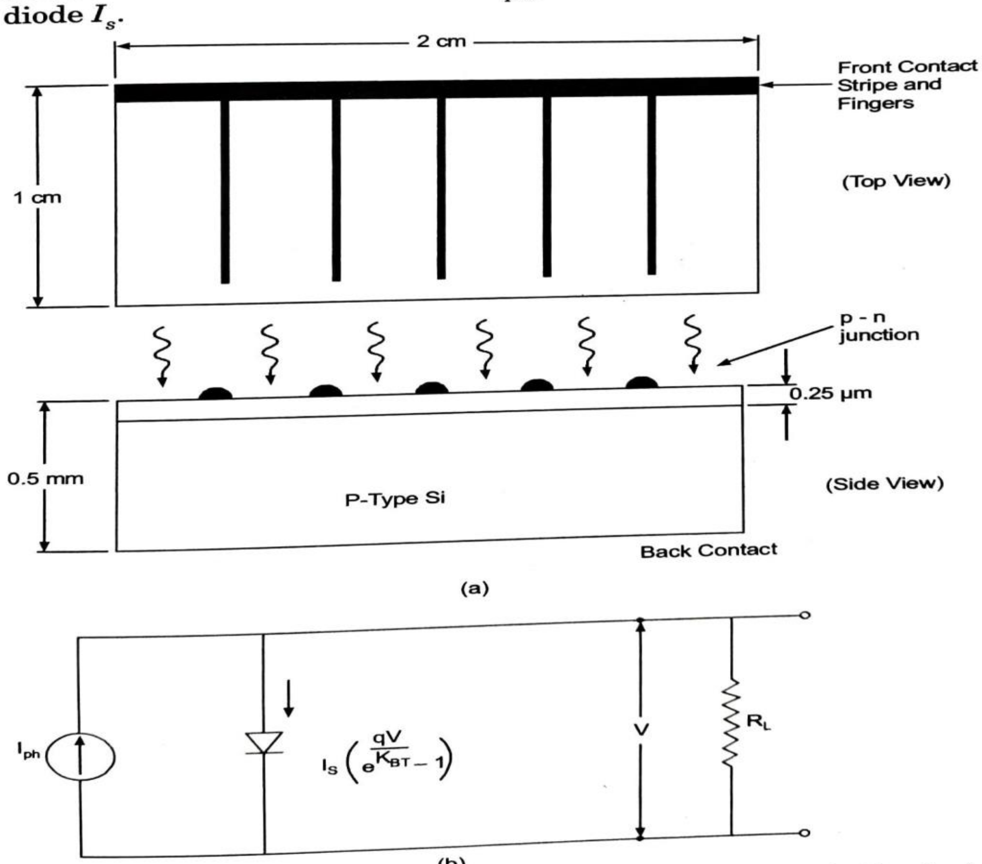


Fig. 3.27. (*a*) Schematic representation of a solar cell (Top and side view).
(*b*) The idealized equivalent circuit of a solar cell.

The current-voltage characteristics of such a device are given by

$$I = I_s \left[e^{\frac{qV}{kT}} - 1 \right] - I_{ph} \qquad ...(68)$$

A plot of Eqn. (68) is shown in Fig. 3.28(*a*). For $I_{ph} = 0.1$ amp, $I_s = 10^{-9}$ amp, and $T = 300°$ K. As shown in the plot, the curve passes through the fourth quadrant and therefore that power can be extracted from the device. By properly choosing a load, it is possible to extract close to 80% of the product $I_{sc} \times V_{oc}$ where I_{sc} is the short-circuit current and V_{oc} is the open-circuit voltage of the cell, as shown by the maximum power rectangle. Figure also defines the quantities I_{mp} and V_{mp} which defines to the current and voltage for the maximum power output ($P_m = I_{mp} \times V_{mp}$) respectively.

Using Eqn. (68), we obtain for the open-circuit voltage

$$V_{oc} \equiv V_{\max} = \frac{kT}{q} \ln\left(\frac{I_{ph}}{I_s} + 1\right) \cong \frac{kT}{q} \ln\left(\frac{I_{ph}}{I_s}\right) \qquad ...(69)$$

The output power is given by

$$P = IV = I_s V \left(e^{\frac{qV}{kT}} - 1 \right) - I_{ph} V \qquad ...(70)$$

For maximum output power; $\frac{\partial P}{\partial V} = 0$

$$0 = I_s \left\{ V e^{\frac{qV}{kT}} \cdot \frac{q}{kT} + e^{\frac{qV}{kT}} \right\} - I_s - I_{ph}$$

$$\frac{I_{ph}}{I_s} = \frac{qV}{kT} e^{\frac{qV}{kT}} + e^{\frac{qV}{kT}} - 1$$

For maximum power $V = V_{mp}$

$$\left(1 + \frac{I_{ph}}{I_s}\right) = \exp\left(\frac{qV_{mp}}{kT}\right)\left[1 + \frac{qV_{mp}}{kT}\right] \qquad ...(71)$$

$$V_{mp} = \frac{kT}{q} \ln\left[\frac{(1 + I_{ph} / I_s)}{1 + (qV_{mp} / kT)}\right]$$

and

$$I_{mp} = \left[I_s \left(e^{\frac{qV_{mp}}{kT}} - 1 \right) - I_{ph} \right]$$

$$= I_s \frac{qV_{mp}}{kT} e^{\left(\frac{qV_{mp}}{kT}\right)} \qquad ...(72)$$

Maximum Power Output, $P_{mp} = I_{mp} \times V_{mp}$

The **efficiency** of solar energy conversion is given then by

$$\eta \equiv \frac{\text{maximum power output}}{\text{power input}} = \frac{I_{mp} V_{mp} / \text{cm}^2}{P_{\text{in}} / \text{cm}^2}$$

$$\eta = \frac{I_{ph}\, qV_{mp}^2}{kT\left(1 + \frac{qV_{mp}}{kT}\right) A} \left(1 + \frac{I_s}{I_{ph}}\right) \frac{1}{P_{in} / cm^2} \qquad ...(73)$$

where A is the exposed front area of the solar cell and P_{in}/cm^2 is the solar power density outside the atmosphere.

The I-V curve is more generally represented by Fig. 3.28(a) which is simply an inversion of Fig. 3.28(b) about the voltage-axis.

Fill factor of a solar cell is defined as

$$\boxed{FF \equiv \frac{I_{mp} V_{mp}}{I_{ph} V_{oc}}} \qquad ...(74)$$

The fill factor is the ratio of the maximum power rectangle [Fig. 3.28 (b)] to the rectangle of $I_{ph} \times V_{oc}$. In most solar cells the fill factor is ~ 0.7.

