18BTCE102 **PHYSICS** **3 1 3 5.5**

(Theory & Lab)

(i) Theory **3 1 0 4**

COURSE OBJECTIVE:

- To introduce Basic concepts of optics and its applications, electricity and magnetism, and quantum physics.

COURSE OUTCOMES:

Students will be familiar with

- The students gain the knowledge of Bragg's Law, interference, diffraction and its applications.
- The students to understand the principles of lasers, types of lasers and its applications ans also gain the knowledge of fiber optics.
- The students will understand the basics concepts of electromagnetism, maxwell equations polarization, etc.
- The students gain the knowledge of dielectrics & magnetic properties of materials.
- The students will know about the some of the basic laws of quantum mechanics, uncertainity principle and scanning electron microscope.

UNIT I DIFFRACTION **12**

Diffraction: Introduction to interference and example; concept of diffraction, Fraunhofer and Fresnel diffraction, Fraunhofer diffraction at single slit, double slit, and multiple slits; diffraction grating, characteristics of diffraction grating and its applications.

UNIT II LASER & FIBER OPTICS **12**

Fibre Optics:

Introduction, optical fibre as a dielectric wave guide: total internal reflection, numerical aperture and various fibre parameters, losses associated with optical fibres, step and graded index fibres, application of optical fibres.

Lasers:

Introduction to interaction of radiation with matter, principles and working of laser: population inversion, pumping, various modes, threshold population inversion, types of laser: CO_2 laser, semiconductor laser, application of lasers.

UNIT III ELECTROMAGNETISM & POLARIZATION **12**

Laws of electrostatics, electric current and the continuity equation, laws of magnetism. Ampere's Faraday's laws, Maxwell's equations.

Polarisation:

Introduction, polarisation by reflection, polarisation by double refraction, scattering of light, circular and elliptical polarisation, optical activity.

UNIT IV DIELECTRICS & MAGNETIC PROPERTIES OF MATERIALS **12**

Permeability and dielectric constant, polar and non-polar dielectrics, internal fields in a solid, Clausius-Mossotti equation, applications of dielectrics. Magnetisation, permeability and susceptibility, classification of magnetic materials, ferromagnetism, magnetic domains and hysteresis, applications.

UNIT V QUANTUM MECHANICS **12**

Introduction to quantum theory – Black body radiation - dual nature of matter and radiation – de Broglie wavelength, uncertainty principle –Schrödinger's wave equation – time dependent and time independent equations – particle in one dimensional box- physical significance of wave function, scanning electron microscope.

KARPAGAM ACADEMY OF HIGHER EDUCATION

(Deemed to be University Established under Section 3 of UGC Act 1956)

COIMBATORE – 641021

FACULTY OF ENGINEERING

DEPARTMENT OF SCIENCE AND HUMANITIES

LECTURE PLAN

Subject : PHYSICS

Code : 18BTCE102

Unit No.	List of Topics	No. of Hours
	Interference and Diffraction	
	Introduction to interference and example	1
	Michelson interferometer	1
	Applications, Airwedge	1
	Concept of diffraction, Fraunhofer and Fresnel diffraction	1
	Tutorial	1
	Fraunhofer diffraction at single slit	1
	Fraunhofer diffraction at double slit	1
UNIT - I	Multiple slits; diffraction grating	1
	Characteristics of diffraction grating and its applications	1
	Tutorial	1
	TOTAL	**10**
	LASER & Fiber Optics	
	Introduction to interaction of radiation with matter	1
	Einstein coefficients	1
	Principles and working of laser: population inversion, pumping, various modes, threshold population inversion	1
	Types of laser: CO_2 laser, semiconductor laser, application of lasers	1
	Tutorial	1
UNIT – II	Introduction, optical fiber as a dielectric wave guide	1
	Total internal reflection, Numerical aperture	1
	Various fiber parameters, losses associated with optical fiber	1
	Step and graded index fibers, application of optical fibers	1
	Tutorial	1
	TOTAL	**10**
	Electromagnetism & Polarisation	
	Laws of electrostatics (Coulomb's law, Gauss law – Applications)	1
	Electric current and the continuity equation	1
	Laws of magnetism (Biot savarts law, Ampere's ciruital Applications)	1
UNIT – III	Faraday's laws	1

	Tutorial	1
	Maxwell's equations.	1
	Introduction, polarisation by reflection	
	Polarisation by double refraction, scattering of light	1
	Circular and elliptical polarisation, optical activity	1
	Tutorial	1
	TOTAL	**10**
UNIT – IV	**Dielectrics & Magnetic Properties of Materials**	
	Permittivity and dielectric constant	1
	Polar and non-polar dielectrics	1
	Internal fields in a solid, Clausius-Mossotti equation	1
	Applications of dielectrics	1
	Tutorial	1
	Magnetisation, permeability and susceptibility	1
	Classification of magnetic materials	1
	Ferromagnetism, magnetic domains	1
	Domain theory and hysteresis and its applications	1
	Tutorial	1
	TOTAL	**10**
UNIT – V	**Quantum Mechanics**	
	Introduction to quantum theory and its merits	1
	Black body radiation and its laws	1
	Dual nature of matter and radiation	1
	De Broglie wavelength , Uncertainty principle	1
	Tutorial	1
	Schrödinger's wave equation – time dependent equation	1
	Time independent equations, Physical significance of wave function	1
	Particle in one dimensional box	1
	Degenerate and non-degenerate states, Scanning electron microscope	1
	Tutorial	1
	TOTAL	**10**
	TOTAL NO OF HOURS	**50**

TEXT BOOK& REFERENCES:

S.No	Author(s) Name	Title of the Book	Publisher	Year of Publication
1	D.K. Bhattacharya &Poonam T	Engineering Physics	Oxford University Press, New York	2015
2	R.K.Gaur and S.L.Gupta	Engineering Physics	Dhanpat Rai Publication, India	2012
3	B.K.Pandey and S. Chaturvedi	Engineering Physics	Cengage Learning, India.	2012
4	D.Halliday, R.Resnick and J.Walker	Principles of Physics	Wiley	2015
5	R.A.Serway and J.W.Jewett	Physics for Scientists and Engineers with Modern Physics	Thomson Brooks/Cole Publishing Co.	2010
6	P.A.Tipler and G.P.Mosca	Physics for Scientists and Engineers with Modern Physics	W.H.Freeman	2007

WEBSITES:

1. www.nptel.ac.in
2. www.ocw.mit.edu

UNIT – I

INTERFERENCE

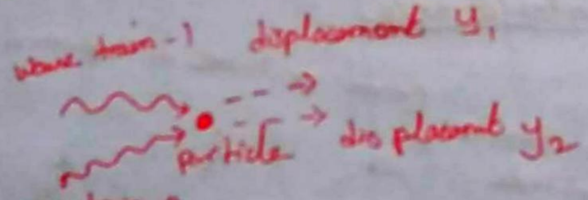
Interference: Unit-1

Google : classroom ①
BE. Chemical Engineering Batch 2019-20
class Code : r3duqc

Principle of superposition

"This principle states that the resultant displacement of a particle of the medium acted upon by two or more waves simultaneously is the algebraic sum of the displacements of the same particle due to individual waves, in the absence of the others."

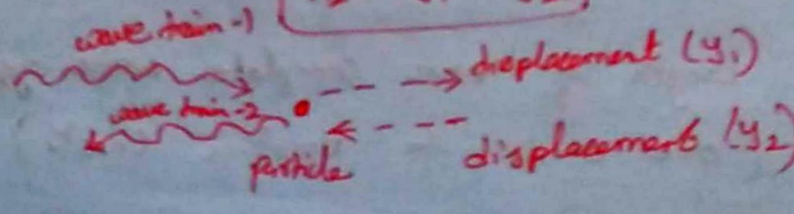
Suppose due to a single wave train the displacement of the particle at a certain point at any instant is y_1 in a given direction and that due to another wave train, the displacement is y_2 in the absence of the first. Then according to the principle of superposition, the instantaneous resultant displacement of the particle due to two waves acting together is expressed by



Resultant $\boxed{R_1 = y_1 + y_2}$

If the two displacements are in opposite directions the instantaneous resultant displacement due to two waves acting together is expressed by

$$\boxed{R_2 = y_1 - y_2}$$



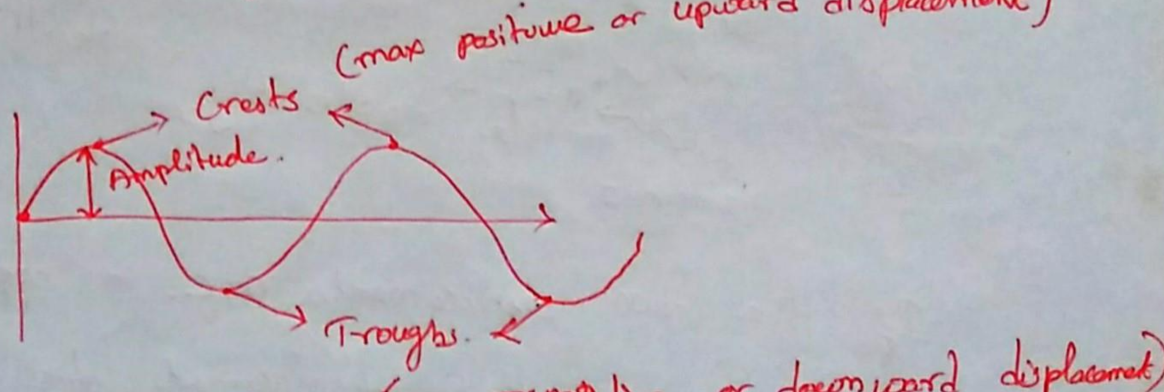
Interference of Light :-

when two light waves superimpose, then the resultant amplitude (or intensity*) in the region of the superposition is different than the amplitude (or intensity) of individual waves. This modification in the distribution of intensity in the region of superposition is called "interference".

when the resultant amplitude is the sum of the amplitudes due to two waves, the interference is known as "Constructive interference".

when the resultant amplitude is equal to the difference of two amplitudes, the interference is known as "destructive interference".

waves:

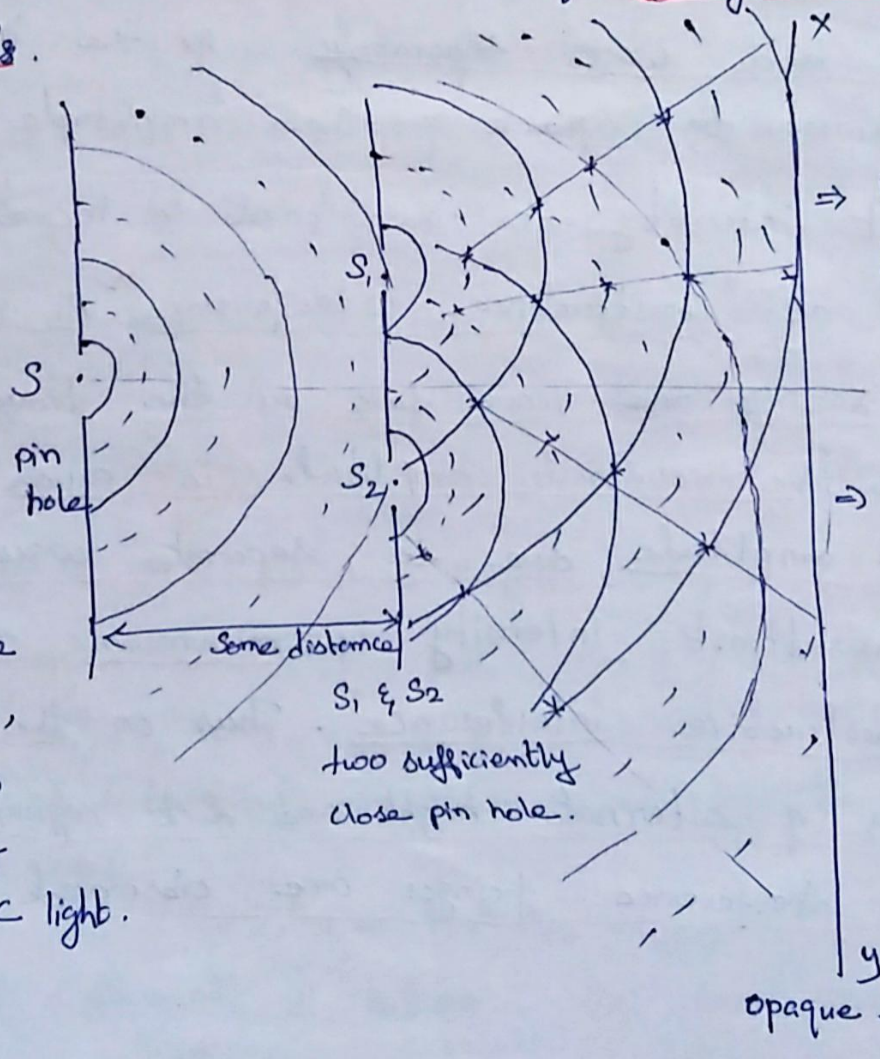


Amplitude: Maximum amount of displacement of a particle on the medium from its rest position.

wavelength: Length of one complete wave cycle (one crest to another crest)

Young's Experiment:-

In 1801, Thomas Young first demonstrated experimentally the phenomenon of interference of light. The apparatus is shown in Fig. 26.1. He allowed the sunlight to pass through a pin hole 'S' and then at some distances through two sufficiently close pin holes S_1 and S_2 in an opaque screen. The interference pattern was observed on a screen XY. He observed few coloured bright and dark bands on the screen. Now a days, to increase the ~~number~~ brightness, pin holes S_1 and S_2 are replaced by narrow slits. Moreover, to increase the number of fringes, sunlight is replaced by monochromatic light. The interference pattern consists of equally spaced bright and dark bands.



⇒ Few coloured bright & dark bands are observed on screen.

⇒ To increase the brightness, the pin holes are replaced by narrow slits.

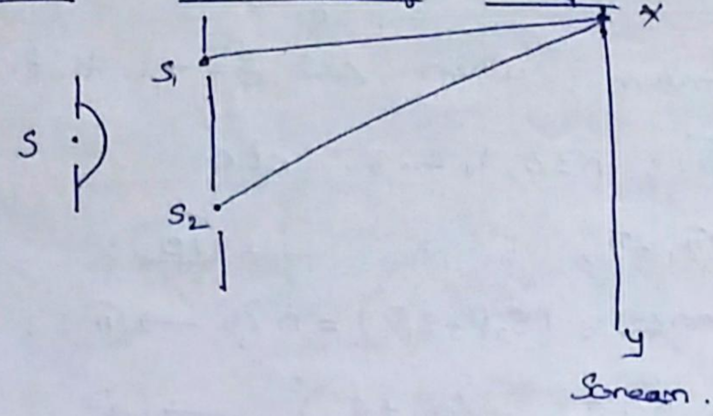
⇒ To increase the number of fringes, the sunlight is replaced by monochromatic light.

Explanation on wave theory:

when sun light passes through pin hole S, spherical waves are spread out. WKT by Huygen's principle that each point on the wavefront is a centre of secondary wavelets. Hence spherical waves also spread out from pin holes S_1 and S_2. The raddii of these wavefronts increase as they move away from S_1 and S_2. ~~They move~~ and hence they superimpose on each other.

In Fig. 26.1, continuous circular arcs represent the wave crests, while dotted circular arcs represent the wave troughs in each wave. At points where a crest due to one wave falls on the crest due to another wave, the resultant amplitude is the sum of the amplitude due to each wave separately. As the intensity is proportional to square of the amplitude and hence the resultant intensity at these points is increased i.e maxmium. This is known as "Constructive interference". At points, where a crests due to one wave falls on the trough of the other wave, the resultant amplitude is equal to the difference of the amplitude due to separate waves and hence the resultant intensity is minimum. This is known as "destructive interference". Thus on "the screen a number of alternate bright and dark regions of equal width called interference fringes are observed".

Analytical Treatment of Interference :-



S : Monochromatic Source

S_1 & S_2 two narrow pin holes equidistant from S.

a_1 & a_2 = amplitude of the waves

δ = path difference b/w two waves reaching pt P.

y_1 & y_2 = displacement of two waves

$y_1 = a_1 \sin \omega t$

$y_2 = a_2 \sin(\omega t + \delta)$.

According to the principle of surperposition.

$y = y_1 + y_2 = a_1 \sin \omega t + a_2 \sin(\omega t + \delta)$

$= a_1 \sin \omega t + a_2 \sin \omega t \cos \delta + a_2 \cos \omega t \sin \delta$.

$= \sin \omega t \, (a_1 + a_2 \cos(\delta)) + \cos \omega t \, (a_2 \sin \delta) \rightarrow (3)$

Let. $a_1 + a_2 \cos \delta = R \cos \theta \rightarrow (4)$.

$a_2 \sin \delta = R \sin \theta \rightarrow (5)$.

R & θ are new constants.

Finally $y = \sin \omega t \; R \cos \theta + \cos \omega t \, . \, R \sin \theta$.

$$\boxed{y = R \sin(\omega t + \theta)} \rightarrow (6).$$

Hence the resultant vibration at P is simple haromonic vibration of amplitude R. The resultant amplitude can be obtained by squaring eq. (4) & (5) and adding

$R^2 \cos^2 \theta + R^2 \sin^2 \theta = (a_1 + a_2 \cos \delta)^2 + (a_2 \sin \delta)^2$

(or)

$R^2 = a_1^2 + a_2^2 \cos^2 \delta + 2a_1 a_2 \cos \delta + a_2^2 \sin^2 \delta$.