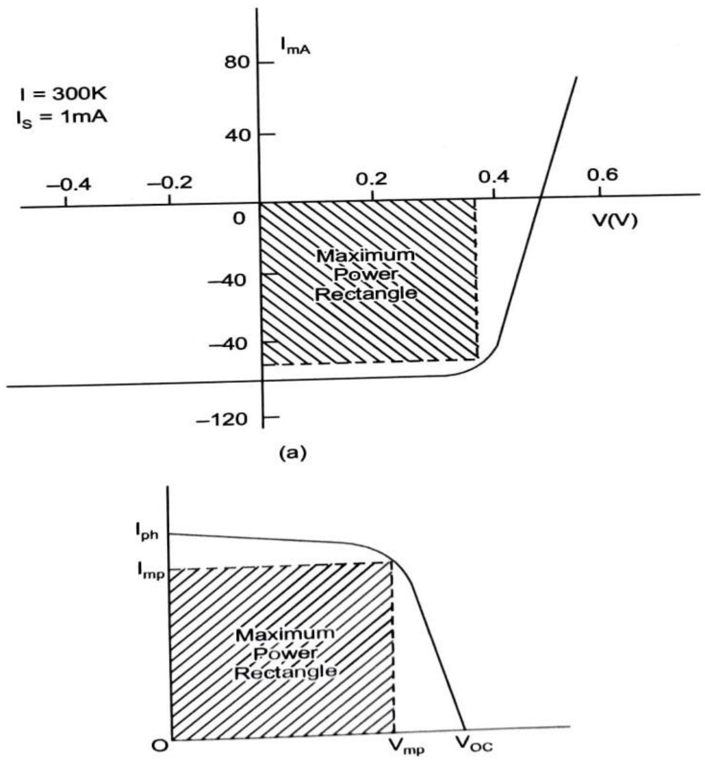


Fig. 3.28. (a) Current-voltage characteristics of a solar cell under illumination (b) Inversion of (a) about the voltage axis.

Unit - 4

Laser.

Laser :- Laser is a device that emit a beam of monochromadic or coherent light of high intensidy and depped on the phenomena of Stimulated emmision. laser stand for light amplification by Stimulated emission of radiation.

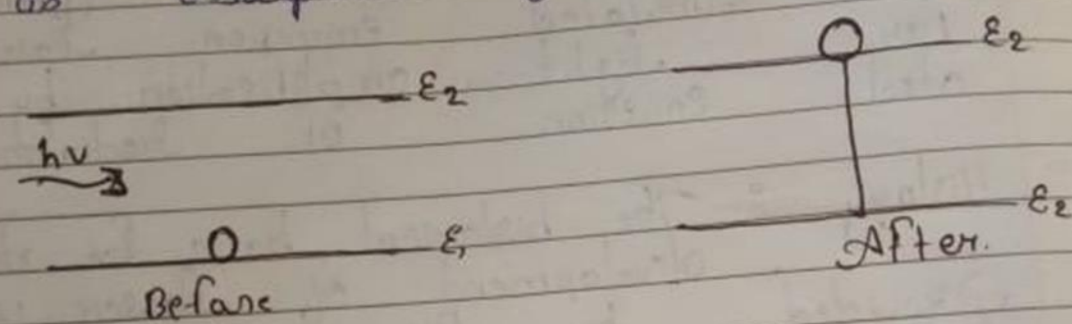
History :- The historical basic for the development of lasser was provided by Albert einstine in 1917.

- In 1960 the first laser device was developed by T.H Maiman - ruby laser emid red light of waves of 694.3Nm.

Energy densidy :- It is defined was radiate energy per unit volume in frequency inter ν and $\nu + d\nu$.

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

Where E_1 and E_2 and the energy of atom in state 1 and 2 respectively this process is known as absarption of radiation.

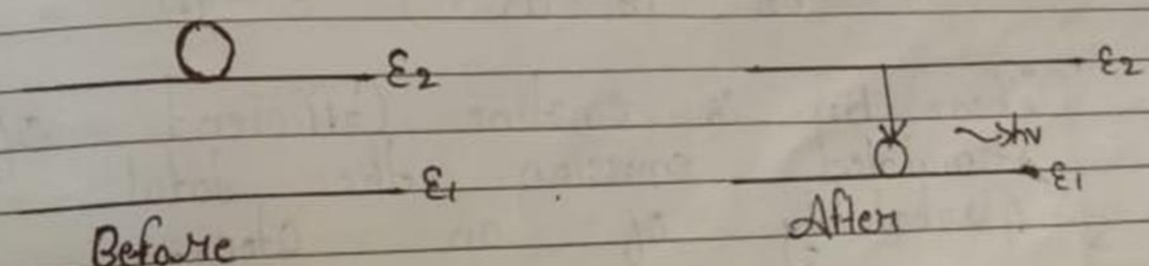


Absarption of radiation.

The Provable rate of accurance of the observation transition to 1-2 is directly proportional to the energy density (u) of the radiation of frequency (v) incident on the atom therefore the probable rate of accurance of absorption transition is.

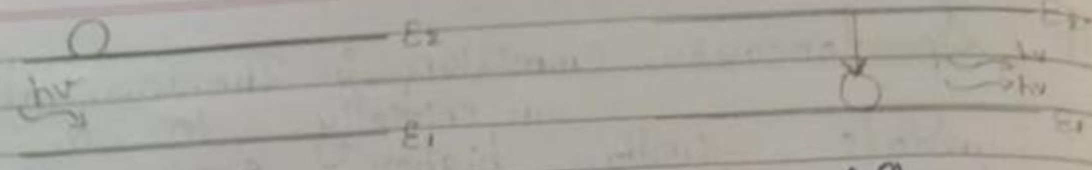
$$P_{12} = B_{12}\, u(\nu) \quad \text{---} (1)$$

Spontaneous emmision :- If an atom enidially in a higher State with higher energy is unstable hence atom exist there was limited Period known as lirde livetime the average livetime of an atom in a excited State a is 10^{-8} second and it lumps to lower State 1 emiding a Photone of frequency ν this is Spontanious emission of radiadion.



The The Probability of Spontaneous emission 2 -> 1 is Independent of energy densidy and it it is denoted by A_{21} and it known as einsding Cofficient of Spontaneous emision of radiadion.

Stimulated emision :- During a Short interval a Photone of ... on the



Before   After

The Probability of Stimulated emission of transidion $2 \to 1$ is Propodional to energy densidy $u(\nu)$ of the Stimulading radiadion and it given by.

$$P_{21} = B_{21}\, u(\nu) \quad \text{—— (2)}$$

Where B_{21} is einsdine Cofficient of Stimulated emission the dotal Probabilidy of an atom.

$$P_{21} = A_{21} + B_{21}\, u(\nu) \quad \text{—— (3)}$$

Reladion b/w einsdine's Cofficient :- Consider an assembly of atoms

In traval equilin of frequency ν equililarium at temprature T with

The no. of atom in State 2 that drop to State 1 either by Spontaneous emission by Stimulated emission is given by.

$$N_1 P_2 = N_1 B_{12} u(v) \quad — (4)$$

The no. of atom in State 1 that absorb a Photone and rise to State 2 per unit time is given by.

$$N_1 P_{12} = N_2 [A_{21} + B_{12} u(v)] \quad — (5)$$

Under the Condition of equilibrium the no. of atom absorbing radiation per unit time is equal to the no. of atom emitting radiation per unit time.

$$N_1 P_{12} = N_2 P_{21} \quad — (6)$$

$$N_1 B_{12} u(v) = N_2 [A_{21} + B_{21} u(v) \quad — (7)$$

$$[N_1 B_{12} - N_2 B_{21}] u(v) = N_2 A_{21} \quad — (8)$$

Thermodynamically, it was proves by einsdine that the prov of Stimulated obsorption is equal do the probability of stimulated emission.

$$B_{12} = B_{21} \quad \text{—— (11)}$$

$$u(v) = \frac{A_{21}}{B_{21}} \frac{1}{\left[\frac{N_1}{N_2}\right] - 1]} \quad \text{—— (12)}$$

According do Balzmann distribution low

$$\frac{N_1}{N_2} = \exp \cdot \left[\frac{\mathcal{E}_2 - \mathcal{E}_1}{kT}\right] = \exp \frac{hv}{kT} \quad \text{—— (13)}$$

k = baltzman Constant

Subsiduding the value of (N_1/N_2) from 13 eqn do eqn 10.

$$u(v) = \frac{A_{21}}{B_{21}} \times \frac{1}{(\exp\left(\frac{hv}{kT}\right) - 1} \quad \text{—— (14)}$$

According do Plank's radiation low

Comparing (14) and (15)

$$\left[\frac{A_{21}}{B_{21}} = \frac{8\pi h \nu^3}{c^3}\right]$$

It show that A_{21}/B_{21} is directly proportional to the ν^3.

This shows the probability of spont emisson increase rapidly with the increase of energy different b/w two states.

Properties of laser beam :-

(1.) **High directionality :-** laser source emit radiation only in one direction i.e beam is highly directional

(2.) **High Intensity :-** Intensity of light is defined as the energy passing normally permit over seconde through a point normal to direction of flow.

$\left[I = \frac{P}{\ldots} \right]$ P - power of the source

100 w Source.

(3.) Monochromocity and Cohrence :- high from a laser beem is nearby monochromatic than from ordinary Source of light.

Coherence :- The laser beam is Compeeredtively Coherent it is Possible to observe interference effects from two laser beam.

Population Inversion :- The Process by which the Population of a Particular higher one energy State is made more than that by Specified lower energy State is Called as Population inversion.

A System in which Population invension is achived is Called active System.

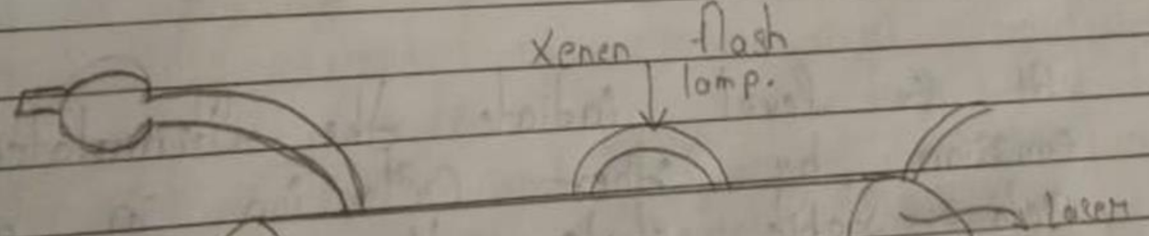
Meta Stable State :- In Order to achive Population

Different types of laser :-

(i) Ruby laser :- Ruby laser is a first Solid State laser build by mainan in 1960 it is based on 3 energy level.

Construction :- It Consist of pink ruby Cylindrical rod whose ends are optically flat and parallel one and hand its fully Silvered and Other is Only partially Silver upon the rod is wound a Called flash lamp filled with xenon.

Basically it Al_2O_3 (Aluminium oxide) Crystal doped with 0.05% by weight of chrominium oxide (Cr_2O_3) Al^{3+} ions rep-laced by Cr^{3+} the impurity of Cr^{3+} are responsible for the pink Colour.

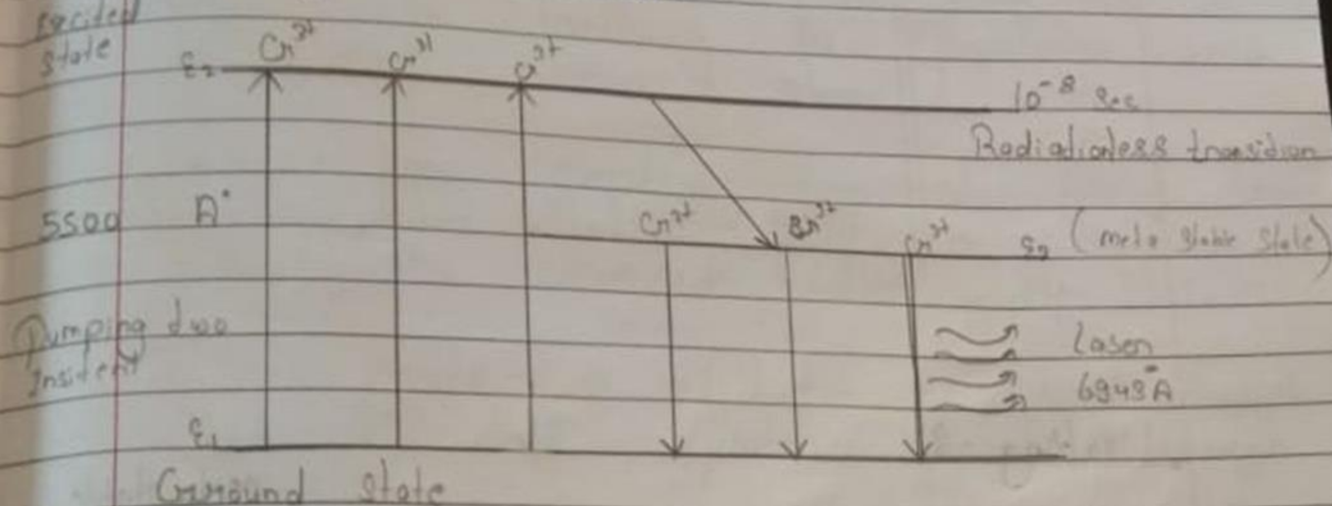


Working :- upper energy level is short lived state ε_2 above the ground state energy level ε_1 there is an intermediate exited state energy level ε_2 (meta stable state) having lifetime 3×10^{-3} cm.

Most of the Cr^{3+} ions are in the ground state ε_1 when the xenon flash lamp of light falls upon the ruby rod 5500 Å of radiation Photone are observed by Cr^{3+} ion which Pumped to ε_3 by optical Pumping transition Cr^{3+} ions decay to metastable state ε_2 that is from ε_3 to ε_2 is radiationless transition form ε_2 the number of E_3^+ ions increasing due to Pumping Population inverse is stablised b/w ε_2 and ε_1 Cr^{3+} ions.

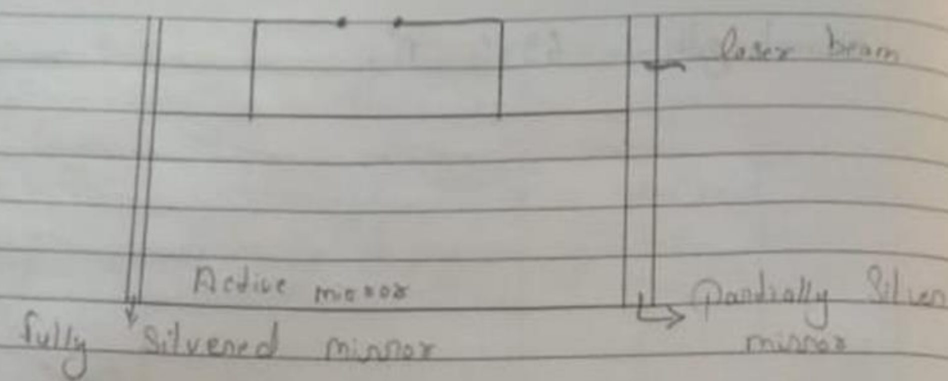
At ε_2 level indiate the Stimulated emission by other Cr^{3+} ion in the

Wavelength 6943 Å.