$R^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos \delta . \rightarrow (7)$

The resultant intensity at P is given by the square of the amplitude R. Thus.

$I = R^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos \delta \rightarrow (8)$.

The phase difference δ between the two waves arriving at P is given by $\delta = \frac{2\pi}{\lambda} \times (\text{path difference}) = \frac{2\pi}{\lambda} \times (S_2P - S_1P) \rightarrow (9)$

Case: (1): Condition for maximum intensity.

Intensity I is maximum, when $\cos\delta = +1$ that is

~~path~~ phase difference: $\delta = 2n\pi$; $n = 0, 1, 2, 3 \ldots$ etc.

$$\delta = 0, 2\pi, 4\pi, \ldots \rightarrow (10)$$

(or) path difference $= (S_2P - S_1P) = n\lambda \rightarrow (11)$.

$$I_{max} = a_1^2 + a_2^2 + 2a_1a_2 = (a_1 + a_2)^2 \rightarrow (12).$$

This shows that the resultant intensity is greater than the sum of two separate intensities $(a_1^2 + a_2^2)$.

Case: (2): Condition for minimum intensity:

Intensity I is minimum, when $\cos\delta = -1$ that is

~~path~~ phase difference: $\delta = (2n+1)\pi$, $n = 0, 1, 2, 3 \ldots$ etc.

$$\delta = \pi, 3\pi, 5\pi \ldots \text{ etc} \rightarrow (13)$$

or path difference $= (S_2P - S_1P) = (2n+1)\lambda/2 \rightarrow (14)$.

$$I_{min} = a_1^2 + a_2^2 - 2a_1a_2 = (a_1 - a_2)^2 \rightarrow (15).$$

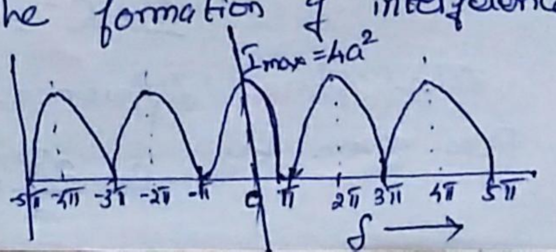
Thus the resultant intensity is less than the ~~sum~~ difference of the two separate intensity $(a_1^2 - a_2^2)$.

Special case: when $a_1 = a_2 = a$ then:

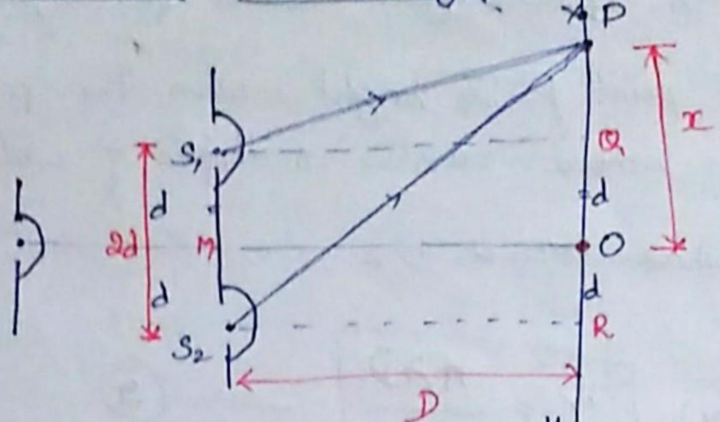
$$I_{max} = a^2 + a^2 + 2a.a = a^2 + a^2 + 2a^2 = 4a^2 \rightarrow (16).$$

and $$I_{min} = a^2 + a^2 - 2a.a = 2a^2 - 2a^2 = 0 \rightarrow (17).$$

Energy Distribution: From (16) & (17), the intensity @ bright pts is $4a^2$ and the intensity at dark pts is zero. Figure shows the variation of intensity as a function δ. The formation of interference fringes is in accordance with the law of conservation of energy.



Theory of Interference Fringes:-



S → Narrow monochromatic Source

S_1 & S_2 → two pin holes @ equidistant from S & vibrating in same phase

2d → Separation b/w S_1 & S_2

D → distance b/w Screen & the pin hole S_1, S_2

path difference: S_2O & S_1O (I is should be max) = zero.

path difference: S_2P & S_1P

P → points @ distance x from O.

· Condition for a bright & Dark fringe at this point P.

From Δ^{le} S_1QP.

$$(S_1P)^2 = (S_1Q)^2 + (QP)^2$$
$$= D^2 + (x-d)^2$$

From Δ^{le} S_2RP

$$(S_2P)^2 = (S_2R)^2 + (RP)^2$$
$$= D^2 + (x+d)^2$$

Then: Path difference is given by (δ):

$$(S_2P)^2 - (S_1P)^2 = (x+d)^2 - (x-d)^2$$
$$= x^2 + d^2 + 2xd - x^2 - d^2 + 2xd$$

$$(S_2P - S_1P)\,(S_2P + S_1P) = 4xd \longrightarrow (6)$$

In Young's expeiment, D is much greater than 2d or x, so if $(S_2P + S_1P)$ is replaced by 2D and the error is less than fraction of one percent. Hence.

$$(S_2P - S_1P)\,2D = 4xd.$$

$$\boxed{\delta = S_2P - S_1P = \frac{2xd}{D}} \longrightarrow (7)$$

path difference:

Position and Spacing of fringes: Consider following two cases:.

i) **Bright fringes:-** Let point P is bright, when the path difference is a whole number multiple of wavelength λ i.e

$S_2P - S_1P = n\lambda$ where $n = 0, 1, 2$.

$$\frac{2xd}{D} = n\lambda \quad (or) \quad \boxed{x = \frac{n\lambda D}{2d}} \longrightarrow (2).$$

This 'x' gives the distance of the bright fringes from point O. At O, the path difference is zero, hence there is a bright fringe. Next bright fringes are formed, when $n = 1, 2, 3 \ldots$ and so on.

when $n = 1$, $x_1 = \frac{\lambda D}{2d}$.

When $n = 2$, $x_2 = \frac{2\lambda D}{2d}$.

$\vdots$

when $n = n$, $x_n = \frac{n\lambda D}{2d}$.

Distance b/w any two consecutive bright fringes is.

$$\boxed{x_2 - x_1 = \frac{\lambda D}{2d}}$$

ii) **Dark fringes:-** The pts P is dark, when the path difference is an odd number multiple of half wavelength, i.e.

$$(S_2P - S_1P) = (2n+1)\lambda/2.$$

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

$$\frac{2xd}{D} = (2n+1)\lambda/2 \Rightarrow \boxed{x = \frac{(2n+1)\lambda D}{4d}} \text{ (or)}$$

$$\boxed{x = \frac{(2n+1)}{2} \times \frac{\lambda D}{2d}}$$

This x gives the distance of the dark fringes from point O.
The dark fringes are formed as follows:-

when $n=0$. $x_0 = \frac{\lambda D}{4d}$.

$n=1$ $x_1 = \frac{3\lambda D}{4d}$.

$n=2$ $x_2 = \frac{5\lambda D}{4d}$.

⋮

$n=n$ $x_n = \frac{(2n+1)}{2} \times \frac{\lambda D}{2d}$

Distance b/w any two Consecutive drak fringe is

$$x_2 - x_1 = \frac{2\lambda D}{4d} = \frac{\lambda D}{2d}.$$

Hence, the spacing between any two Consecutive maxima or minima is the same. This is expressed by $\left(\beta = \frac{\lambda D}{2d}\right)$. and this is known as fringe width. It is obvious, that the spacing 'β' is directly proportional to D and λ and inversely proportional to 2d.

Conditions for Interference of Light:

To obtain a permanent or stationary interference pattern, the conditions are classified into the following three parts:

1) Conditions for sustained Interference :-

(i) The two sources should be coherent : i.e, they should vibrate in the same phase or there should be a constant phase difference between them.

$$I = a_1^2 + a_2^2 + 2a_1a_2 \cos \delta.$$

(ii) The two sources must emit continuous waves of the same wavelength and time period.

(2) Conditions for observation:-

(i) The separation between the two sources (2d) should be small

(ii) The distance 'D' between the two sources and screen should be large. $\left[\frac{D\lambda}{2d} = \beta\right]$

(iii) The background should be dark.

(3) Conditions for good Contrast:-

(i) The amplitude of the interfering waves should be equal or nearly equal.

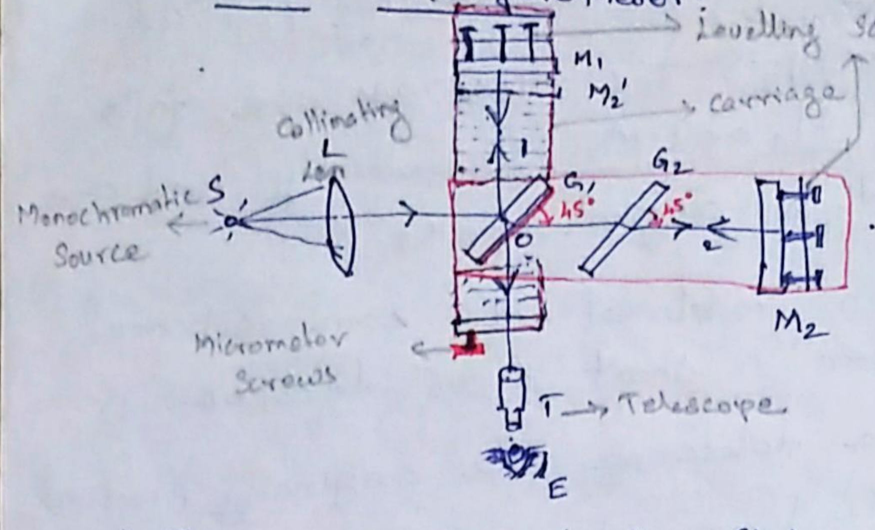
$$I_{max} = (a_1 + a_2)^2 \quad \& \quad I_{min} = (a_1 - a_2)^2$$

$= zero$ $(a_1 = a_2)$ good contrast b/w I_{max} & I_{min}

(ii) The sources must be narrow i.e., they must be extremely small.

(iii) The sources should be monochromatic

Michelson Interferometer:



Construction:

Apparatus is shown in figure. It consists.

→ 2 excellent optically plane, highly polished plane mirrors M_1 & M_2, which are at right angles to each other.

→ There are 2 optically flat glass plates, G_1 & G_2 of same thickness and of the same materials. placed parallel to each other. These plates are also inclined at angle 45° with the mirrors M_1 and M_2.

→ The face of G_1 toward G_2 is semi-silvered. The mirror M_1 is mounted on a carriage which can be moved. forward or backward. The motion is controlled by a very fine micrometer screw (capable of reading upto 10^{-5} cm)

→ The mirrors M_1 & M_2 are provided with three levelling Screws at their backs. which is help to tilter about horizontal and vertical axes, so that they can be made exactly perpendicular to each other. T is a telescope which receives the reflected lights from mirrors M_1 and M_2.

Working:-

→ Light from a monochromatic extended source 'S', after being rendered parallel by a collimating lens L falls on the semi-silvered glass plate G_1.

→ It is divided into two parts, one being reflected from the semi-silvered surface of G_1 giving rise to ray (1) which travels towards mirror M_1.

→ other being transmitted giving rise to ray (2), which travels towards mirror M_2. The two rays are falls normally on mirror M_1 and M_2 respectively and are reflected back along their original paths.

→ The reflected ray again meet at the semi-silvered Surface of G_1 and enter a short focus telescope T.

→ Two rays entering the telescope are originally derived from the same single beam, hence they are in a position to produce interference fringes in the field of veiwg the telescope.

→ A desired path difference can be introduced between the two reflected rays by moving the mirror M_1.

→ It can be noted from the figure that ray No.1 passes through G_1 twice whereas the ray No. 2. does not do so even once. Thus, in the absence of glass plate G_2, the two paths OM_1 and OM_2 are not equal. To equalise the two paths, a glass plate G_2 of same thickness and material as that of G_1 is introduced in the path of ray No 2. Because of this nature, the glass plate G_2, is called as "Compensating plate." The introduction of G_2 is not essential in monochromatic light but it is a must in case of white light.

→ Looking in the direction M_1 from E, one observes M_1 and also a virtual image M_2' of M_1 and M_2 formed in G_1. Thus the two interfering beams come by reflection from mirror M_1 and the other which is reflected from M functions as if it had been reflected from M_2'. Hence the Michelson interferometer is optically equivalent to an air film between M_1 and M_2'.

→ The interference fringes may be straight, circular, parabolic etc. depending upon path difference and the angle between mirrors M_1 and M_2'. The nature of fringes is described in the next article.

Types of Fringes:-

1) Circular fringes:

Here, M_2 is $\perp$ to M_1 (or) M_1 is $\parallel^{el}$ to M_2'. Here an air film of constant thickness is enclosed between the M_1 and M_2 (or) M_1 and M_2'. The air film gives reflected beam to interfere. The path difference depends upon.

(a) Separation between M_1 and M_2'

(b) angle subtended on the eye.

(c) inclination between M_1 and M_2'

Hence the path difference which satisfies the condition of maxima appears bright, while the path difference which satisfies the condition of minima appear dark.

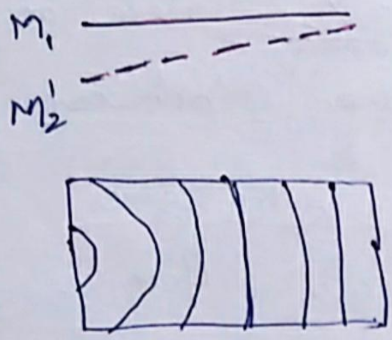
For maxima, $2t \cos r + \lambda/2 = n\lambda$,

Each fringe is a locus of constant r. Since the loci of constant r are concentric circles, circular fringes are obtained. These fringes are formed at infinity, hence they are observed through a telescope focussed at infinity.

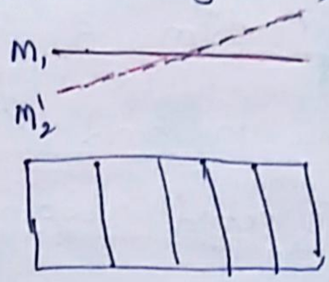
2) Localized fringes Conditions:-

Here, M_2 not exactly ⊥ to M_1, or, not exactly M_2' (virtual mirror) not exactly parallel to M_1. Here, a wedge shaped air film of variable thickness is enclosed between them. The shapes of the fringes depends on thickness of air film and the angle of incidence. Their shapes are shown in Fig 24 below.

These fringes have curved shape towards decreasing thickness of air film enclosed between M_1 and M_2' in Fig (a).

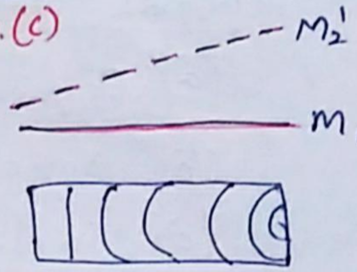


If M_1 and M_2' images cross each other as shown in the middle diagram, the pattern comes out in the form of straight lines, Fig (b).



If the thickness of air film enclosed between M_1 and M_2' is increasing then the curved shaped fringes are formed

Fig. (c)



3) Localized white light fringes:

when monochromatic light source is replaced by a white source, the coloured and curved localized fringes are obtained. The fringes of zero thickness are perfectly dark and straight. other fringes are coloured due to overlapping of various colours

Applications: Michelson's Interferometer has be used for no. purpose:

a) Determination of wavelength of monochromatic light.

b) Determination of difference in wavelength of light

c) Determination of thickness 't' of thin plate

DIFFRACTION

Fundamental concept of diffraction:

- The phenomenon of bending of light around the corner of an aperture or at the edge of an obstacle is known as diffraction
- The diffraction is possible for all types of waves
- The diffraction verifies the wave nature of light
- Diffraction takes place is due to superposition of light waves coming from two different points of a single wave front
- Diffraction takes place when the dimension of the obstacle is comparable with the wavelength of the incident light.

Explanation of diffraction:

To explain diffraction, let us consider an obstacle AB is placed on the path of an monochromatic beam of light coming from a source 'S' which produces the geometrical shadow CD on the screen. This proves the rectilinear propagation of light.

If the dimension or size of the obstacle is comparable with the wave length of the incident light, then light bends at the edge of the obstacle and enters in to the geometrical shadow region of the obstacle. According to Fresnel inside a well region, the destructive interference takes place for which we get brightest central maxima, which is associated with the diminishing lights on either side of the shadow as the constructive interference takes place outside the well region. This explains the diffraction phenomena.

Types of Diffraction:

Depending on the relative position of the obstacle from the source and screen, the diffraction is of 2 types.

a. Fresnel Diffraction

b. Fraunhoffer Diffraction

Fresnel’s Diffraction	Fraunhoffer Diffraction
(1) The type of diffraction in which the distance of either source or screen or both from the obstacle is finite, such diffraction is known as Fresnel"s diffraction.	(1) The type of diffraction in which the distance of either source or screen or both from the obstacle is infinite, such diffraction is known as Fraunhoffer diffraction.
(2) No lenses are used to make the rays converge or parallel.	(2) Lenses are used to make the rays converge or parallel.
(3) The incident wave front is either cylindrical or spherical.	(3) The incident wave front is plane.
Ex: The diffraction at the straight edge.	Ex:. The diffraction at the narrow.