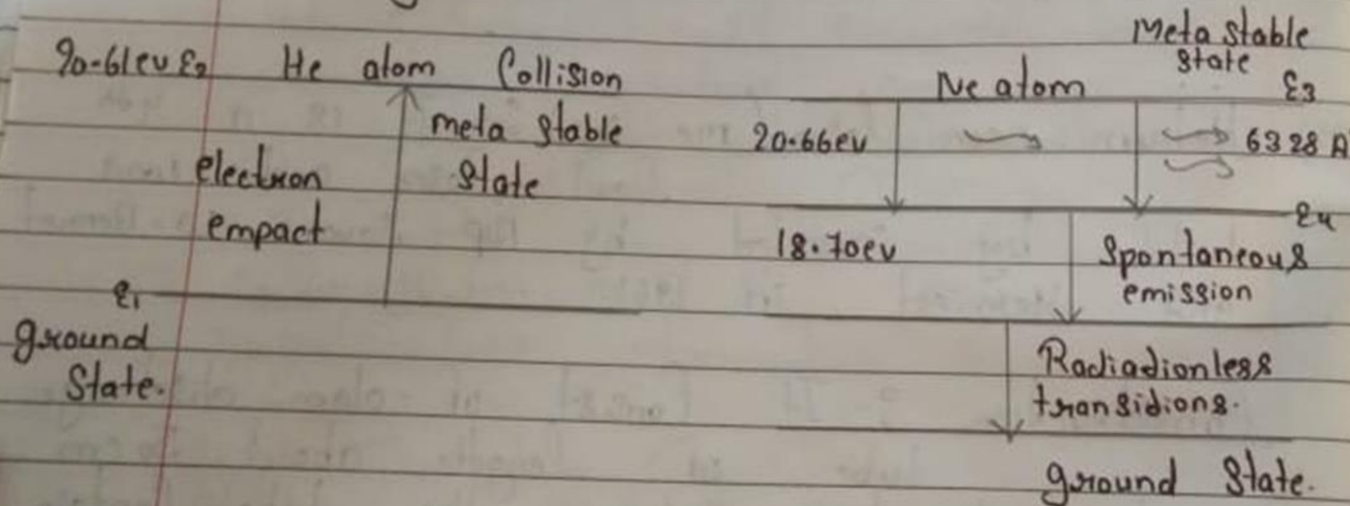


(ii.) <u>Helium - neon laser (He - Ne)</u> :- It is a 4th level laser and was build by inverted by Alp Javan, W. Bennet and Herriest in 1961.

<u>Construction</u> :- It Consist of glass discharge tube of length about 50 cm and diameter 1 cm the tube Contain a mixture of 10 parts of helium and 1 Part of Neon at low Pressure are filled at both ends of the tube ... Parallel mirror one



Working :-



When the Power is Swiched on the e⁻ from the dischange Coilled width and Pump the he and Ne atom metastable State 20,61ev and 20.66ev

The purpose of the He atom is to help in achiving a population inversion in the neon atom.

When an excited neon atom passes from the meta stable state of 20.66eV to an excited state of 13070 eV. It emits a photon of wave length 6328 A° this photon travels through the gas mixture and moving in the tube is reflected by the mirror ends until it stimulated an excited neon atom and causes it to emit a fresh 6328 A° photons in the phase with stimulated photon this process is continue and when a been of coherent radiation becomes intence, a portion of its scope through the partially silver end the neon atom passes spontaneously to lower energy level and finally comes down to the ground state by

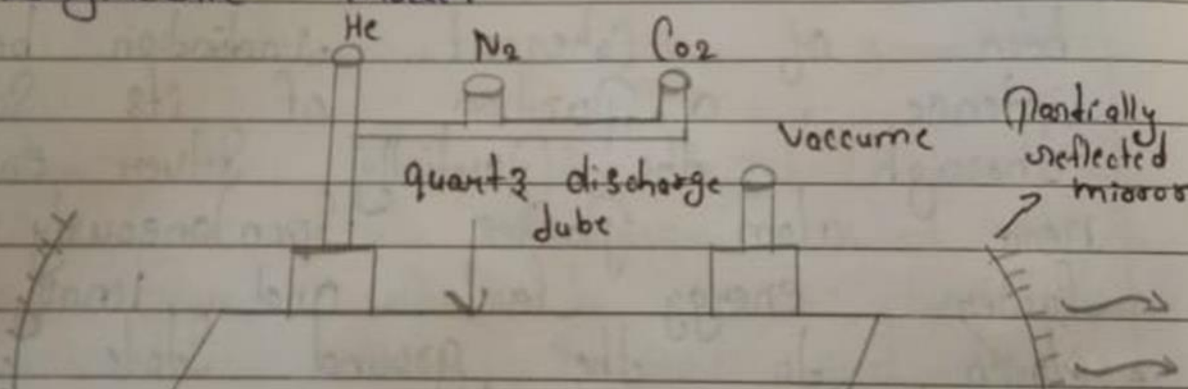
It is a four level molecular gas laser in this laser transidion takes place b/w viberadion energy state of Carbon dioxide molecules it is very efficient laser.

Construcdion :- It Consist of a quartz dischange tube 2m long and 2.5 cm in diameter this discharge tube is filled with the gas mixture of CO_2 nitrogen and helium with Suitable Pressure.

(1.) Streatch mode.

(2.) Bending mode.

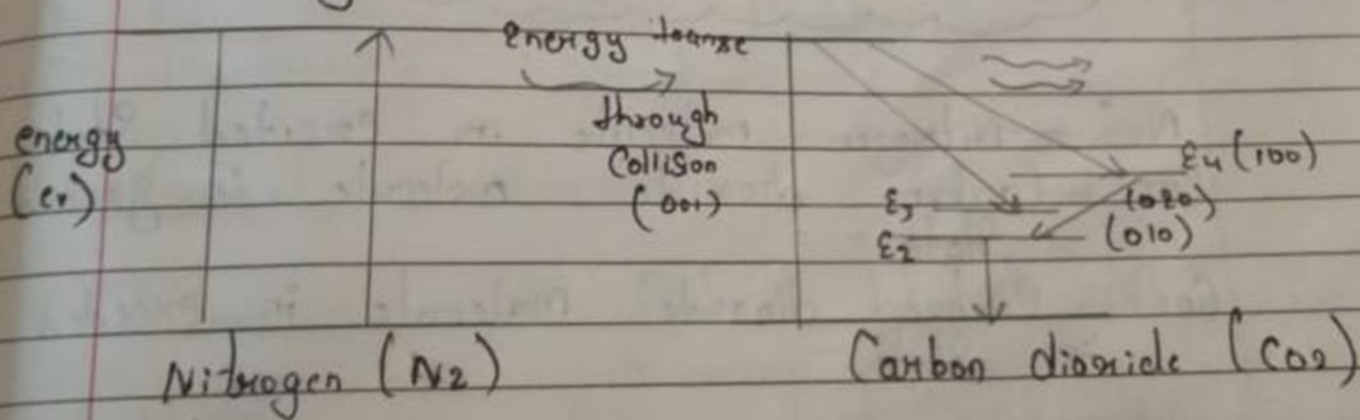
(3.) Assymetric mode.