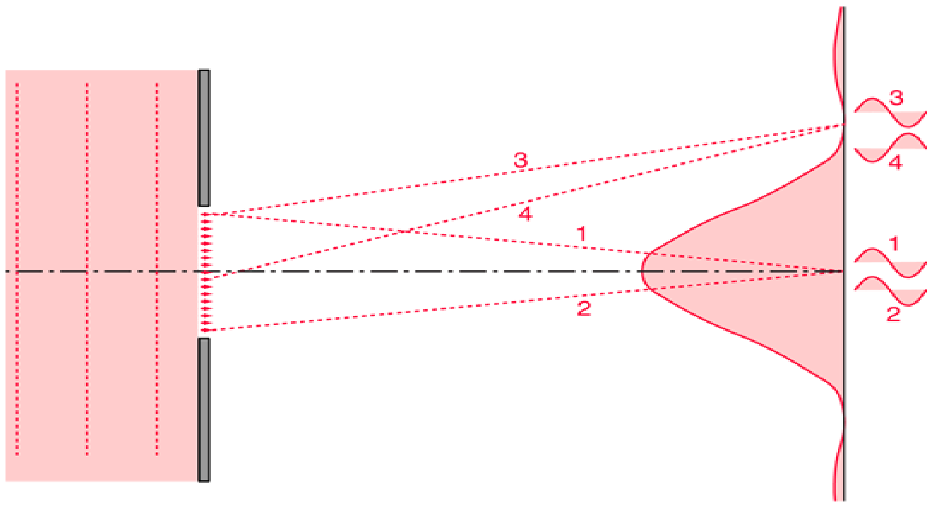
Difference between interference and diffraction:

Interference	Diffraction
1. Interference is due to interaction of light coming from two different wave fronts originating from the same source.	1. Diffraction is due to interaction of light coming from different parts of the same wave front.
2. Interference fringes are of the same width.	2. Diffraction fringes are not of the same width.
3. All bright fringes are of the same intensity.	3. All bright fringes are not of the same intensity.
4. All point of minimum intensity are perfectly dark.	4. All point of minimum intensity are not perfectly dark.
5: The spacing between fringes is uniform.	5. The spacing between fringes is not uniform.

Fraunhoffer Diffraction due to a single slit

- It is a common observation with the waves of all kind that they bend round the edge of an obstacle
- Light like other waves also bends round corners but in comparison to sound waves small bending of light is due to very short wavelength of light which is of the order of 10^{-5}
- We now define diffraction of light as the phenomenon of bending of light waves around the corners and their spreading into the geometrical shadows
- According to Fresnel, diffraction occurs on account of mutual interference of secondary wavelets starting from portions of the wavefront which are not blocked by the obstacle or from portions of the wavefront which are allowed to pass through the aperture.
- Thus we can explain diffraction phenomenon using Huygen's principle
- The diffraction phenomenon are usually divided into two classes
  i) Fresnel class of diffraction phenomenon where the source of light and screen are in general at a finite distance from the diffracting aperture.
  ii) Fraunhofer class of diffraction phenomenon where the source and the screen are at infinite distance from the aperture, this is easily achieved by placing the source on the focal plane of a convex lens and placing screen on focal plane of another convex lens. This class of diffraction is simple to treat and easy to observe in practice

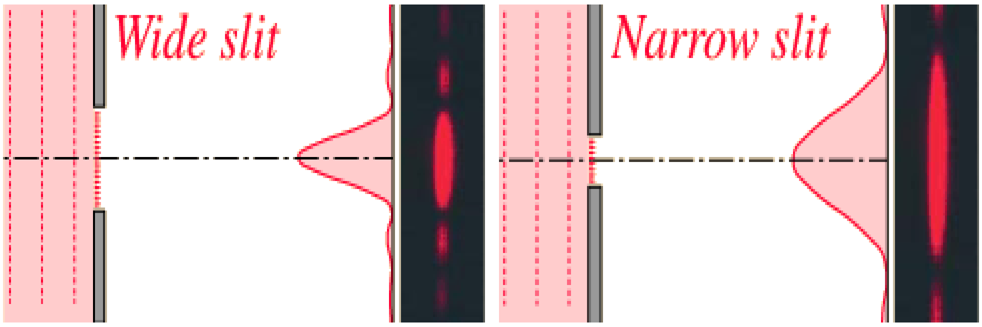
This is an attempt to more clearly visualize the nature of single slit diffraction. The phenomenon of diffraction involves the spreading out of waves past openings which are on the order of the wavelength of the wave. The spreading of the waves into the area of the geometrical shadow can be modeled by considering small elements of the wavefront in the slit and treating them like point sources.



If light from symmetric elements near each edge of the slit travels to the centerline of the slit, as indicated by rays 1 and 2 above, their light arrives in phase and experiences constructive interference. Light from other element pairs symmetric to the centerline also arrive in phase. Although there is a progressive change in phase as you choose element pairs closer to the centerline, this center position is nevertheless the most favorable location for constructive interference of light from the entire slit and has the highest light intensity.

The first minimum in intensity for the light through a single slit can be visualized in terms of rays 3 and 4. An element at one edge of the slit and one just past the centerline are chosen, and the condition for minimum light intensity is that light from these two elements arrive 180° out of phase, or a half wavelength different in pathlength. If those two elements suffer destructive interference, then choosing additional pairs of identical spacing which progress downward across the slit will give destructive interference for all those pairs and therefore an overall minimum in light intensity.

One of the characteristics of single slit diffraction is that a narrower slit will give a wider diffraction pattern as illustrated below, which seems somewhat counter-intuitive. One way to visualize it is to consider that rays 3 and 4 must reach one half wavelength difference in light pathlength, and if the slit is narrower, it will take a greater angle of the rays to achieve that difference.



MORE EXAMPLES OF VARIATION WITH SLIT WIDTH

The diffraction patterns were taken with a helium-neon laser and a narrow single slit. The slit widths used were on the order of 100 micrometers, so their widths were 100 times the laser wavelength or ore. A slit width equal to the wavelength of the laser light would spread the first minimum out to 90° so that no minima would be observed. The relationships between slit width and the minima and maxima of diffraction can be explored in the single slit calculation.

in the region of the geometrical shadow. The intensity distribution due to Fresnel's diffraction at a straight edge is given in Fig. 9.17 on page 429.

9.22 FRAUNHOFER DIFFRACTION AT A SINGLE SLIT

To obtain a Fraunhofer diffraction pattern, the incident wavefront must be plane and the diffracted light is collected on the screen with the help of a lens. Thus, the source of light should either be at a large distance from the slit or a collimating lens must be used.

In Fig. 9.33, S is a narrow slit perpendicular to the plane of the paper and illuminated by monochromatic light. L_1 is the collimating lens and AB is a slit of width a. XY is the incident spherical wavefront. The light passing through the slit AB is incident on the lens L_2 and the final refracted beam is observed on the screen MN. The screen is perpendicular to the

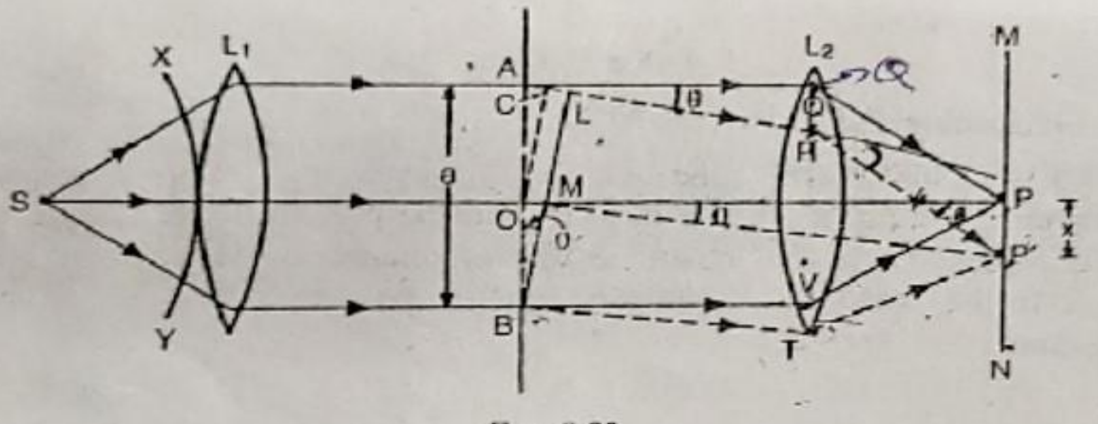


Fig. 9.33

plane of the paper. The line SP is perpendicular to the screen. L_1 and L_2 are achromatic lenses.

A plane wavefront is incident on the slit AB and each point on this wavefront is a source of secondary disturbance. The secondary waves travelling in the direction parallel to OP viz. AQ and BV come to focus at P and a bright central image is observed. The secondary waves from points equidistant from O and situated in the upper and lower halves OA and OB of the waterfront travel the same distance in reaching P and hence the path difference is zero. The secondary waves reinforce one another and P will be a point of maximum intensity.

Now, consider the secondary waves travelling in the direction AR, inclined at an angle θ to the direction OP. All the secondary wave travelling in this direction reach the point P' on the screen. The point P' will be of maximum or minimum intensity depending on the path difference between the secondary waves originating from the corresponding points of the wavefront. Draw OC and BL perpendicular to AR.

P corresponds to the position of the central bright maximum and the points on the screen for which the path difference between the points A and B

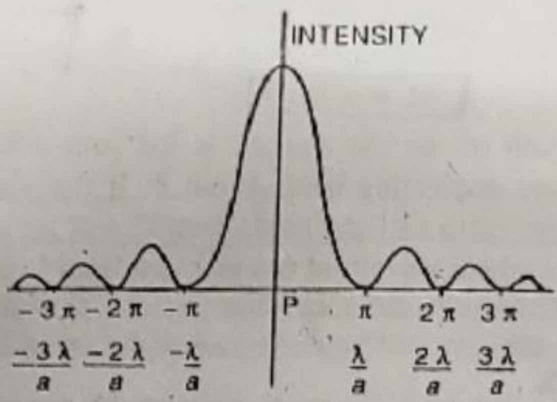


Fig. 9.34

is λ, 2λ etc., correspond to the positions of secondary minima. The secondary maxima are of much less intensity. The intensity falls off rapidly from the point P outwards.

If the lens L_2 is very near the slit or the screen is far away from the lens L_2, then

$$\sin\theta = \frac{x}{f} \qquad ...(i)$$

where f is the focal length of the lens L_2

But,
$$\sin\theta = \frac{\lambda}{a} \qquad ...(ii)$$

∴
$$\frac{x}{f} = \frac{\lambda}{a}$$

or
$$x = \frac{f\lambda}{a}$$

where x is the distance of the secondary minimum from the point P. Thus, the width of the central maximum = $2x$.

or
$$2x = \frac{2f\lambda}{a} \qquad ...(iii)$$

The width of the central maximum is proportional to λ, the wavelength of light. With red light (longer wavelength), the width of the central maximum is more than with violet light (shorter wavelength). With a narrow slit, the width of the central maximum is more. The diffraction pattern consists of alternate bright and dark bands with monochromatic light. With white light, the central maximum is white and the rest of the diffraction bands are coloured. From equation (*ii*), if the width a of the slit is large, $\sin\theta$ is small and hence θ is small. The maxima and minima are very close to the central maximum at P. But with a narrow slit, a is small and hence θ is large. This results a distinct diffraction maxima and minima on both the sides of P.

Example 9.9. *Find the half angular width of the central bright maximum in the Fraunhofer diffraction pattern of a slit of width* 12×10^{-5} *cm when the slit is illuminated by monochromatic light of wavelength 6000 Å.*

Here $$\sin\theta = \frac{\lambda}{a}$$

where θ is half angular width of the central maximum.

$$a = 12 \times 10^{-5} \text{ cm}, \lambda = 6000 \text{ Å} = 6 \times 10^{-5} \text{ cm}.$$

$$\therefore \quad \sin\theta = \frac{\lambda}{a} = \frac{6 \times 10^{-5}}{12 \times 10^{-5}} = 0.50$$

or $$\theta = 30^\circ$$

Example 9.10. *In Fraunhofer diffraction due to a narrow slit a screen is placed* 2 m *away from the lens to obtain the pattern. If the slit width is 0.2* mm *and the first minima lie 5* mm *on either side of the central maximum, find the wavelength of light.* [*Delhi (Sub) 1977*]

In the case of Fraunhofer diffraction at a narrow rectangular aperture,

$$a\sin\theta = n\lambda$$

$$n = 1$$

$$\therefore \quad a\sin\theta = \lambda$$

$$\sin\theta = \frac{x}{D}$$

$$\therefore \quad \frac{ax}{D} = \lambda$$

$$\lambda = \frac{ax}{D}$$

Here
$$a = 0.2 \text{ mm} = 0.02 \text{ cm}$$
$$x = 5 \text{ mm} = 0.5 \text{ cm}$$
$$D = 2 \text{ m} = 200 \text{ cm}$$

$$\therefore \quad \lambda = \frac{0.02 \times 0.5}{200}$$

$$\lambda = 5 \times 10^{-5} \text{ cm}$$

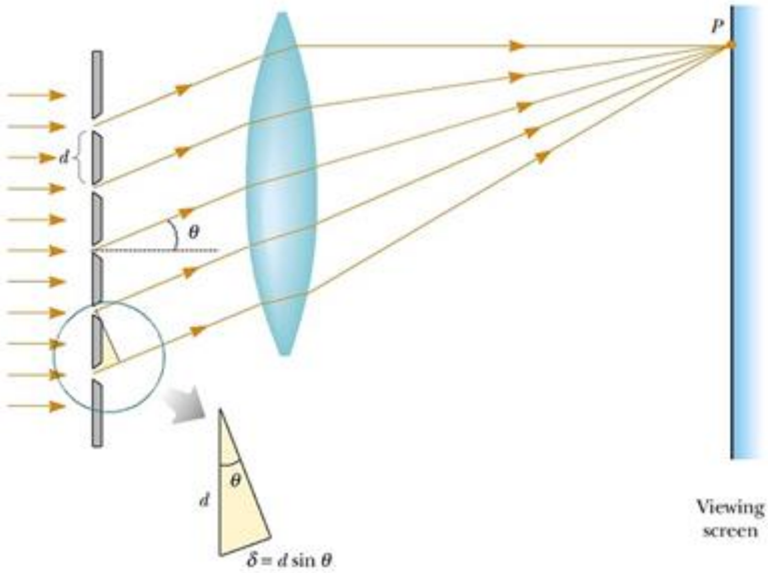
$$\lambda = \mathbf{5000\ Å}$$

MULTIPLE SLIT DIFFRACTION/INTERFERENCE - DIFFRACTION GRATINGS

(PLANE DIFFRACTION GRATING)

Interference: **Superposition of waves from a finite number of "point" sources.**

***Diffraction*:** **Superposition of waves from an infinite number of "point" sources, comprising a single large source.**



The diagram at right illustrates a 5 slit configuration, where the path difference at point P between waves from each of the slits is dsinθ with a slit separation of "d". Clearly, if the waves from all five slits are in phase, maximum intensity will be observed at P when

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

where n = 0, 1, 2,...

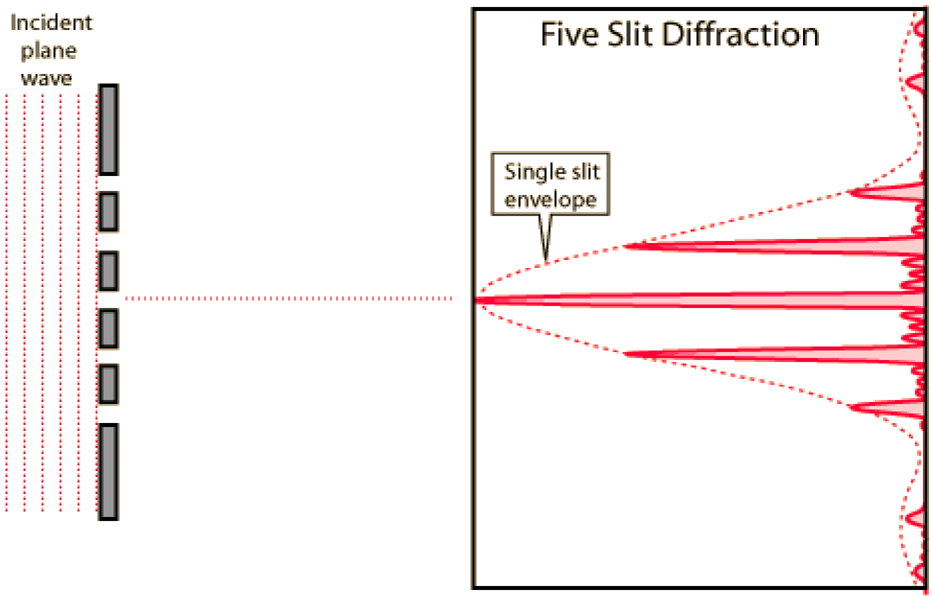
- A detailed mathematical analysis yields an intensity pattern for N slits each of width d given by

$$I_\theta = I_0 \frac{\sin^2\beta}{\beta^2}\frac{\sin^2 N\gamma}{\sin^2\gamma}$$

where β is the same β as in the single slit diffraction and

$$\gamma = \frac{\pi d\sin\theta}{\lambda}$$

Note that this pattern is comprised of a diffraction envelope together with the $(\sin^2 N\gamma)/\sin^2\gamma$ term. This latter term leads to the existence of ***principal maxima*** predicted by $d\sin\theta = n\lambda$ together with much weaker ***secondary maxima*** between the principal maxima as shown below for a five slit example.