The terminals of the discharge tube are connected to DC power supply the ends of this tube are fitted with NaCl Bewster window so that the laser light generated is plane polarised.

The optical resonator is formed with two concave mirror one fully reflecting M_1 with the other partially reflecting M_2.

Working :-



When the electrical discharge occurs in gas mixture the electrons collide with nitrogen molecule and they raised to

N_2 — Nitrogen molecule in ground state
e^* — electron with high energy
N_2^* — Nitrogen molecule in excited State.
e — Same electron with laser energy

Since excited energy level of nitrogen is very close to E_5 energy level of CO_2 molecule CO_2 molecule are excited by energy transfer and population inversion.

$$N_2^* + CO_2 \rightarrow CO_2^* + N_2$$

N_2^* — Nitrogen molecule in excited State.
CO_2 — Carbon dioxide molecule in ground State.
CO_2 — Carbon dioxide molecule in excided State.

There are two possible type of laser transition.

(i) transition $E_5 - E_4$:- This transition

of wavelength 9.6 μm.
Normally 10.6 μm transition is more intense than 9.6 μm transition the power output from this laser is lower.
The presence of helium with CO_2 decrease the population at E_1 by colliding and the lasing action continue.

A. **Application.**

(1.) Used in surgery.
(2) As laser fusion facilities.
(3) Macheining operation.

Optical fiber:

Introduction to Optical fiber :- After the invension of laser in 1960 there has been fast growth in the field of fibre optics in 1973 the airbone light optical fiber technology (ALOFT) programe replaced 302 cables which weight 40 kg by fiber system which weight only

Them and works on the Principle of the Total internal Re-fraction (TIR).

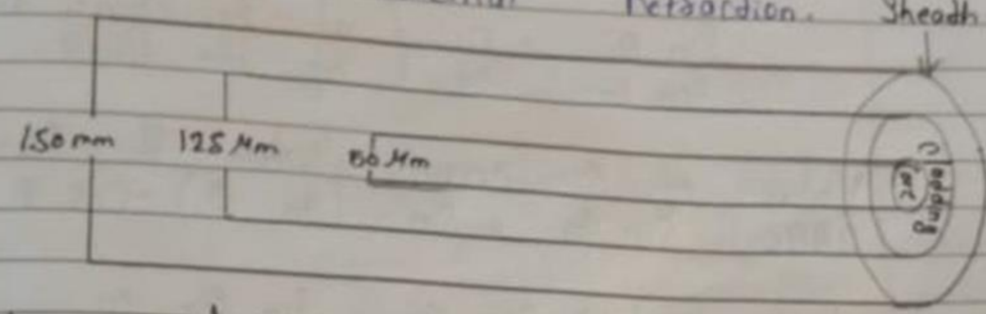
When light enters into the Opdicle fiber it undergoes TIR from Side walls and travelled down along a zig-zag Path it Consist of three regions the Central region is Core the middle region is Care the middle region is Cladding the outer region Sheath

<u>Total Internal Refrection</u> :- When the angle of refraction in rear medium is 90° a Critical angle is reached at the Point of incidence.

The angle of incident in denser medium is known as Critical angle (θ) by the Snell's low.

$$\frac{n_2}{n_1} = \frac{\sin \theta}{\sin 90^\circ} \Rightarrow \frac{n_2}{n_1} = \sin \theta_c.$$

light will be reflected back to the incident medium this phenomenon is Called total internal Refraction.



☆ Acceptance Angle, Cone and numerical Aperture :-

Let us Consider light traveling in a opticle fiber the end at which the enters the fiber is Called launching ends if the refractive index of the Core be n_1 and the refractive index of the cladding be n_2 $(n_2 \to n_1)$ let the Outside medium have a refreactive index n_0. and a light ray enter at an angle θi to the axis of the fiber let the refracted ray make an angle θr with axis and strikes the Core- Cladding interference at angle ϕ.

For TIR $\phi > \theta_c$ (critical angle) Applying Snell's law.

$$\frac{\sin \theta_i}{\sin \theta_r} = \frac{n_1}{n_0} \quad \text{(at launching face of the fiber.)} \quad (1)$$

Value of θ_i occurs when $\phi = \phi_c$ from ΔABC, $\sin \theta_r = \sin(90 - \phi) = \cos \phi$ — (2)

from eq (1) $\sin \theta_i = \sin \theta_r \frac{n_1}{n_0}$

$$\sin \theta_i = \frac{n_1}{n_0} \cos \phi$$

when $\phi = \phi_c$, $\phi_i = \theta_{max}$

$$\sin \theta_{max} = \frac{n_1}{n_0} \cos \phi_c \quad (3), \quad \sin \phi_c = \frac{n_2}{n_1}$$

$$\cos \phi_c = \frac{\sqrt{n_1^2 - n_2^2}}{n_1^2} \quad (4)$$

$$\sin^2 \phi_c = n_2^2 / n_1^2$$

$$1 - \sin^2 \phi_c = 1 - \frac{n_2^2}{n_1^2} = \frac{n_1^2 - n_2^2}{n_1^2}$$

If $n_0 = 1$, θ_{max} will be θ_m

$$\sin \theta_m = \sqrt{n_1^2 - n_2^2}$$

$$\theta_m = \sin^{-1} \sqrt{n_1^2 - n_2^2}$$

Acceptance angle :- Acceptance angle is define as the maximum angle that a light way can have relative to the axis of the fibre and propogate down the fibre the light way contains with the phone having a full angle 2θm are accepted and transmitted along the fibre, this phene is known as acceptance phone.

Fractional Refracted index change :- It is defused as the radio of difference between the refractive indeses of the and the cladding to the refractive index of the core.

$$\Delta = \frac{n_1 - n_2}{}$$

acceptance angle this angle is the measurement of a light gathering Power of fibre.

$NA = \sin\theta = \sqrt{N_1^2 - N_2^2}$

$NA = \sqrt{n_1^2 - n_2^2} = n_1\sqrt{2\Delta}$

Que. 1 Calculate the numerical Aperture and acceptance angle for an optical given that $N_1 = 1.45$ and $N_2 = 1.41$

$= \frac{1.45 - 1.41}{1.45} = \frac{0.04}{1.41} = 0.02$

$NA = 1.45 \times \sqrt{\frac{0.014 \times 2}{1.41}} = 0.33$

Que. 2. $N_1 = 1.55$, $N_2 = 1.50$ Calculate N_A

$N_A = \sqrt{N_1^2 - N_2^2}$ $\sqrt{(1.55)^2 - (1.50)^2} = 0.39$

V Number :- V number is the fundamental is relationship b/w numericals Aperture (NA) cut off wavelength and

$$V = \frac{2\pi a}{\lambda}(NA) \text{ or } V = \frac{2\pi a}{\lambda} \times n\sqrt{2\Delta}$$

Where a = radius of the Core wavelength
The wavelength Corresponding to the value of V = 2.405 is knowing as out of wavelength of the fiber.

$$\lambda c = \frac{\lambda V}{2.405}$$

Pyqs:

Q. 1:- What is the working Principle of Optical fibre. ?

Jan. 2023

(a) How do light Propegates through it? Define -ne.

(1.) Terms : numerical Operture, Population inversion number.

(b.) Explain Construction and Working of CO_2 laser with Suitable energy level diagram.

(Dec. 2023)

Q(1)(a) Explain Population inversion.