DIFFRACTION GRATINGS

5.7.2 Diffraction grating

An arrangement consisting of a large number of equidistant parallel narrow slits of equal width separated by equal opaque portions is known as a diffraction grating.

The plane transmission grating is a plane sheet of transparent material on which opaque rulings are made with a fine diamond pointer. The modern commercial form of grating contains about 6000 lines per centimetre.

The rulings act as obstacles having a definite width '*b*' and the transparent space between the rulings act as slit of width '*a*'. The combined width of a ruling and a slit is called grating element (e). Points on successive slits separated by a distance equal to the grating element are called corresponding points.

Theory

MN represents the section of a plane transmission grating. AB, CD, EF ... are the successive slits of equal width a and BC, DE ... be the rulings of equal width b (Fig. 5.21). Let $e = a + b$.

Let a plane wave front of monochromatic light of wave length λ be incident normally on the grating. According to Huygen's principle, the points in the slit AB, CD ... etc act as a source of secondary wavelets which spread in all directions on the other side of the grating.

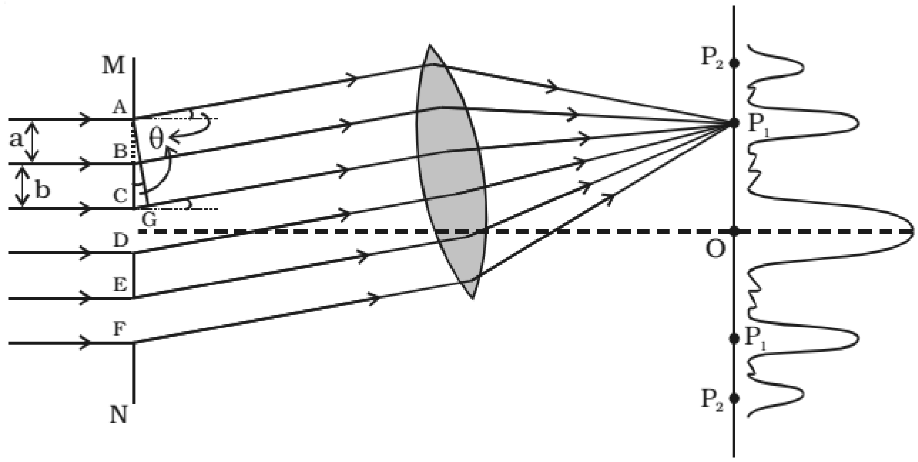


Fig 5.21 Diffraction grating

Let us consider the secondary diffracted wavelets, which makes an angle θ with the normal to the grating.

The path difference between the wavelets from one pair of corresponding points A and C is CG = $(a + b) \sin \theta$. It will be seen that the path difference between waves from any pair of corresponding points is also $(a + b) \sin \theta$

The point P_1 will be bright, when

$(a + b) \sin \theta = m\lambda$ where m = 0, 1, 2, 3

In the undiffracted position θ = 0 and hence sin θ = 0.

$(a + b) \sin \theta = 0$, satisfies the condition for brightness for m = 0. Hence the wavelets proceeding in the direction of the incident rays will produce maximum intensity at the centre O of the screen. This is called zero order maximum or central maximum.

If $(a + b) \sin \theta_1 = \lambda$, the diffracted wavelets inclined at an angle θ_1 to the incident direction, reinforce and the first order maximum is obtained.

Similarly, for second order maximum, $(a + b) \sin \theta_2 = 2\lambda$

On either side of central maxima different orders of secondary maxima are formed at the point P_1, P_2.

In general, $(a + b) \sin \theta = m\lambda$ is the condition for maximum intensity, where m is an integer, the order of the maximum intensity.

$$\sin \theta = \frac{m\lambda}{a+b} \quad \text{or} \quad \sin \theta = Nm\lambda$$

where N = $\frac{1}{a+b}$, gives the number of grating element or number of lines per unit width of the grating.

When white light is used, the diffraction pattern consists of a white central maximum and on both sides continuous coloured images are formed.

In the undiffracted position, $\theta = 0$ and hence $\sin\theta = 0$. Therefore $\sin\theta = Nm\lambda$ is satisfied for m= 0 for all values of λ. Hence, at O all the wavelengths reinforce each other producing maximum intensity for all wave lengths. Hence an undispersed white image is obtained.

As θ increases, $(a + b) \sin\theta$ first passes through $\frac{\lambda}{2}$ values for all colours from violet to red and hence darkness results. As θ further increases, $(a + b) \sin\theta$ passes through λ values of all colours resulting in the formation of bright images producing a spectrum from violet to red. These spectra are formed on either side of white, the central maximum.

5.7.3 Experiment to determine the wavelength of monochromatic light using a plane transmission grating.

The wavelength of a spectral line can be very accurately determined with the help of a diffraction grating and spectrometer.

Initially all the preliminary adjustments of the spectrometer are made. The slit of collimator is illuminated by a monochromatic light, whose wavelength is to be determined. The telescope is brought in line with collimator to view the direct image. The given plane transmission grating is then mounted on the prism table with its plane is perpendicular to the incident beam of light coming from the collimator. The telescope is slowly turned to one side until the first order diffraction image coincides with the vertical cross wire of the eye piece. The reading of the position of the telescope is noted (Fig. 5.22).

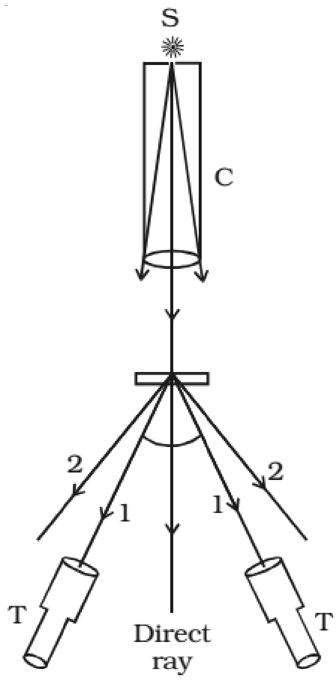


Fig 5.22 Diffraction of monochromatic light

Similarly the first order diffraction image on the other side, is made to coincide with the vertical cross wire and corresponding reading is noted. The difference between two positions gives 2θ. Half of its value gives θ, the diffraction angle for first order maximum. The wavelength of light is calculated from the equation $\lambda = \frac{\sin\theta}{Nm}$. Here N is the number of rulings per metre in the grating.

5.7.4 Determination of wavelengths of spectral lines of white light

Monochromatic light is now replaced by the given source of white light. The source emits radiations of different wavelengths, then the beam gets dispersed by grating and a spectrum of constituent wavelengths is obtained as shown in Fig 5.23.

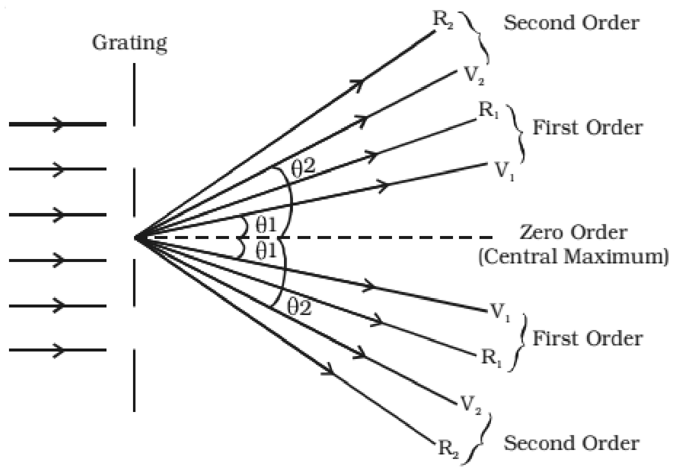


Fig 5.23 Diffraction of white light

knowing N, wave length of any line can be calculated from the relation

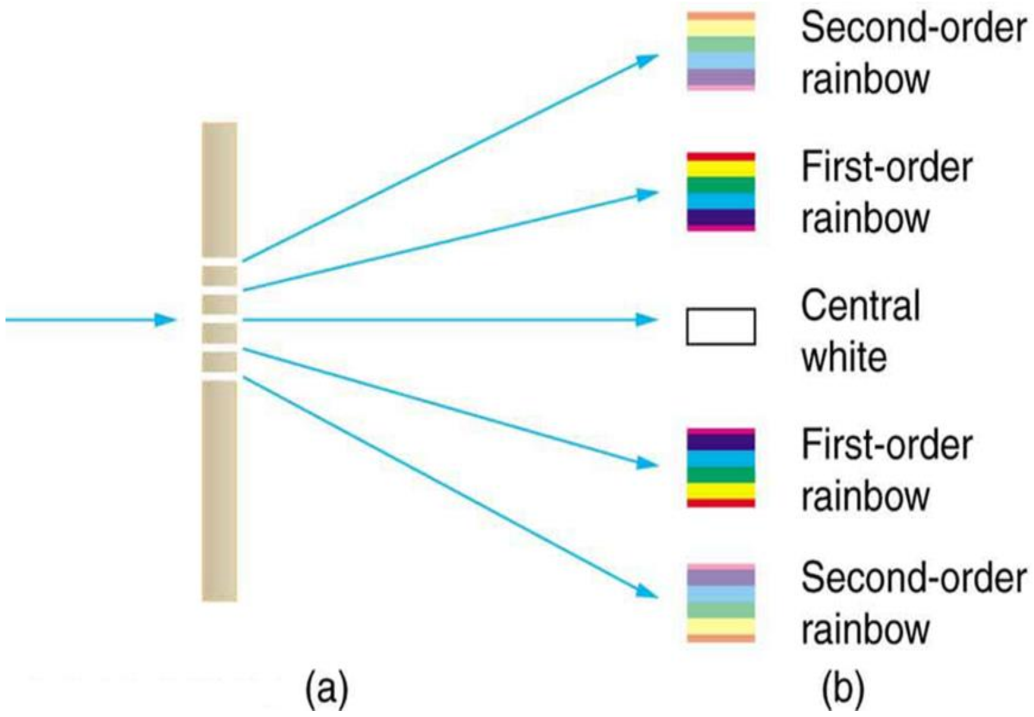
$$\lambda = \frac{\sin\theta}{Nm}$$

5.7.5 Difference between interference and diffraction

	Interference	Diffraction
1.	It is due to the superposition of secondary wavelets from two different wavefronts produced by two coherent sources.	It is due to the superposition of secondary wavelets emitted from various points of the same wave front.
2.	Fringes are equally spaced.	Fringes are unequally spaced.
3.	Bright fringes are of same intensity	Intensity falls rapidly
4.	Comparing with diffraction, it has large number of fringes	It has less number of fringes.

DIFFRACTION GRATINGS

- The diffraction grating is an important experimental application of the multiple slit maximum/minimum phenomenon. In its simplest form a diffraction grating consists of a metal or glass plate with many very finely spaced grooves or slits.
- For a metal grating interference occurs in the reflected light. For a glass grating reflected or transmitted light will interfere.
- The "slit" spacing, d, is typically defined by the number of grooves per cm (or inch).
- Principal maxima are located at angles θ given by $\sin\theta = n\lambda/d$. Therefore, the smaller "d" (or the more grooves per cm) the larger the angle θ.
- By examining the exact intensity formula it can be shown that the smaller "d" the brighter the principal maxima when compared to the secondary maxima.
- When an atom is "excited" , it emits the spectrum of light and de-exciting back to its ground state is characteristic of that particular atom. Thus, observing the spectrum of light emitted by a star gives an accurate measure of the elemental compostion of the star. Since the angle θ depends on the wavelength λ we can use a diffraction grating to obtain the spectrum of the light emitted by the star.
- For a "white" light source a diffraction grating may lead to several "orders", corresponding to n = 1, 2, 3,... Each order will contain the complete spectrum of colors (see below).



Coherence :

A wave which appears to be a pure sine wave for an infinitely large period of time or in an infinitly extended space be said to be a perfectly coherent wave. In such a wave there is a definite relationship between phase of wave and a given time and at a certain time later for at a point and at a certain distance away.

"Coherence describes all properties of the correlation between physical quantities of a single wave or between several waves or wave packets"

No actual light source however emits aperfect coherent wave. Light waves which are pure sine waves only for a limited period of time or in a limited space, are partially coherent waves.

There are two types of Coherence :

i) Temporal

ii) Spatial

i. Temporal Coherence :

It's a measure of the average correlation between the value of a wave and itself delayed by T, at any pair of times. Temporal coherence tells us how monochromatic a source is.

Example of temporal coherence:

A wave containing only a single frequency is perfectly correlated with itself at all time delays. On the other hand a wave whose phase drifts quickly will have a short coherence time.

Similarly pulses of waves which naturally have a broad range of frequencies also have a short coherence time since the amplitude of the wave changes quickly.

Finally white light which has very broad range of frequencies is a wave which varies quickly in both amplitude and phase since it consequently has a very short coherence time it is often called incoherent.

ii. Spatial Coherence:

The spatial coherence is the phase relationship between the radiation field at different points in space.

In some system such as water waves or optics wave-like states can extend over one or two dimensions. Spatial coherence describes the ability for two points in space in the extent of a wave to interfere when averaged over time

The spatial coherence is the cross-correlation between two points in a wave for all times if a wave has only 1 value of amplitude over an infinite length it is perfectly spatially coherent.

UNIT-II

LASER AND FIBRE OPTICS

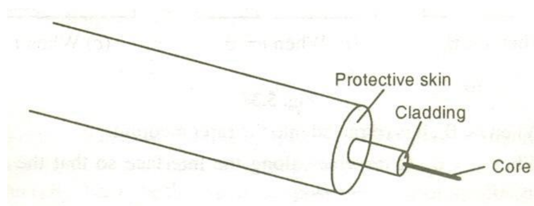
INTRODUCTION TO FIBRE OPTICS

The development of lasers and optical fiber has brought about a revolution in the field of communication systems. Experiments on the propagation of information – carrying light waves through an open atmosphere were conducted. The atmospheric conditions like rain, fog etc affected the efficiency of communication through light waves. To have efficient communication systems, the information carried by light waves should need a guiding medium through which it can be transmitted safely. This guiding mechanism is optical fiber. The communication through optical fiber is known as light wave communication or optical communication. A light beam acting as a carrier wave is capable of carrying more information than that of radio waves and microwaves due to its larger bandwidth. Currently in most part of the world, fiber optics is used to transmit voice, video and digital data signals using light waves from one place to other place.

OPTICAL FIBER

It is made up of transparent dielectrics (SiO_2), (glass or dielectrics).

An optical fibre of a central core glass (50µm dia) surrounded by a cladding (125-200µm) which is of slightly lower refractive index than core as as shown in figure.



The cladding is enclosed by strength members and polyurethane jacket, which act as protective skin for core and cladding as shown in figure. The protective layer is used so has to make the optical cable to withstand for hard pulling, bending, sketching, rolling etc.. the layer also traps the escaping light from the core.

Features of Optical fibers

(i) It is light in weight

(ii) It is smaller in size

(iii) It is flexible

(iv) It is non – conductive, non – radiative and non – inductive

(v) It has high bandwidth and low loss

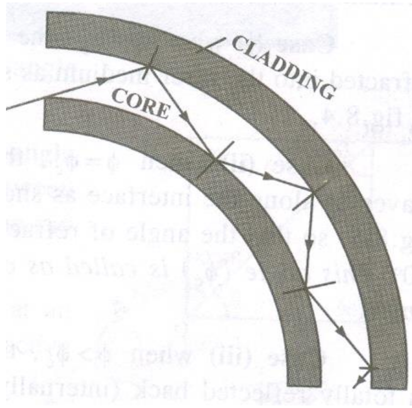
(vi) There is no cross talk / internal noise

(vii) It can withstand to any range of temperature and moisture condition.

(viii) No voltage problem occurs

PRINCIPLE AND PROPAGATION OF LIGHT IN OPTICAL FIBERS

For optical fibers, the process of propagation of light (optical signal) is simple, because once the light enters the fiber, the rays do not encounter any new surfaces, but repeatedly they hit the sane surface. The reason of confining the light beam inside the fibers is the total internal reflection. Even for a bent fiber, the light guidance takes place by multiple total internal reflections all over the length of the fiber as shown in figure.



Principle

The principle of optical fiber communication is Total Internal Reflection.

Total Internal Reflection

The phenomenon of Total Internal Reflection takes place when it is satisfies the following two conditions.