(b) Write the Properties of lasers.

(C) Discuss the working of He-Ne laser with labelled diagram.

Q.(2) (a) Write down the importance of TIR in Optical fiber.

(b) Write down the application of laser in engineering and madicine.

(c.) Calculate NA and acceptance angle for an optical fiber given to refractive indices the Core and Cladding are 1.45 and 1.41 respectively.

Nov. 2022:

Q.1:- (a) Drive the relationship b/w einstine and B Cofficient.

Q.2:- (a.) Explain the Constoucdion and Working of He - Ne laser.

(b.) Explain NA of an Opdical fibre Calculate the NA of a fiber with refraction -es of Core and cladding are 1.55 and 1.50 respectively.

... note on :- Properties of laser light unit - 5.

Electrostatics

Coulombs law :-

$$F \propto q_1 q_2$$

$$F \propto \frac{1}{r^2}$$ [inverse Square law]

$$F \propto \frac{q_1 q_2}{r^2}$$

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

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

$$k = \frac{Nm^2}{C^2}$$

- Linear charge density => $\lambda = \frac{Q}{l}$
- Surface — // — => $\sigma = \frac{Q}{A}$
- Volume — // — => $\rho = \frac{Q}{V}$

Electric field intensity (E) =>

$$F = \frac{kq^2}{r^2}$$

$$F = \frac{kqQ}{r^2}$$

$$E = \frac{F}{q} = \frac{kQ}{r^2}$$

Electric flux (ϕ) =>
$\phi = E \cdot dA = EdA \cos\theta$.

The Operator $\vec{\nabla}$ (del)

$$\vec{\nabla} = \hat{i}\frac{d}{dx} + \hat{j}\frac{d}{dy} + \hat{k}\frac{d}{dz}$$

Operation with del Operator ($\vec{\nabla}$)
Let a function ϕ

(1) $\vec{\nabla}\phi$ (Gradient) Simply Product :-
Gradient of a Scalar.

Gradient of a Scalar :-
The gradient of a Scalar field V is a vector that gives its magnitude and is directed allow the maximum rate of change of V

It is denoted by ($\vec{\nabla}V$)

Example :-

Q. => If $V = 3x^2y - y^2z^2$, find the grad V at the point (1, -2, -1)

Solve

$$\vec{\nabla} \Rightarrow \hat{i}\frac{d}{dx} + \hat{j}\frac{d}{dx} + \hat{k}\frac{d}{dz}.$$

$V = 3x^2y - y^2z^2$
grad $V = \vec{\nabla}V$
$= \left(\hat{i}\frac{d}{dx} + \hat{j}\frac{d}{dy} + z\frac{d}{dx}\right)(3x^2y - y^2z^2)$

$= \hat{i}\frac{d}{dx}(3x^2 - y - y^2 - z^2) + \hat{j}(3x^2 - y - y^2 - z^2) + z\frac{d}{dz}(3x^2y - y^2 - z^2)$

$\vec{\nabla}V = \hat{i}\,6xy + \hat{j}(3x^2 - 2yz^2) - \hat{k}(2y^2z)$

at the point (1, -2, -1)

$\vec{\nabla}V = -12\hat{i} + 7\hat{j} + 3\hat{k}$

(ii) $\vec{\nabla}\cdot\phi$ (Divergence)

① Divergence of a vector :-

The divergence of a vector flux density A is the out flow of flux from a small closed surface where per unit volume shrinks zero..

Let us consider closed surface S and closing a volume V in a region in which the vector flux A is specify. then close surface.
$\oint A \cdot ds$

it is the gives the net out flow of the flux. in the limit.

Let its volume shrinks to a point the quantity.

$$\lim_{\Delta v \to 0} \frac{\oint \cdot A ds}{\Delta v}$$

it is the amount of a flux of a quantity is vector represented by $\frac{A}{\nabla \vec{v}}$ per / volume. where the volume is called is known as the divergence of a vector.

Example :-

Q. => Find div. D at the origin. if $D = e^{-x} \sin y \hat{i} - e^{-x} \cos y \hat{j} + 2z \hat{k}$

Solve.

$$D = e^{-x} \sin y \hat{i} - e^{-x} \cos y \hat{j} + 2z \hat{k}$$

$$\vec{\nabla} = \hat{i} \frac{d}{dx} + \hat{j} \frac{d}{dy} + \hat{k} \frac{d}{dz}$$

$$\vec{\nabla} \cdot \vec{D} = \left[\hat{i} \frac{d}{dx} + \hat{j} \frac{d}{dy} + \hat{k} \frac{d}{dz} \right] \cdot \left[e^{-x} \sin y \hat{i} - e^{-x} \cos y \hat{j} + 2z \hat{k} \right]$$

$$= \frac{d}{dx} \left(e^{-x} \sin y \right) + \frac{d}{dy} \left(e^{-x} \cos y \right) + \frac{d}{dz} (2z) =>$$

A vector point function A is set to be solenoidal in a region if its

Read flux accross any closed surface in that region be zero.

$$\text{div } A = \nabla A = 0$$

(iii) $\vec{\nabla} \times \phi$ (curl)

Curl of a vector.

The curl of a vector of at any point is a vector whose mangnitude is maximum net circulation curl. is a normal direction of the area when the area is oriented to make the net circulation maximum the circulation of a vector field a around the closed l is given as $\oint A \cdot dl$. a vector point function A is set to be irrotational if the curl of a vector A is zero.

$$A = \vec{\nabla} \times \vec{A} = 0$$

Example :-

Q. => If $A = xz^3 \hat{i} - 2x^2 yz \hat{j} + 2yz^4 \hat{k}$ find curl A at the point (1, -1, 1)

Solve

$$\vec{\nabla} \times \vec{A}$$

$$= \left[\hat{i} \frac{d}{dx} + \hat{j} \frac{d}{dy} + \hat{k} \frac{d}{dz} \right] \times \left[xz^3 \hat{i} - 2x^2 yz \hat{j} + 2yz^4 \hat{k} \right]$$

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$$\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{d}{dx} & \frac{d}{dy} & \frac{d}{dz} \\ xz^3 & -2x^2yz & 2yz^4 \end{vmatrix}$$

$= \hat{i}\left[\frac{d}{dy} 2yz^4 - \frac{d}{dz}(2x^2yz)\right] - \hat{j}\left[\frac{d}{dx}(2yz^4) - \frac{d}{dz}(xz^3)\right] + \hat{k}\left[\frac{d}{dx}(2x^2yz) - \frac{d}{dy} xz^3\right]$

$= \hat{i}[2z^4 + 2x^2y] + \hat{j}[3xz^2] - \hat{k}[4xyz]$

at $(1, -1, 1)$

$\hat{i}[(2(1)^4 + 2(1)^2(-1)] + \hat{j}[3(1)\times(1)^2] - \hat{k}[4(1)\times(-1)\times(1)]$

$\hat{i}[2-2] + \hat{j}(3) - \hat{k}[-4]$

$\hat{i} + 3\hat{j} + 4\hat{k}$

$= 3\hat{j} + 4\hat{k}$

Q.→ Find gradient ϕ. if $\phi = 4x^2 - 3xy - 8z^2y$

$\vec{\nabla} = \hat{i}\frac{d}{dx} + \hat{j}\frac{d}{dy} + \hat{k}\frac{d}{dz}$

$\phi = 4x^2 - 3xy - 8z^2y$

grad:- $\vec{\nabla} \times \phi$

$\left[\hat{i}\frac{d}{dx} + \hat{j}\frac{d}{dy} + \hat{k}\frac{d}{dz}\right] \cdot \left[4x^2 - 3xy - 8z^2y\right]$

$\hat{i}(4x^2 - 3xy - 8z^2y) + \hat{j}(4x^2 - 3xy - 8z^2y) + \hat{k}\left(\frac{d}{dx} 4x^2 - 3xy - 8z^2y\right)$

$= \hat{i}\frac{d}{dx}(8x - 3y) + \hat{j}\frac{d}{dy}(0 - 3x - 8z^2) + \hat{k}\frac{d}{dz}(0 - 0 - 8zy)$

$= \hat{i}\frac{d}{dx}(8x - 3y) + \hat{j}\frac{d}{dy}(-3x - 8z^2) + \hat{k}\frac{d}{dz}(8zy)$

$= \hat{i}(8x - 3y) - \hat{j}(3x - 8z^2) - \hat{k}(8zy)$

(ii) Find $\vec{\nabla} \times \vec{f}$, if $= 3x\hat{i} - 2yz\hat{k} + 4x^2yz\hat{j}$

$\vec{\nabla} \times \vec{f} = \left[\hat{i}\frac{d}{dx} + \hat{j}\frac{d}{dy} + \hat{k}\frac{d}{dz}\right] \cdot \vec{f} = 3x\hat{i} + 4x^2yz\hat{j} - 2yz\hat{k}$

$$\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{d}{dx} & \frac{d}{dy} & \frac{d}{dz} \\ 3x & 4x^2yz & -2yz \end{vmatrix}$$

$\hat{i}\left[\frac{d}{dy} 4x^2y^2 - \frac{d}{dz}(-2yz)\right] - \hat{j}\left[\frac{d}{dx} 3x - \frac{d}{dz}(-2yz)\right] + \hat{k}\left[\frac{d}{dx} 3x - \frac{d}{dz}(-2yz)\right]$

$\hat{i}[8x^2y + 2z] - \hat{j}(3$

Divergence Theorem :- The Divergence theorem States that the flux of a vector field A our any closed surface S is equal to the value integral of the divergence of the vector field our the volume and closed by the surfaced S.

$$\int_V \nabla\cdot A\, dv = \oint_S A\cdot ds$$

* This Equation is known as divergence theorem and glass gauss theorem. it is used convert the surface integral of the divergen of the vector field to volume integral of the vector field and voice versa.

Imp

Stoke's law :- Stokes theorem it states that the flux of the curl of a vector field a over closed surfaced S of any shape is equall to the line integral of the vector field a over the boundary of that surface.

$$\int_V (\vec{\nabla}\times A)\, ds = \oint_V A\cdot dl$$

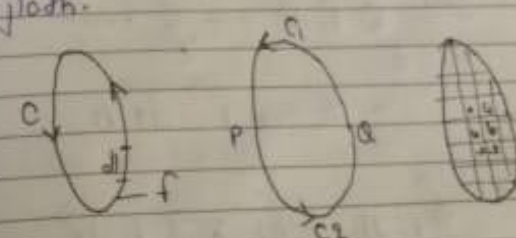
This Equation is called Stoke theorem it is used to convert surface integral of the curl of the vector field a into the line integral of the vector field and voice versa.

Proof

Let A vector f we the function of position than its line integral along a closed surfaced c is given as.

$$I = \oint_C \vec{f}\cdot\vec{dl} \quad \text{--- (1)}$$

Where dl is a small element of path.



If I_1 and I_2 are the line integrals for the two parts C_1 and C_2 then

$$I = I_1 + I_2$$

$$\oint \vec{f}\cdot\vec{dl} = \oint_{C_1} \vec{f}\cdot\vec{dl} + \oint_{C_2} \vec{f}\cdot\vec{dl}$$

PQ is traversed for the curves C_1 and C_2 so that its contribution is called thus the area enclosed by the curve C into no. of smaller area such as ds_1, ds_2 ... then.

$$\oint_C f\cdot dl = \sum_{C_n} \oint \vec{f}\cdot\vec{dl}$$

From the defination.

$$\oint f\cdot dl = \text{curl } f\cdot\vec{ds}$$

here the surface area ds_n so

$$f\cdot ds_n = \oint_{C_n} f\cdot dl$$

We get

$$\oint_C f\cdot dl = \sum \oint_c f\cdot dl$$

$$= \sum \text{cur } \vec{f}\cdot\vec{ds}\, n$$

Therefore

$$\oint_c f\cdot dl = \iint_s \overrightarrow{\text{curl}}\, f\cdot\vec{ds}$$

$$= \int_s (\nabla\times\vec{f})\,\vec{ds}$$

Imp

Conservation of Charge :- (i.e Continuity Equation.

Charge can never be create nor be destroyed but can be transfer from but it can be that is charge is conserve in nature. the current I out of a closed surface be present the rate of charge, close the volume v at closed by if there is a near charge out of the closed surface that is the charge has crossed the surface. the amount of charge inside must describe according to conservation of charge.

$$i = \frac{-d}{dt}(Q_{in}) = \int \vec{J}\cdot\hat{n}\, ds \quad —(1)$$

Where q_{in} is the charge inside the surface.

$$Q_{in} = \int_v \rho\, dv \quad —(2)$$

$$i = \frac{-d}{dt}\int \rho\, dv = \int_s \vec{J}\cdot\vec{n}\, ds$$

using divergence theorem then we get.

$$\int_S \vec{J}\cdot\vec{n}\, ds = \int_v \vec{\nabla}\cdot\vec{J}\, dv.$$

hence. $\int_v \vec{\nabla} \cdot \vec{J} \, dv = \frac{-\partial}{\partial t} \int_v \rho \, dv$

$$\vec{\nabla} \cdot \vec{J} = \frac{-\partial}{\partial t} \rho$$

This equation is Called Continuity eqn and described then the Charge is Conserve for Study Current $\frac{\partial \rho}{\partial t} = 0$ then $\vec{\nabla} \cdot \vec{J} = 0$ this indicates that for Stasmary current the current density is Solidnoidal on above equation Kirchoff's Current law which State that net current Giving a Junction of Conductor is zero.

Maxewell's Equations :-

(1) Gauss's law :- $\nabla \cdot D = \rho v$

(2) Gauss's law for magnetic field.

$$\nabla \cdot B = 0$$

(3) Faraday's law.

$$\nabla \cdot E = \frac{-\partial B}{\partial t}$$

(4) modified Ampere's law.

$$\nabla \times H = J + \frac{\partial D}{\partial t}$$

Topic :- Maxewell's Equation.

(1) $\vec{\nabla} \cdot D = \rho$

Proof :- By using Gauss's law

$$\int E \cdot ds = \frac{q}{\varepsilon_0}$$

$$\int \varepsilon_0 E \cdot ds = q \quad [\because \vec{D} = \varepsilon_0 \vec{E}]$$

$$\iint \vec{D} \cdot ds = \iiint \rho \, dv$$

$\rho = \frac{dq}{dv}$

$\rho \, dv = dq$

$\rho \, dv = q$

Gauss divergence theorem :-

$$\iint_S \vec{D} \cdot ds \quad \iiint (\vec{\nabla} \cdot \vec{D}) dv$$

$$\iiint (\vec{\nabla} \cdot \vec{D}) \, dv . \iiint \rho \, dv$$

$$= \boxed{\vec{\nabla} \cdot \vec{D} \cdot \rho}$$

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Physical Significance: it is signifite that net outward flux of electric displacement vector is equall to the total charge with in the volume.