Condition 1:

Light should travel from denser medium to rarer medium i.e $n_1 > n_2$

Where n_1= refractive index of core

n_2 = refractive index of cladding

Condition 2:

The angle of incidence on core should be greater than the critical angle.

i.e. $\phi > \phi_c$

Where,

ϕ - angle of incidence

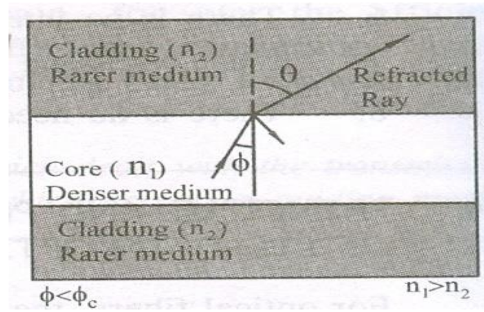
ϕ_c – critical angle

Propagation Phenomenon

Let the light rays traverses from denser medium to rarer medium.

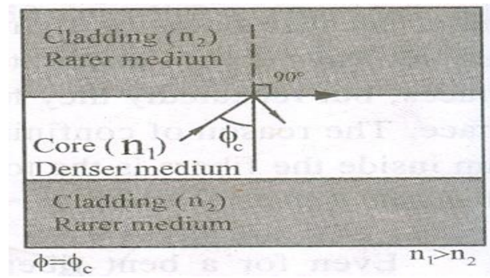
Case i.

When $\phi < \phi_c$ the ray is refracted into the rarer medium as shown in figure.



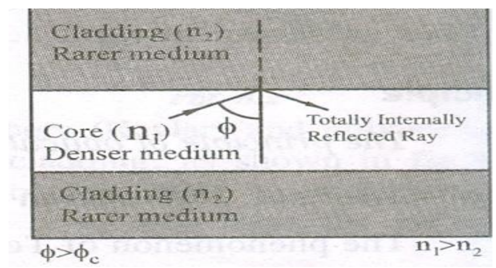
Case ii.

When $\phi = \phi_c$, the ray traverses along the interface as shown in figure. So that the angle of refraction is 90˚. This angle is called as critical angle.



Case iii.

When $\phi > \phi_c$ the ray is totally reflected back (internally) into the denser medium itself as shown in figure. From Snell's law (the maximum angle for Total Internal Reflection ϕ_c).



$n_1 \sin\phi_c = \mathbf{n_2 \sin 90^\circ}$

$\sin\phi_c = \mathbf{n_2/n_1}$

since sin 90˚ = 1, we have

$$\phi_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

ACCEPTANCE ANGLE AND NUMERICAL APERATURE

Let us consider a cylindrical fiber. it consists of core of refractive index n_1, and cladding of refractive index n_2 and let n_0 be the refractive .

The incident ray travels along AO and enters the core at an angle' i' to the fiber axis.

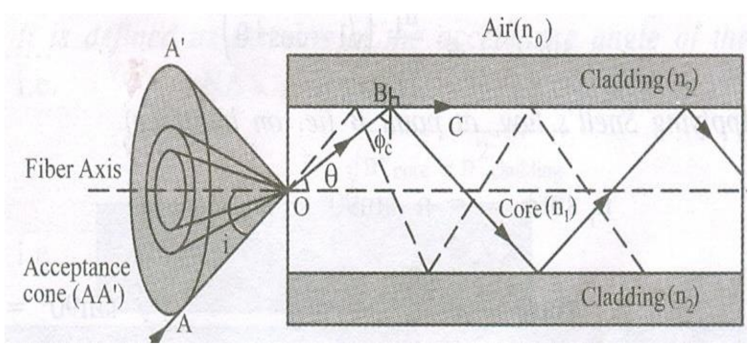
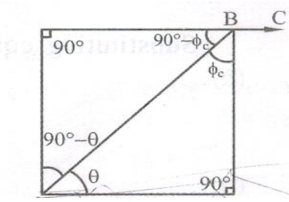


Fig.5.24

The ray is refracted along OB at an angle θ in the core as shown in figure 5.24.

It further proceeds to fall at critical angle of incidence (ϕ_c) = 90- θ on the interface between core and cladding. At this angle the ray just moves along BC.

Any ray which enters in to the core at an angle of incidence less than I will have refractive angle less than θ.



Hence, the angle of incidence (ϕ = 90- θ) at the interface of core and cladding will be more than the critical angle. Hence the ray is totally internally reflected ray. Thus, only those ray which passes with in the acceptance angle (cone) will be totally internally reflected. Therefore, the light incident on the core within this maximum external incident angle (i_m) can be coupled into the fiber to propagate. This angle (i_m) is called as wave guide acceptance angle.

Mathematical Relation

i. Applying snell's law, at point entry of ray (AO) we have

$$n_0 \sin i = n_1 \sin \theta$$

$$\sin i = \frac{n_1}{n_0} \sin \theta$$

$$\sin i = \frac{n_1}{n_0} \sqrt{1-\cos^2\theta} \qquad \text{------------------ (1)}$$

ii. Applying snell's law, at point B (ie.on surface)

$$n_1 \sin \phi_c = n_2 \sin 90^\circ.$$

$$\sin \phi_c = \frac{n_2}{n_1} \qquad (\sin 90^\circ = 1)$$

$$\sin(90-\theta) = \frac{n_2}{n_1}$$

$$\cos\theta = \frac{n_2}{n_1} \qquad \text{-----------------(2)}$$

substituting equation (2) in equation (1) we get

$$\sin i = \frac{n_1}{n_0}\left[\sqrt{1-(\frac{n_2}{n_1})2}\right]$$

$$\sin i = \frac{n_1}{n_0} \cdot \frac{1}{n_1}\sqrt{n_1^2 - n_2^2}$$

$$i = \sin^{-1}\left(\frac{\sqrt{\sqrt{n_1^2-n_2^2}}}{n_0}\right)$$

If the refractive index of air, n_0 =1, then the maximum value of sin i is given as

$$\text{Sin } i_{max} = \sqrt{n_1^2 - n_2^2} \qquad \text{-------------------(3)}$$

Where, $n_1$and n_2 are refractive indices of core and cladding respectively.

Acceptance angle

Thus the maximum angle at or below which the light can suffer Total Internal Reflection is called acceptance angle. The cone is referred as acceptance cone.

Numerical Aperture [NA]

It is defined as the sine of the acceptance angle of the fiber.

NA = sin i_m

$$= \sqrt{n_{core}^2 - n_{cladding}^2}$$

$$NA = \sin i_m = \sqrt{n_1^2 - n_2^2} \quad \text{----------------(4)}$$

Fractional index change (Δ)

It is the ratio of refractive index difference in core and cladding to the refractive index of core.

$$\Delta = \frac{n_1 - n_2}{n_1} \quad \text{----------------(5)}$$

Relation between NA and Δ

$$n_1\Delta = n_1 - n_2 \quad \text{----------------(6)}$$

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

(Or) NA = $\sqrt{(n_1 + n_2)(n_1 - n_2)}$ --------------(7)

Substituting equation (6) in equation (7) we have

or NA = $\sqrt{(n_1 + n_2)(n_1\Delta)}$

if $n_1 \approx n_2$, then NA = $\sqrt{2n_1^2\Delta}$

$$NA = n_1\sqrt{2\Delta}$$

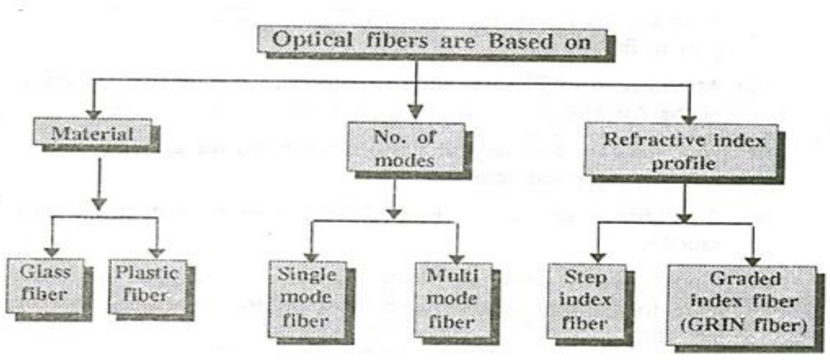
TYPES OF OPTICAL FIBERS

Optical fibers are classified into three major categories

i. The type of material used

ii. The number of modes

iii. The refractive index profile



GLASS AND PLASTIC FIBERS

Based on the type of the material used, they are classified into two types.

Glass fibers:

The glass fibres are made up of mixture of metal metal oxides and silica glasses.

Example: The glass fibres are made by the following combinations of core and cladding.

Core: SiO_2, Cladding: SiO_2

Core: GeO_2- SiO_2, Cladding: SiO_2

Plastic fibers:

The fibers which are made up of plastics can be handled without any care due to its toughness and durability are called plastic fiber.

Example: The plastic fibres are made by the following combinations of core and cladding.

Core: polymethyl methacrylate , Cladding: Co- Polymer

Core: Polystyrene, Cladding: Methyl methacrylate

SINGLE AND MULTIMODE FIBER

Light propagates as electromagnetic waves through an optical fiber. Based on the modes of propagation the fibers are classified into two types.

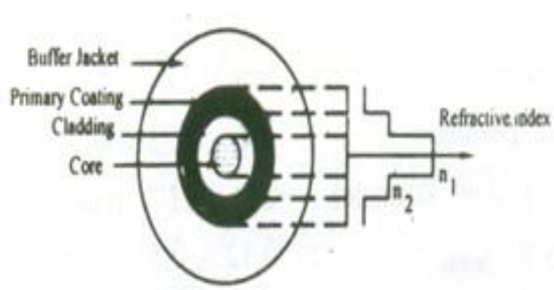
1. Single mode fiber
2. Multimode fiber

1. Single mode fiber

In general, the single mode fibers are step – index fibers. These types of fibers are made from doped silica. It has a very small core diameter so that it can allow only one mode of propagation and hence called single mode fibers.

The cladding diameter must be very large compared to the core diameter. Thus in the case of single mode fiber, the optical loss is very much reduced. The structure of a single mode fiber as shown in figure.

Structure



Core diameter	: 5-10μm
Cladding diameter	: Around 125μm
Protective layer	: 250 to 1000μm
Numerical aperture	: 0.08 to 0.10
Band width	: More than 50MHz km.

Application:

Because of high bandwidth, they are used in long haul communication systems.

2. Multimode fiber

The multi modes fibers are useful in manufacturing both for step – index and graded index fibers. The multi-mode fibers are made by multi-component glass compounds such as Glass – Clad Glass, Silica – Clad – Silica, doped silica etc. Here the core diameter is very large compared to single mode fibers, so that it can allow many modes to propagate through it and hence called as Multi mode fibers. The cladding diameter is also larger than the diameter of the single mode fibers. The structure of the multimode fiber is as shown in the figure.

Structure

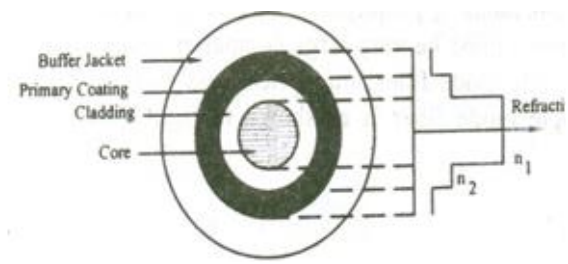
Core diameter : 50-350μm

Claddingdiameter : 125μm - 500μm

Protective layer : 250 to 1100μm

Numericalapertur : 0.12 to 0.5

Band width : Less than 50MHz km.



Application:

Because of its less band width it is very useful in short haul communication systems.

DIFFERENCE BETWEEN SINGLE AND MULTIMODE FIBER

S. No.	SINGLE MODE FIBER	MULTI MODE FIBER
1.	In single mode fiber only one mode can propagate through the fiber	In multimode it allows a large number of paths or modes for the light rays travelling through it.
2.	It has smaller core diameter and the difference between the refractive index of the core and cladding is very small.	It has larger core diameter and refractive index difference is larger than the single mode fiber.
3.	**Advantages:** No dispersion(i.e. there is no degradation of signal during propagation)	**Disadvantages:** Dispersion is more due to degradation of signal owing to multimode.
4.	The fiber can carry information to longer distances.	Information can be carried to shorter distances only.
5.	**Disadvantages:** Launching of light and connecting of two fibers difficult.	**Advantages:** Launching of light and also connecting of two fibers is easy.
6.	Installation (fabrication) is difficult as it is more costly	Fabrication is easy and the installation cost is low.

STEP INDEX AND GRADED INDEX FIBERS

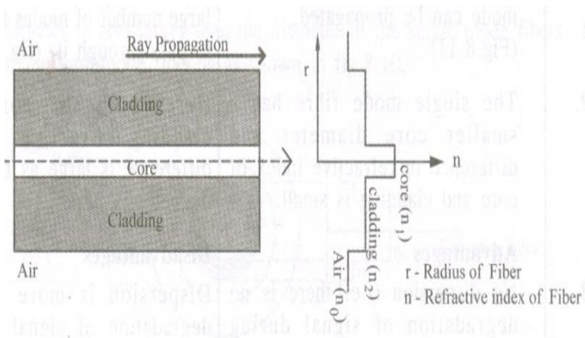
Based on the variation in the refractive index of the core and the cladding, the fibers are classified into two types

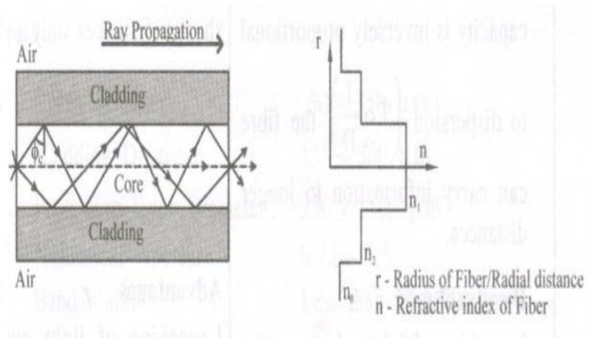
i. Step index fiber

ii. Graded index fiber

Step index fiber

The refractive indices of air, cladding and core vary by step by step and hence it is called as step index fiber. In step index fiber we have both single mode and multimode fibers as shown in figure 5.28.

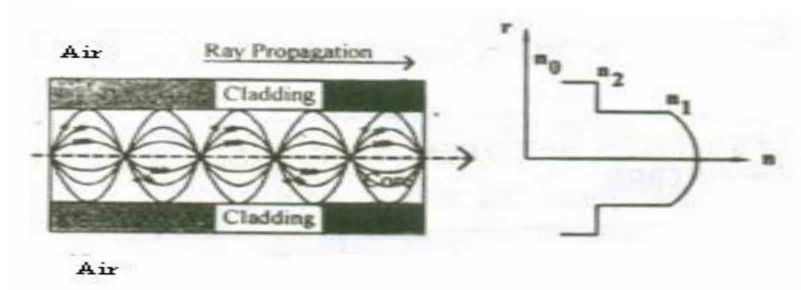




Single mode step index fiber Multi mode step index fiber

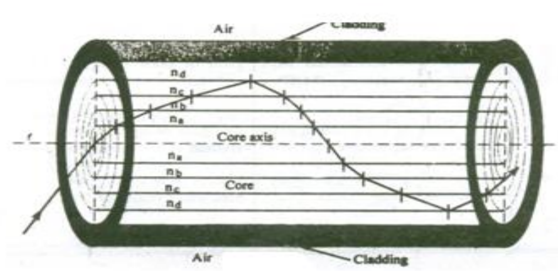
Graded index fiber

The refractive index of the core varies radially from the axis of the fiber. The refractive index of the core is maximum along the fiber axis and it gradually decreases. Thus it is called as graded index fiber. Here the refractive index becomes minimum at the core-cladding interface. In general the graded index fibers will be of multi mode system. The multi mode graded index fiber has very less intermodal dispersion compared to multi mode step index fiber. A typical multi mode graded index fiber is as shown in figure.



Propagation of light in GRIN fiber

Let n_a, n_b,n_c,n_d etc be the refractive index of different layers in graded index fiber with $n_a > n_b > n_c > n_d$ etc. then the propagation of light through the graded index fiber is as shown in the figure .



Here, since $n_a > n_b$ the ray gets refracted. Similarly since $n_b > n_c$, the ray gets refracted and so on. In a similar manner, due to decrease in refractive index the ray gets gradually curved towards the upward direction and at one place, where in it satisfies the condition for total internal reflection,($\phi > \phi_c$) it is totally internally reflected. The reflected rays travels back towards the core axis and without crossing the fiber axis, it is refracted towards downwards direction and again gets totally internally reflected and passes towards upward direction. In this manner the ray propagates inside the fiber in a helical or spiral manner.