(ii) $\vec{\nabla} \cdot B = 0$

Proof :- $\iint_S \vec{B} \cdot \vec{ds} = 0$

Gauss div. theorem :-

$$\iint_S \vec{B} \cdot \vec{ds} = \iiint (\vec{\nabla} \cdot \vec{B}) \, dv$$

$$= \vec{\nabla} \cdot \vec{B} = 0$$

It signifite that the magnetic induction flux through any closed surface is equall to zero.

(iii) $\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$

Proof. By Faraday's law.

$$e = \frac{-d\phi}{dt} \quad , \quad V = El, \quad V = \int E \cdot dl.$$

$$\int \vec{E} \cdot dl = \frac{-d\phi_B}{dt}$$

$$\int E \cdot dl = \frac{-d}{dt} \iint B \cdot ds$$

$$\int E \cdot dl = -\iint \frac{\partial \vec{B}}{\partial t} \cdot ds$$

Stoke's theorem $\int E \cdot dl = \iint_S (\nabla \times E) \cdot ds$

$$= \boxed{\nabla \times E = \frac{-\partial \vec{B}}{\partial t}}$$

The value of EMF around the closed loop is equall to the negative of the rate of change of magnetic flux linked with path.

(iv.) $\vec{\nabla} \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$

By Ampear's law

$$\int B \cdot dl = \mu_0 I$$

$I = JA$ (current density)

$I = J \int ds$

$I = \iint J \cdot ds$

$$\int B \cdot dl = \mu_0 \iint J \cdot ds$$

$$\int \frac{B}{\mu_0} \cdot dl = \iint J \cdot ds$$

$$\int H \cdot dl = \iint J \cdot ds$$

By Stokes theorem :- $\vec{\nabla} \times \vec{H} = \vec{J}$ — (1)

Taking div. both sides.

$$\nabla \cdot (\nabla \cdot H) = \nabla \cdot J$$

By using equation of continuity

$$\nabla \cdot J = -\frac{\partial \rho}{\partial t} \text{ and } \nabla \cdot J = 0$$

Maxwell's Modification.

$$\nabla \times H = J + Jd \quad -(2)$$

Dividing both sides

$\nabla \cdot (\nabla \times H) = \nabla \cdot J + D\, Jd$ By using Property (div(curl) = 0)

$$0 = \nabla \cdot J + \nabla Jd$$

$\therefore \nabla \cdot J = -\nabla Jd$ and $\nabla \cdot Ja = \frac{\partial \rho}{\partial t}$

from Maxwell's 1st eq

$$\nabla \cdot D = \rho$$

$$\nabla \cdot Jd = \frac{\partial \nabla}{\partial t} \cdot D$$

$$Jd = \frac{\partial D}{\partial t} \cdot D$$

By putting the value of Ja in eq(2)

$$\boxed{\nabla \times H = J = \frac{\partial D}{\partial t}}$$

Maxwell's Equation in Vaccum :-

In vaccum (or free space)

$\sigma = 0$
$\varepsilon = \varepsilon_0$
$\mu = \mu_0$
$\rho_v = 0$

So, the maxwell's eq^n are as follows

$\nabla \cdot E = 0$
$\nabla \cdot H = 0$
$\nabla \times E = -\mu_0 H$
$\nabla \times H = \varepsilon_0 E$

In Non-Conducting Medium :-

$\sigma \neq 0$
$\varepsilon = \varepsilon_r \varepsilon_0$
$\mu = \mu_r \mu_0$

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$\rho_v = 0$

So, the Maxwell's eq^n are as follows.

$$\nabla \cdot E = 0$$
$$\nabla \cdot H = 0$$
$$\nabla \times E = \mu H$$
$$\nabla \times H = (\sigma + \varepsilon) E$$

Topic :- Poynting Vector :-

An electromagnetic waves can transport energy from one point to another. the direction of EMW at a given point is the direction in which energy is being transmitted. It can be describe by a it is define as $\vec{S} = \frac{1}{\mu_0}(\vec{E} \times \vec{B})$ or $\vec{E} \times \vec{H}$)

Poynting theorem states that the total power flow living the volume is equal to the decrease of the energy densities of energy stored in electric and magnetic field and dissipated ohmic power. the calculation for the poynting vector $\vec{S}$ for electromagnetic field increases these

$$\rightarrow \nabla \cdot \frac{1}{\mu_0}(\vec{E} \times \vec{B}) = \frac{1}{\mu_0}[B \cdot (\nabla \times E) - \vec{E}(\vec{\nabla} \times \vec{B})]$$

Substituting $\vec{\nabla} \times \vec{E}$ and $\vec{\nabla} \times \vec{B}$ we get.

$$\nabla \cdot \frac{1}{\mu_0}(\vec{E} \times \vec{B}) = \frac{1}{\mu_0}\left[-B \cdot \frac{\partial \vec{B}}{\partial t} - E_0 \mu_0 \frac{\partial \vec{D}}{\partial t}\right]$$

$$= \frac{1}{\mu_0}\left[\mu_0 \varepsilon_0 E \cdot \frac{\partial E}{\partial t} + B \cdot \frac{\partial B}{\partial t}\right] [\text{since } \vec{D} = \varepsilon_0 \vec{E}]$$

$$= \frac{-\partial}{\partial t}\left[\frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2\mu_0}B^2\right]$$

$$\nabla \cdot (\vec{E} \times \vec{H}) = \frac{-\partial}{\partial t}\left[\frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\mu_0 H^2\right]$$

[Since $B = \mu_0 H$]

On integrating over the volume V enclosed by the surface S. we get.

$$\int_V \nabla (E \times H) dv = \frac{-\partial}{\partial t}\int_V \left[\frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\mu_0 H^2\right] dv$$

By divergence theorem.

$$\int_V (E \times H) \, dA = \frac{-\partial}{\partial t}\int_V \left(\frac{1}{2}\varepsilon E^2 + \frac{1}{2}\right.$$

$$\int_V (E \times H)\, dA = -\frac{\partial}{\partial t}\left(\frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\mu_0 H^2\right) dv$$

$$\int_S (E \times H) \cdot \vec{dA} = -\frac{\partial}{\partial t} \iint \left[\frac{1}{2}\varepsilon E^2 + \frac{1}{2}\mu H^2\right] dv$$

We know that electrostatics field energy per unit volume $\frac{1}{2}\varepsilon E^2$ and megnetostatic field energy per unit volume is $\frac{1}{2}\mu H^2$. Thus the total electromegnetic energy in a given volume free space as given as $W = \frac{1}{2}\int (\varepsilon_0 E^2 + \mu_0 H^2)\, dv$

therefore.

$$\int_S (E \times H) \cdot dA = -\frac{dW}{dt}$$

The term $-\frac{dW}{dt}$ represent the rate avarage energy is decreasing in a given volume. The rate of decreases of energy must be equall to the net rate at which energy is following out of the volume. these, the left hand side field represent the total outward flux

~~as vector represent the amount of power per unit area~~

of energy over the surface andessing the volume as vector represent the amount of power per unit area.