DIFFERENCE BETWEEN STEP INDEX FIBER & GRADED INDEX FIBER

S. No.	STEP INDEX FIBER	GRADED INDEX (GRIN) FIBER
1.	The difference is refractive indices is obtained in single step and hence called as step-index fiber.	Due to non-uniform refractive indices, the difference in refraction index is obtained gradually from centre towards interface and hence called graded index fiber.
2.	The light ray propagation is in the form of meridional rays and it passes through the fiber axis.	The light ray propagation is in the form of skew rays and it will not cross the fiber axis.
3.	The path of light propagation is in zig-zig manner.	The path of light is **helical** in manner
4.	This fiber has **lower bandwidth**	This fiber has **higher bandwidth**
5.	**Attenuation is more** for multimode step index fiber but for single mode it is very less. Explanation: When a ray travels through the longer distances there will be some difference in reflected angles. Hence high angle rays arrive later than low angle rays causing dispersion resulting in distorted output.	**Attenuation is less.** Explanation: Here the light rays travel with different velocity inn different paths because of their variation in their refractive indices. At the outer edge it travels faster than near the center. But almost all the rays reach the exit at the same time due to helical path. Thus, there is no dispersion.
6.	**No of modes of Propagation** $N_{step} = 4.9\left(\frac{d\ x\ NA}{\lambda}\right)^2 = \frac{V^2}{2}$ Where d= diameter of the fiber core λ= wavelength NA = Numerical Aperture V- V-number is less than or equal to 2.405 for single mode fibers & greater than 2.405 for multimode fibers.	**No of modes of Propagation** $N_{step} = 4.9\left(\frac{d\ x\ NA}{\lambda}\right)^2 = \frac{V^2}{2}$ Or $N_{graded} = \frac{N_{step}}{2}$

LOSSES IN OPTICAL FIBERS- ATTENUATION

When light propagates through an optical fiber, a small percentage of light is lost through different mechanisms. The loss of optical power is measured in terms of decibels per kilometer for attenuation losses.

Attenuation

It is defined as the ratio of the optical power output (P_{out}) from a fiber of length 'L' to the power input (p_{in})

$$\text{ie. Attenuation } (\alpha) = \frac{-10}{L} \log \frac{P_{in}}{P_{out}} \text{ dB/km}$$

Since attenuation plays a major role in determining the transmission distance, the following attenuation mechanisms are to be considered in designing an optical fiber.

(1) Absorption

(2) Scattering

(3) Radiative losses.

1. Absorption

Usually absorption of light occurs due to imperfections of the atomic structure such as missing molecules, (OH^-) hydroxyl ions, high density cluster of atoms etc., which absorbs light. Absorption also depends on the wavelength of the light used. The three bands of wavelength at which the absorption increases drastically is 950 nm, 1250 nm and 1380 nm. For example, at the wavelength say 850 nm the absorption is 1.5 dB/Km and for 1500 nm, it is 0.5 dB/Km.

2. Scattering

Scattering is also a wavelength dependent loss, which occurs inside the fibers. Since the glass is used in fabrication of fibers, the disordered structure of glass will make some variations in the refractive index inside the fiber. As a result, if is passed through the atoms in the fiber, a portion of the light is scattered (elastic scattering). This type of scattering is called Rayleigh scattering. i.e., Rayleigh scattering loss $\alpha \frac{1}{\lambda^4}$

3. **Radiative losses**

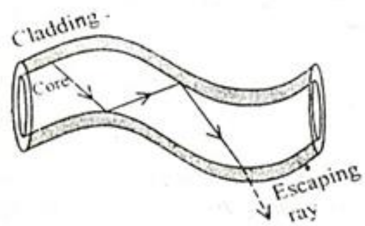
Radiative loss occurs in fibers, due to bending of finite radius ofc curvature in optical fibers. The types of bends are

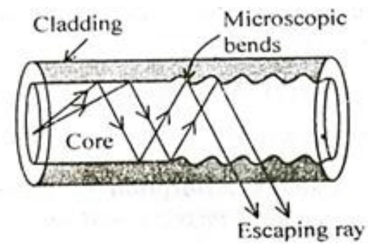
(a) Macroscopic bend and

(b) Microscopic bend

(a) Macroscopic bends

If the radius of core is large compared to fiber diameter as shown in fig. it may cause large-curvature at the position where the fiber cable turns at the corner. At these corners the light will not satisfy the condition for total internal reflection and hence it escapes out from the fiber. This is called as macroscopic/macro bending losses. Also note that this loss is negligible for small bends.





(b) Microscopic bends

Micro-bends losses are caused due to non-uniformities (or) micro-bends inside the fiber as shown in fig. This micro bends in fiber appears due to non uniform pressures created during the cabling of the fiber (or) even during the manufacturing itself. This lead to loss of light by leakage through the fiber.

Remedy

Micro-bend losses can be minimized by extruding (squeezing out)a compressible jacket over the fiber. In such cases even when the external forces are applied, the jacket will be deformed but the fiber will tend to stay relatively straight and safe, without causing more loss.

Fiber optic cables find many uses in a wide variety of industries and applications. Some uses of fiber optic cables include:

APPLICATION OF OPTICAL FIBER

- **Medical**

  Used as light guides, imaging tools and also as lasers for surgeries
- **Defense/Government**

  Used as hydrophones for seismic waves and SONAR , as wiring in aircraft, submarines and other vehicles and also for field networking
- **Data Storage**

  Used for data transmission
- **Telecommunications**

  Fiber is laid and used for transmitting and receiving purposes
- **Networking**

  Used to connect users and servers in a variety of network settings and help increase the speed and accuracy of data transmission

- **Industrial/Commercial**

  Used for imaging in hard to reach areas, as wiring where EMI is an issue, as sensory devices to make temperature, pressure and other measurements, and as wiring in automobiles and in industrial settings

- **Broadcast/CATV**

  Broadcast/cable companies are using fiber optic cables for wiring CATV, HDTV, internet, video on-demand and other applications

INTRODUCTION

The word "**laser**" is an acronym for Light Amplification by Stimulated Emission of Radiation. Lasers have many important applications. They are used in common consumer devices such as DVD players, laser printers, and barcode scanners.

They are used in medicine for laser surgery and various skin treatments, and in industries for cutting and welding materials.

CHARACTERISTICS OF LASER

(i) Directionality

Ordinary light spreads in all directions and its angular spread is 1 metre/metre. But it is found that laser is highly directional and its angular spread its 1mm/metre.

(ii) Intensity

An ordinary light spreads in all directions; the intensity reaching the target is very less. But in the case of laser, due to high directionality the intensity of laser beam reaching the target is of high intense beam.

For example, 1 milli watt power of He-Ne laser appears to be brighter than the sunlight.

(iii)Monochromaticity

Laser beam is highly monochromatic i.e. the wavelength is single, whereas in ordinary light like mercury vapour lamp, many wavelengths of light are emitted.

(iv)Coherence

The light from a laser is said to be highly coherent, which means that the waves of laser light are in same amplitude and phase. There are two types of coherence,

- temporal coherence
- spatial coherence.

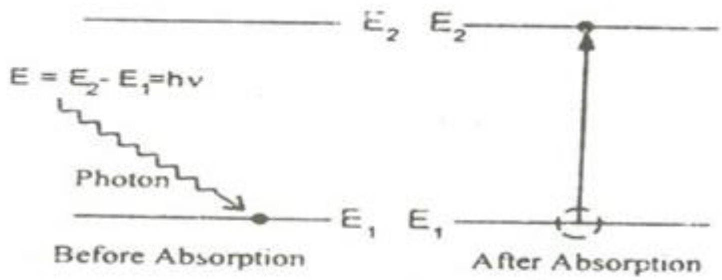
PRINCIPLE OF SPONTANEOUS AND STIMULATED EMISSION EINSTEIN'S QUANTUM THEORY OF RADIATION

When light is absorbed by the atoms or molecules, then it goes from the lower energy level (E_1) to the higher energy level (E_2) and during the transition from higher energy level (E_2) to lower energy level (E_1), the light is emitted from the atoms or molecules.Let us consider an atom exposed to (light) photons of energy E_2-E_1= h^{γ}, three distinct processes takes place.

i. Absorption
ii. Spontaneous emission
iii. Stimulated emission

i. Absorption

An atom in the lower energy level or ground state energy level E_1absorbs the incident photon radiation of energy (h^{γ}) and goes to the higher energy level or excited energy state E_2 as shown in fig 5.1. This process is called as absorption.



If there are many number of atoms in the ground state then each atom will absorb the energy from the incident photon and goes to the excited state then,

The rate of absorption (R_{12}) is proportional to the following factors.

i.e. R_{12} α Energy density of incident radiation (ρ_v)

α No of atoms in the ground state (N_1)

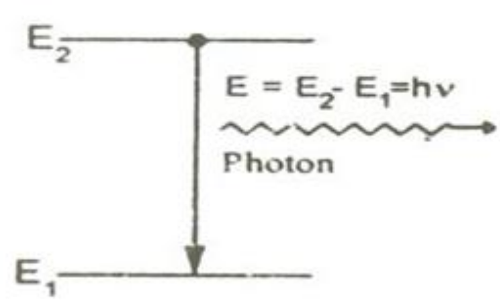
i.e. $R_{12} \alpha \rho_v N_1$

or $R_{12} = B_{12} \rho_v N_1$ ----(1)

Where, B_{12} is a constant which gives the probability of absorption transition per unit time.

ii. Spontaneous emission

The atom in the excited state returns to the ground state by emitting a photon of energy E= (E_2– E_1) = h^{γ}, spontaneously without any external triggering as shown in figure.



This process is known as spontaneous emission. Such an emission is random and is independent of incident radiation.

If N_1 and N_2 are the numbers of atoms in the ground state (E_1) and excited state (E_2) respectively, then

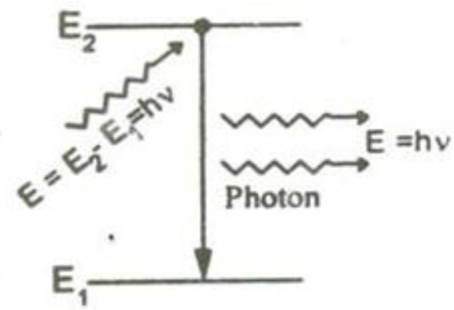
The rate of spontaneous emission is R_{21} (Sp) α N_2

(or) R_{21} (Sp) = $A_{21}N_2$ -----(2)

Where, A_{21} is a constant which gives the probability of spontaneous emission transition per unit time.

iii. Stimulated emission

The atom in the excited state can also return to the ground state by external triggering (or) inducement of photon there by emitting a photon of energy equal to the energy of the incident photon, known as stimulated emission. Thus results in two photons of same energy, phase difference and of same directionality as shown in figure.



The rate of stimulated emission is R_{21} (St) α ρ_v N_2

(or) R_{21} (St) = B_{21} ρ_v N_2 ----(3)

Where, B_{21} is a constant which gives the probability of stimulated emission transition per unit time.

Einstein's theory

Einstein's theory of absorption and emission of light by an atom is based on Planck's theory of radiation. Also under thermal equilibrium, the population of energy levels obeys the Boltzmann's distribution law.

i.e. under thermal equilibrium

The rate of absorption = The rate of emission

$$B_{12}\,\rho_v\,N_1 = A_{21}N_2 + B_{21}\,\rho_v\,N_2$$

$$\rho_v\,[B_{12}\,N_1 - B_{21}\,N_2\,] = A_{21}N_2$$

$$\therefore\ \rho_v = \frac{A_{21}N_2}{B_{12}N_1 - B_{21}N_2}$$

$$\therefore\ \rho_v = \frac{A_{21}}{B_{12}({}^{N_1}/_{N_2}) - B_{21}} \qquad ----(4)$$

We know from Boltzmann distribution law

$$N_1 = N_0 e^{-E_1/K_BT}$$

Similarly

$$N_2 = N_0 e^{-E_2/K_B T}$$

Where

K_B - Boltzmann Constant

N_0 - Number of atoms at absolute zero

T- Absolute temperature

At equilibrium, we can write the ratio of population levels as follows,

$$\frac{N_1}{N_2} = e^{(E_2 - E_1)/K_B T}$$

Since $E_2 - E_1 = h\vartheta$, we have

$$\frac{N_1}{N_2} = e^{h\vartheta/K_B T} \quad \text{----(5)}$$

Sub eqn (5) in (4), we get

$$\rho_v = \frac{A_{21}}{B_{12}(e^{h\vartheta/K_B T}) - B_{21}}$$

$$\rho_v = \frac{A_{21}}{B_{21}} \frac{1}{(B_{12}/B_{21}) e^{h\vartheta/K_B T} - 1} \quad \text{----(6)}$$

This equation has a very good agreement with plank's energy distribution radiation law

$$\rho_v = \frac{8\pi h\vartheta^3}{C^3} \frac{1}{e^{h\vartheta/K_B T} - 1} \quad \text{---(7)}$$

Therefore comparing (6) and (7), we have

$$B_{12} = B_{21} = B$$

and

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\vartheta^3}{C^3} \quad \text{----(8)}$$

Taking $A_{21} = A$

The constants A and B are called as Einstein Coefficients, which accounts for spontaneous and stimulated emission probabilities. Ratio of magnitudes of stimulated and spontaneous emission rates are as follows,

From eqn (2) and (3) we have

$$\frac{R_{21}(st)}{R_{21}(sp)} = \frac{B_{21}\rho_v N_2}{A_{21}N_2}$$

$$\frac{R_{21}(st)}{R_{21}(sp)} = \frac{B_{21}\rho_v}{A_{21}} \quad \text{---(9)}$$

Rearranging eqn (6) we can write

$$\frac{B_{21}\rho_v}{A_{21}} = \frac{1}{(B_{12}/B_{21}) e^{h\vartheta/K_B T} - 1}$$

Since $B_{12} = B_{21}$, we have

$$\frac{1}{e^{h\vartheta/K_BT}-1} = \frac{B_{21}\rho_v}{A_{21}} \quad \text{--- (10)}$$

Comparing (9) and (10) we get

$$\frac{R_{21}(st)}{R_{21}(sp)} = \frac{1}{e^{h\vartheta/K_BT}-1} = \frac{B_{21}\rho_v}{A_{21}}$$

In simpler way the ratio can be written as

$$\mathbf{R} = \frac{\mathbf{B_{21}\rho_v}}{\mathbf{A_{21}}}$$

Generally spontaneous emission is more predominant in the optical region (ordinary light). To increase the number of coherent photons stimulated emission should dominate over spontaneous emission.

DIFFERENCE BETWEEN SPONTANEOUS AND STIMULATED EMISSION OF RADIATION

S. No	**Stimulated emission**	**spontaneous emission**
1.	An atom in the excited state is induced to return to ground state, thereby resulting in two photons of same frequency and energy is called stimulated emission.	The atom in the excited state returns to ground state thereby emitting a photon, without any external inducement is called spontaneous emission.
2.	The emitted photons move in same direction and is highly directional	The emitted photons move in all directions and are random.
3.	The radiation is high intense, monochromatic and coherent.	The radiation is less intense and is incoherent.
4.	The photons are in phase (i.e.) there is a constant phase difference.	The photons are not in phase (ie.) there is no phase relationship between them.
5.	The rate of transition is given by $R_{21}(St) = B_{21}\rho_v N_2$	The rate of transition is given by $R_{21}(Sp) = A_{21}N_2$

POPULATION INVERSION

Consider two energy level systems E_1 and E_2. Suppose a photon of energy equal to the energy difference between the two energy levels, incident on the system, then there is equal chances for stimulated emission and absorption to occur. At this situation the chance for emission or absorption depends only on the number of atoms in the ground state and in the excited state.

Let N_1 be the number of atoms in ground state and N_2 be the number of atoms in excited state. Then,

If $N_1 > N_2$ there is more chance for absorption takes place.

If $N_2 > N_1$ there is more chance for stimulated emission takes place.

Therefore, the number of atoms in the excited state should be increased by some means. **Thus the state of achieving more number of atoms in the excited state compared to the ground state atoms is called population inversion.**

We know from Boltzmann distribution law $N_1/ N_2 = e^{(E_2-E_1)}/K_BT$

Case (i): If T is +ve

$N_1 = N_2\, e^{+ve}$

For example if $N_2 = 5$ and if $(E_2 – E_1) / k_BT \approx 2$,

Then, $N_1 = 5.\ e^{+2} = 36.9$

$N_1 > N_2$ since 36.9 >5

Case (ii) If T is -ve

$N_1 = N_2\, e^{-ve}$

For example If $N_2 = 5$ and if $(E_2 – E_1) / k_BT \approx 2$,

$N_1 = 5.\ e^{-2} = 0.6766$

$N_2 > N_1$ since 5>0.6766

This shows that number of atoms in excited state can be made more than number of atoms in the ground state only under negative temperature. But, the negative temperature is practically not possible. Therefore population inversion can be achieved by some other artificial process known as pumping process.

Active medium

The medium in which the population inversion takes place is called as active medium.

Active centre

The material in which the atoms are raised to excited state to achieve population inversion is called as active centre.

PUMPING METHODS

Pumping

The process of raising more number of atoms to excited state by artificial means is called as pumping process. There are several methods by which the population inversion (pumping) can be achieved. Some of the most commonly used methods are as follows,

(i) Optical pumping

(ii) Electric discharge

(iii) Inelastic atom – atom collision.

(iv) Direct conversion

(v) Chemical process

(i) Optical pumping

The atoms are excited with help of photons emitted by an external optical source. The atoms absorb energy from the photons and raises to excited state.

Ex. Ruby laser, Nd-YAG laser.

(ii) Electric discharge

The electrons are accelerated to very high velocity by strong electric field and they collide with gas atoms and these atoms are raised to excited state (e.g) argon laser, Helium-Neon laser, CO_2 Laser etc…

(iii)Inelastic atom-atom collision

In this method a combination of two types of gases are used. Say A and B, either having same (or) nearly coinciding excited states A*and B*.

During electric discharge ‘A’ atoms get excited due to collision with electrons. The excited A* atoms now collide with ‘B’ atoms so that B goes to excited state B*(e.g), Helium-Neon laser, CO_2 Laser.

$$e^- + A^* \rightarrow A^*$$

$$A^* + B \rightarrow B^* + A$$

(iv)Direct conversion

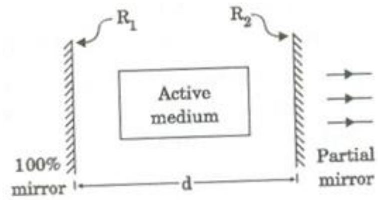
Due to electrical energy applied in direct band gap semiconductor like GaAs etc., the combination of electrons and holes take place and electrical energy is converted into light energy directly. (e.g) Semiconductor laser.

(v) Chemical process

Due to some chemical reactions, the atoms may be raised to excited state**.** (e.g) Dye laser

OPTICAL RESONATOR

The Optical resonator constitutes an active medium kept in between a 100% reflecting mirror and a partially reflecting mirror as shown in figure 5.4. This optical resonator acts as a feedback system in amplifying the light emitted from the active medium, by making it to undergo multiple reflections between the 100% mirror and partial mirror. Here the light bounces back and forth between the two mirrors and hence the intensity of the light is increased enormously. Finally the intense, amplified beam called LASER is allowed to come out through the partial mirror as shown in figure 5.4.



TYPES OF LASERS

Based on the type of active medium, Laser systems are broadly classified into the following categories.

S.No	TYPES OF LASER	EXAMPLES
1.	Solid State Laser	Ruby Laser Nd:YAG laser
2.	Gas laser	He-Ne Laser, CO_2 Laser, Argon – ion Laser
3.	Liquid Laser	SeOCL2 Laser, Europium Chelate Laser
4.	Dye Laser	Rhodamine 6G laser, Coumarin dye laser
5.	Semiconductor Laser	GaAs laser, GaAsP laser

CARBON – DI - OXIDE LASER

Characteristics of co_2 laser

Type – Molecular Gas laser

Active medium – Mixture of CO_2 , N_2 and helium or Water vapour

Active centre – Co_2

Pumping method – Eletric discharge method

Optical resonator – Metallic mirror of gold or silicon mirrors coated with aluminium

Power output – 10Kw

Nature of output – continuous or pulsed

Wavelength emitted – 9.6µm & 10.6 µm

Principle:

In the active medium, CO_2 molecule moves to various vibrational energy states on absorption of energy from N_2 atoms. Transition between various vibrational energy levels leads to the laser output.

Construction:

It consists of a gas discharge tube (made of quartz) in which CO2, N2 and He are filled under various pressure levels.

Both ends of the discharge tube is attached with Brewster windows. It is used to produce plane polarized light by reflecting the perpendicularly polarized light. Apart from this, one end of the discharge tube is attached to fully reflecting mirror (100% reflector) and the other end is attached to partially reflecting mirror (50% reflector) as shown in the figure, which act as resonant cavity.

The electrodes that are fixed with the inner wall of the discharge tube are connected to the radio frequency oscillator which provides the necessary electrical discharge.

A Screw arrangement (S) is given so that the length of the active medium can be varied.

Note : Nitrogen helps to increase the population of atoms in the upper level of CO2, While helium helps to depopulate the atoms in the lower level of CO2 and also to cool the discharge tube.

Working

Figure shows the various vibrational levels taking part in the laser transition.

When radio frequency oscillator is switched on, the fast moving electrons from the cathode collide mostly with the nitrogen atoms and hence nitrogen atoms goes to the excited state.

$$e^- + N_2 \rightarrow N_2^*$$

These excited levels happen to be at an energy very close to the energy of the asymmetric vibrational state in the CO2 molecule. Now the excited N2 molecules populate the asymmetric vibrational states in the CO2 molecule through collisions.

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

Once excitation is achieved, the CO2 molecules at asymmetric state (001) will give out energy and jump to lower energy states, i.e., to symmetric state (100) or to bending mode (020), thus giving out laser light at frequency 10.6 µm and 9.6 µm respectively.

$$CO_2^* \rightarrow CO_2 + \text{laser}$$

The remaining decay from state (100) to (010),(020) to (010) or (010) to ground state (000) will dissipate energy in the form of heat instead of light.

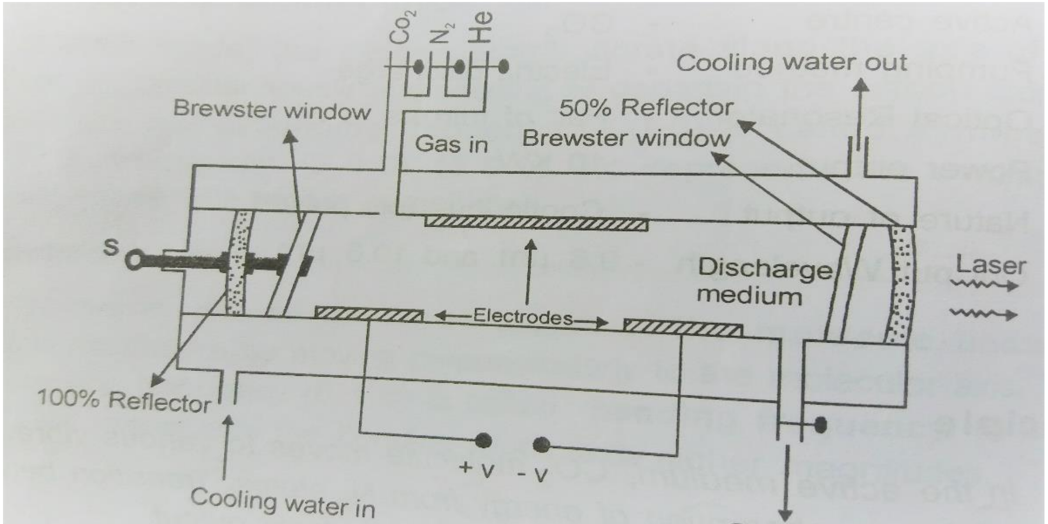


Fig 2.20

Working Summary

Case 1: Transition from asymmetric mode (001) to symmetric mode (100) gives laser beam of wavelength 10.6 µm.

Case 2: Transition from asymmetric mode (001) to bending mode (020) gives laser beam of wavelength 9.6 µm.

Note: CO2 laser gives laser beam of different wavelengths. We can get laser beam of desired wavelength by simply changing the length of the active medium. For this purpose, a screw arrangement is provided in the instruments.

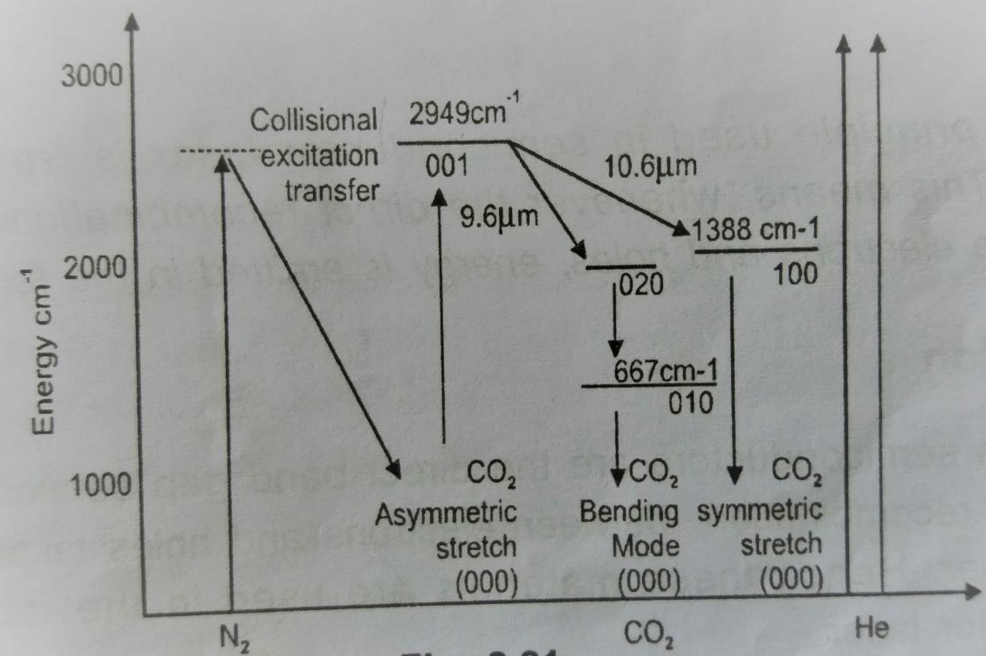


Fig. 2.21

Merits

It gives high power output.

Demerit

Contamination of oxygen may take place.

Applications

1. Used in material processing.
2. Used in medical field such as neurosurgery. Microsurgery, treatment of liver, lungs and also in bloodless operations/surgery.
3. Used in laser fusion.
4. Used in the military field.
5. Used in open air communication.

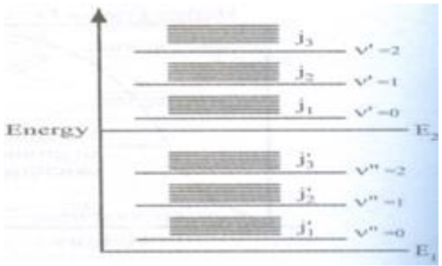
Introduction

An Indian engineer C.K.N designed the co_2 laser we know I n the case if atoms, electrons can be excited to higher energy levels of the molecule eg. He - Ne laser. Besides these electronic energy levels, the molecule can have other energy levels also due to rotation and vibration of the molecule (co_2) they give rise to various vibrational and rotational energy levels as shown in figure 5.6.

Where, E_1E_2 – electronic energy levels

v', v'' – vibrational energy levels

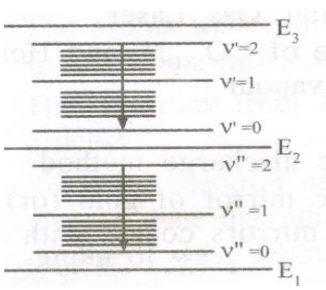
j,j' – rotational energy levels.

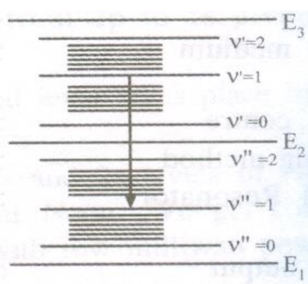


Principle

The transition between these vibrational and rotational energy levels leads to the construction of molecular gas laser. Here the nitrogen atoms are initially raised to excited stare. The nitrogen atoms deliver the energy to co_2 atoms which has closest energy level to it. Then, the transition takes place between the vibrational energy 7 levels of the CO_2 atoms and hence laser beam is emitted. The molecular gas laser can have two types of transitions such as,

i. Transition between vibrational levels of same electronic state as shown in figure.
ii. Transition between vibrational levels of different electronic state as shown in figure.





CO_2 laser satisfies them first condition. i.e. here the laser transition occurs between vibrational levels of same electronic state.

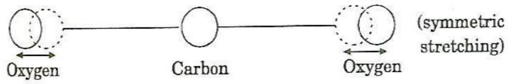
Fundamental modes of vibration of the co_2 molecule.

There are three fundamental modes of vibration.

1. Symmetric stretching mode (10˚0)
2. Bending mode (01˚0, 02˚0)
3. Asymmetric stretching mode (00˚1, 00˚2)

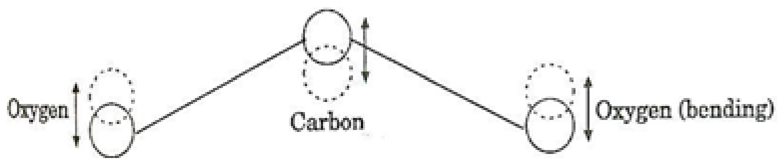
Symmetric stretching mode (10˚0)

The carbon atom is stationary and the oxygen atoms oscillate or vibrate along the axis of the molecule as shown in figure. The state of vibration is given by 3 integers (mn^lq) here (10°0), which corresponds, to the degree of excitation.



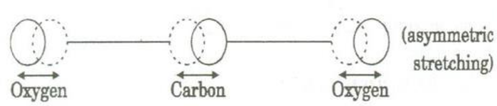
Bending mode (01°0, 02°0)

Here the atoms will not be linear, rather the atoms will vibrate perpendicular to the molecular axis as shown in figure. This gives rise to two quanta of frequency represented by (01°0, 02°0).



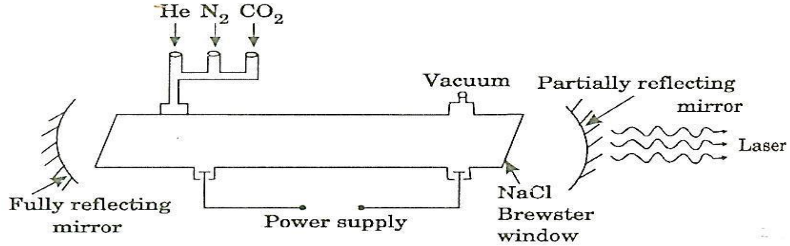
Asymmetric stretching mode (00°1, 00°2)

Here all the atoms will vibrate. Here the oxygen atoms vibrate in the opposite direction to the vibration direction of carbon atom as shown in figure 5.10. This gives the quanta of frequency (00◦1, 00◦2).



Construction

It consists of a discharge tube in which co_2 is taken along with nitrogen and helium gases with their pressure level of 0.33:1.2:7 mm of Hg for co_2, nitrogen and the He respectively. Nitrogen helps to increase the population of atoms in the upper level of co_2, while helium helps to depopulate the atoms in the lower level of co_2 and also to cool the discharge tube.



The discharge is produced by DC excitation. At the ends of the tube sodium chloride/Brewster windows are placed as shown in figure. Confocal silicon mirrors coated with aluminium or metallic mirror of gold is employed for proper reflection, which form the resonant cavity. The output power can be increased by increasing the diameter of the tube.

Working

(i) The discharge is passed through the tube first, the nitrogen atoms are raised to excited state $e^- + N_2 \rightarrow N_2^*$

(ii) The excited N_2 atoms undergo resonant energy transfer with co_2 atom and raises co_2 (00˚1) to excited state due to closer energy level of co_2 (00˚1) and nitrogen.

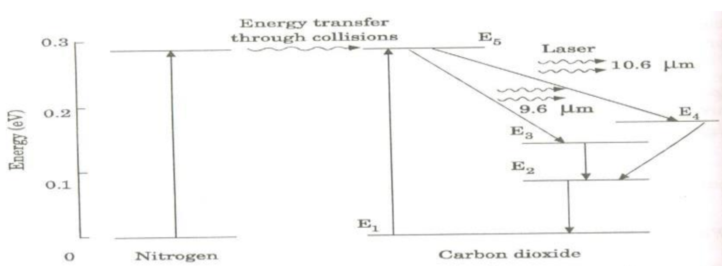
$$N_2^* + CO_2 + CO_2^* + N_2$$

(iii)When transition takes place between 00˚1 to 10˚0, the laser of wavelength 10.6 µm is emitted as shown in figure.

(iv)Similarly when transition takes place between 00˚1 and 02˚0 laser beam of wavelength 9.6 µm is emitted as shown in figure.

(v) Since 00˚1 to 10˚0 has higher gain than 00˚1 to 02˚0 transition, usually the laser beam of wavelength 10.6µm is produced more.

(vi)When the gas flow is longitudinal power output is 50 to 60 watts but if the gas flow is perpendicular to the discharge tube the output power may be raised to 10 kilo watt/m.



(vii) This type of co_2 laser is known as TEA laser.

(i.e.), (Transversely Excited Atmospheric Pressure laser).

(viii)The contamination of carbon monoxide and oxygen will also have some effect on the laser action. To avoid these unused gases can be pumped out and fresh CO_2 must be inside the discharge tube.

Application of CO_2 laser

(i) This laser has applications in medical field such as neurosurgery. Microsurgery, treatment of liver, lungs and also in bloodless operations.

(ii) It is widely used in open air communication.

(iii) This laser also has wide applications over military field.

HOMOJUNCTION SEMICONDUCTOR LASER

Characteristics of Homojunction laser

Type – Homojunction semiconductor laser

Active medium – PN junction diode

Active centre – Recombination of electrons and holes

Pumping method – Direct pumping

Optical resonator – junctions of diodes- polished

Power output – The power output from this laser is 1mW.

Nature of output – The nature of output is continuous wave or pulsed output

Wavelength emitted – 8400 – 8600 A°

Principle

The principle used in semiconductor laser is " recombination radiation". This means, whenever the direct recombination takes place between the electrons and holes, energy is emitted in the form of light.

Constructuion

GaAs semiconductors are the direct band gap semiconductors in which direction between electrons and holes takes places in a large manner. Hence, these materials are used in the fabrication of semiconductor laser.

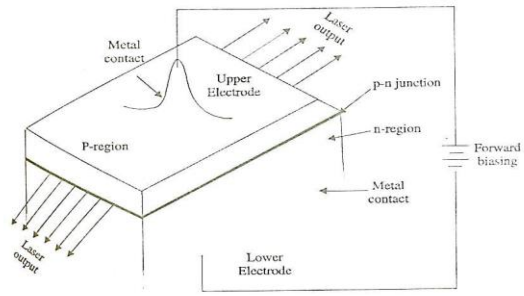
Figure shows the pictorial representation of GaAs homojunction semiconductor laser. The active medium is a P-N junction made from a single crystalline materials i.e., Galliium Arsenide, in which P-region is doped with germanium and n-region with Tellurium.

The thickness of the P-N junction layer is very narrow so that the emitted laser radiation has large divergence. The sides through which laser comes out are well polished and paralled to each other. Since the refractive index of GaAs is high, polished ends acts as optical resonator so that the external mirrors are not needed.

The upper and lower electrode strips fixed in the P and N region helps for the flow of current to the device when forward bias is applied.

Principle

The electron in conduction band combines with a hole in the valence band and hence the recombination of electron and hole produces energy in the form of light. This photon, in turn may induce another electron in the conduction band to valence band and there by stimulate the emission of another photon.

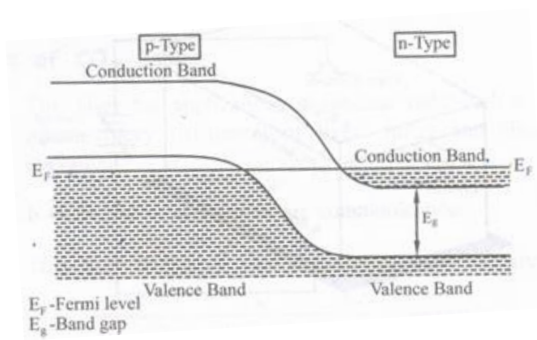


Construction

The active medium is a p-n-junction diode made from a single crystalline material ie. Gallium Arsenide, in which p-region is doped with germanium and n-region with tellurium. The thickness of the p-n-junction layer is very narrow so that the emitted laser radiation has large divergence. The junctions of the p and n are well polished and are parallel to each other as shown in figure. Since the refractive index of GaAs is high, it acts as optical resonator so that the external mirrors are not needed. The upper and lower electrodes fixed in the p and n region helps for the flow of current to the diode while biasing.

Working

(i) The population inversion in a p-n-junction is achieved by heavily doping p and n materials, so that the Fermi level lies within the conduction band of n type and within the valence band of p type as shown in figure.

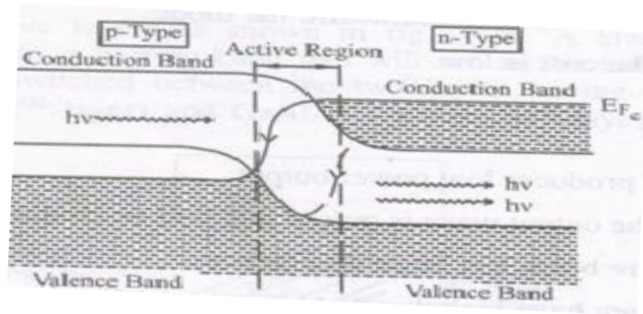


(ii) If, the junction is forward biased with an applied voltage nearly equal to the band gap voltage, direct conduction takes place. Due to high current density, active region is generated near the depletion region.

(iii) At this junction, if a radiation having frequency (γ) is made to incident on the p-n-junction then the photon emission is produced as shown in figure.

Thus the frequency of the incident radiation should be in the range

$$E_g < \gamma < \frac{(E_{F_C} - E_{F_V})}{h}$$



(iv) Further the emitted photon increases the rate of recombination of injected electrons from the n region and holes in p region by inducing more recombination. Hence the emitted photons have the same phase and frequency as that of original inducing photons and will be amplified to get intense beam of laser.

(v) The wavelength of emitted radiation depends on i. the band gap and ii. The concentration of donor and acceptor atoms in GaAs,

1. Calculation of wavelength

Band gap of GaAs = 1.44ev

$$E_g = h\,\gamma = h\frac{c}{\lambda}$$

$$\lambda = \frac{hc}{E_g}$$

$$= \frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{1.44 \times 1.6 \times 10^{-19}}$$

$$= 8626\ A^{\circ}$$

The wavelength is near IR region.

Advantages

(i) It is easy to manufacture the diode.

(ii) The cost is low.

Disadvantages

(i) It produces low power output.

(ii) The output wave is pulsed and will be continuous only for some time.

(iii) The beam has large divergence.

(iv) They have high threshold current density.

HETEROJUNCTION SEMICONDUCTOR LASER

Characteristics of Hetero junction semiconductor laser

Type - Hetero junction semiconductor laser

Active medium - p-n-junctions with various layers

Active centre – Recombination of electrons and holes

Pumping method – Direct pumping

Optical resonator – Junctions of diodes- polished

Power output – The power output from this laser is 10mW.

Nature of output – continuous wave form

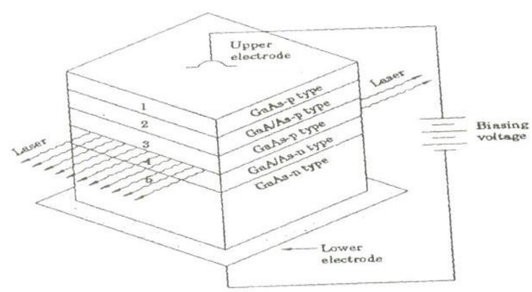
Band gap – 1.55ev

Principle

The electron in conduction band combines with a hole in the valence band and hence the recombination of electron and hole produces energy in the form of light. This photon, in turn may induce another electron in the conduction band to valence band and there by stimulate the emission of another photon.

Construction

It consists of five layers as shown in figure. A layer of GaAs- p-type (3rd layer) which has narrow band gap will act as the active region. This layer (3rd layer) is sandwitched between the two layers having wider band gap viz. GaAlAs – p-type (2nd layer) and GaAlAs – n-type (4th layer).



A contact layer made of GaAs – p-type (1st layer) is made to form at the top of the 2nd layer for necessary biasing. All these four laters are grown over the substrate (5th layer) made of GaAs-n-type. The junctions of GaAs – p-type (3rd layer) and GaAlAs – n-type (4th layer) are well polished and hence it acts as an optical resonator. The upper and lower electrodes help in forward biasing the diode.

Working

Working of a heterojunction laser is similar to that of the working of a homojunction laser.

(i) The diode is forward biased with the help of upper and lower electrodes.

(ii) Due to forward biasing the charge carriers are produced in the wide band gap layers (2 and 4).

(iii) These charge carriers are injected into the active region (layer 3).

(iv) The charge carriers are continuously injected from 2nd and 4th layer to the 3rd layer, until the population inversion is achieved.

(v) At this state some of the injected charge carriers recombines and produces spontaneously emitted photons.

(vi) These spontaneously emitted photons stimulate the injected charge carriers to emit photons.

(vii) As a result more number of stimulated emissions arises and thus large number of photons is produced.

(viii) These photons are reflected back and forth at the junction and hence an intense, coherent beam of LASER emerges out from the p-N junctions of active region ie. Between layer-3 and layer-4 as shown in figure.

(ix) The wavelength of the emitted radiation is given by $\lambda = \frac{hc}{E_g}$

$$= \frac{6.625 \text{ x } 10^{-34} \text{ x } 3 \text{ x } 10^{8}}{1.55 \text{ x } 1.6 \text{ x } 10^{-19}}$$

$$= 8014 \text{ A}^{\circ}$$

The wavelength lies IR region.

Advantages

i. Power output is high.
ii. It produces continuous wave output.
iii. It has high directionality and high coherence.
iv. It has low threshold current density compared to homojunction laser.
v. These diodes are highly stable and have longer life time.

Disadvantages

i. Cost is higher than homojunction laser.
ii. Practical difficulties arise while growing the different layers of p-n junction.

INDUSTRIAL APPLICATIONS [LASERS IN WELDING, HEAT TREATMENT AND CUTTING]

Laser heat treatment

Laser is a light beam of high intensity, directionality and coherence. So, when laser light is focused on a particular area, even of micrometer size, for a very longer time, then that particular area alone will be heated and the other area will remain as such. This is called thermal effect or laser heat treatment. In this process the light energy is converted into heat energy.

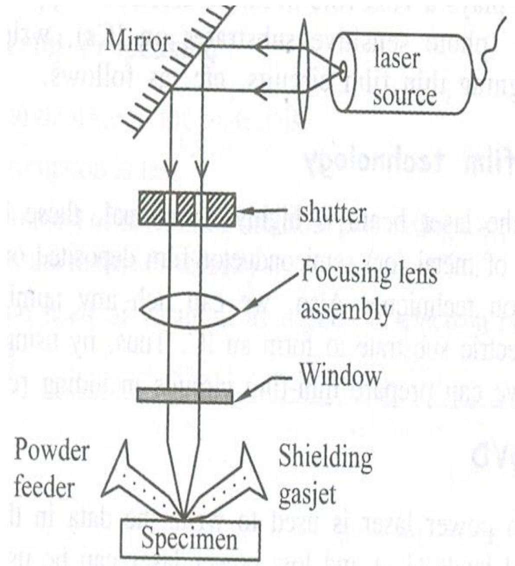
Instrumentation technique

Principle

The technique of laser heat treatment is used in engineering applications like surface hardening, coating, glazing, alloying, cutting, welding, drilling and perforating holes in the materials and hence this process is called material processing. In general ruby laser , Nd-YAG laser and co_2 laser are used for this purpose.

Instrumentation

The Instrumentation for materials processing consists of a laser source to produce laser beam, shutter to control the intensity of the laser beam and an assembly of lenses to effectively focus the laser onto the specimen as shown figure.



Apart from these Instrumentation, separate control arrangements are made for removing the molten materials, smokes, fumes etc.. with the help of a shielding gas jet, which consist of the assisting gases such as sir, N_2, o_2,Ar etc. the powder feeder is used feed the metal powder, wherever necessary.

Processing

Laser source is switched on. The light by the plane mirror is made to pass through the shutter. The intensity of the laser beam is controlled by the shutter and the controlled laser beam is allowed to fall on the focusing lens assembly. This lens assembly focuses the light effectively onto the window and is made to incident on the specimen.

Now the specimen gets heated, giving rise to smokes, fumes and molten materials. These smokes, fumes and molten materials are removed immediately by blowing the assisting gas from the shielding gas jet and this in turn makes the laser beam to continuously fall on the specimen, thereby increasing the cutting rate. Thus the materials can be drilled, cut, put holes etc. using this technique effectively and easily. In case of alloying, cladding, molding, welding etc. the power feeder will be used to spray the metal power over the specimen, during the focusing of laser beam on to the specimen.

Applications

Laser in Microelectronics

Laser plays a vital role in micro-electronics applications, such as making photos masks, writing/reading CDs and DVDs, designing thin film circuits, etc as follows.

(i) Thin film technology

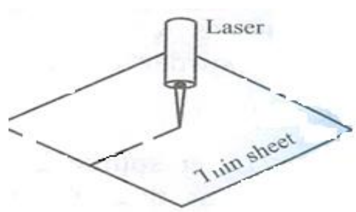
As the laser beam is highly directional, these beams are used to trim off a portion of metal or semiconductor film deposited on the dielectric substrate, by evaporation technique. Also, we can itch any number of micro components over the dielectric substrate to form an IC. Thus, by using as accurately controlled laser beam we can prepare thin film circuits including resistors, capacitors etc…

(ii) CD/DVD

High power laser is used to write the data in the CD/DVD by creating pits (0's) and lands (1's) and low power laser can be used to read the data.

Laser cutting

Laser is used as a tool to cut thin metal sheets by properly focusing the laser onto any particular area to be cut, for a longer time. Thus due to thermal effect the sheet is cut as shown in figure.



Laser drilling and perforating holes

The same technique as used for cutting will be adopted for drilling and perforating holes, even upto 0.2 to 0.5 µm of thickness.

Laser welding

In ordinary welding process heat will be made to fall on the area to be welded, so that the material in that area will go to molten state. This on cooling will join the material. In this process the heat will spread all over the surroundings and will affect the other areas of the material and hence the material gets damaged. To avoid this difficulty, laser is used for welding. Due to its high directionality, it is focused on to that particular area alone, even of very small size and the other area remains unaffected. Thus due to thermal effect the parts can be welded. This process is also called Micro-Welding.

Medical Applications of LASER:

1. Laser light can detect and removes caries
2. Cancer treatment can be done with the help of laser
3. They are used in bloodless surgery
4. It has endoscope applications.
5. Laser can be used to correct defect of the lens and cornea as well as repair tears and holes in the retina.
6. A laser beam fired into the heart can help people suffering from angina pectoris.
7. Liver tumors can be destroyed using a laser beam.

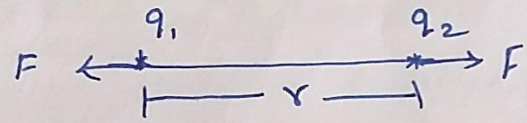
UNIT- III

ELECTROMAGNETISM & POLARISATION

→ Coulomb's Law:-

Coulomb's law states that, the magnitude of the electrostatic force of attraction or repulsion between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them. The direction of forces is along the line joining the two point charges.

Hence, the electrostatic force, between two charges q_1 and q_2 placed at a distance r from each other is given by



$$F \propto q_1 q_2 \quad \& \quad F \propto \frac{1}{r^2} \Rightarrow F \propto \frac{q_1 q_2}{r^2}$$

$K \rightarrow$ Constant of proportionality.

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

$K = \frac{1}{4\pi\epsilon_0}$, $\epsilon \Rightarrow$ permittivity of free space (Vacuum)

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$\epsilon \rightarrow 8.854 \times 10^{-12}\ C^2 N$

$$K = \frac{1}{4\pi\epsilon_0} = 10 \times 10^{9} \cdot Nm^2 C^{-2}$$

Problems:- Two insulated charged spheres of charges 6.5×10^{-7}C each are separated by a distance of 0.5m. ⓐ Calculate the electrostatic force between them (Ans:- $F = 1.52 \times 10^{-2}$ N) ⓑ when the charges are doubled and the distance of separation is halved: (Ans: $F_N = 16$ times F, i.e $= 16 \times 1.52 \times 10^{-2}$ N $= 0.24$ N)

Electric Field Intensity (E) :-

Electric field at a point is measured in terms of electric field intensity.

Electric field intensity at a point, in a electric field ~~at a point~~ is defined as the force experienced by a unit positive charge kept at that point. Vector quantity

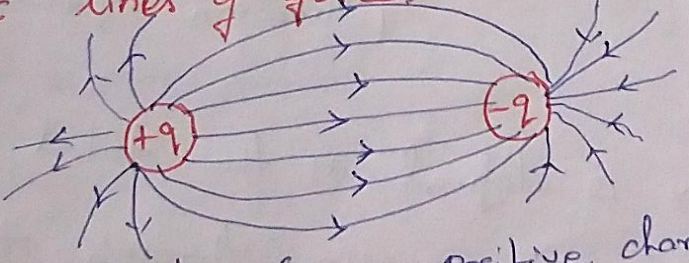
$$|\vec{E}| = \frac{|\vec{F}|}{q_0} \ NC^{-1}$$

It is also called as electric field strength, or simply electric field.

Electric Field :-

Electric field due to a charges is the space around the test charge in which it experiences a force. The presence of an electric field around a charge cannot be detected unless another change is brought towards it.

Electric lines of force :-



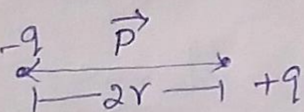
→ Lines starts from positive charge (+q) and terminate at negative charge (-q)

→ Lines of force never intersect.

→ No. of lines per unit area, through a plane at right angles to the lines, is proportional to the magnitude of 'E'.

→ Each unit positive charge gives rise to $\frac{1}{\varepsilon_0}$ lines of force in free space. Hence no. of lines of force originating from a point charge q is $N = \frac{q}{\varepsilon_0}$ in free space.

Electric Dipole:-



Two equal and opposite charges are separated by a very small distance constitute an electric dipole. Eg:- H_2O, CO_2 molecules. - permanent electric dipoles.

Electric Dipole Moment:-

Two point charges +q & -q are kept at a distance 2r apart. The magnitude of the dipole moment is given by the product of the magnitude of the one of the charges and the distance between them.

$$p = q2r = 2qr$$ Vector quantity; Unit: Cm. (Direction -q to +q)

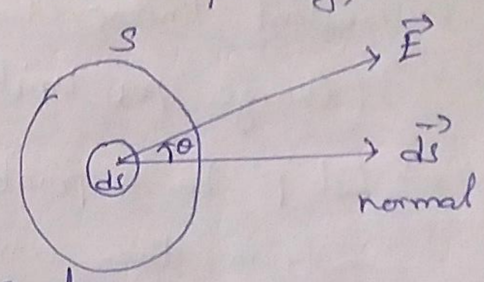
Electric Flux:-

The electric flux is defined as the total no. of electric lines of forces crossing through the given area. The electric flux $d\phi$ through the area ds is

$$d\phi = \vec{E}.\vec{ds} = E ds \cos\theta$$

The total flux through the closed surface S is obtained by integrating the above equation over the surface.

$$\phi = \oint d\phi = \oint \vec{E}.\vec{ds}$$ Scalar quantity, Nm^2C^{-1}



Gauss's Law:-

It states that, "the total electric flux through any closed surface in free space of any shape drawn in an electric field is proportional to the total electric charge enclosed by the surface.

Mathematically, Gauss's law takes the form of an integral equation $\oint E.dA = \frac{1}{\varepsilon_0} Q$ enclosed.

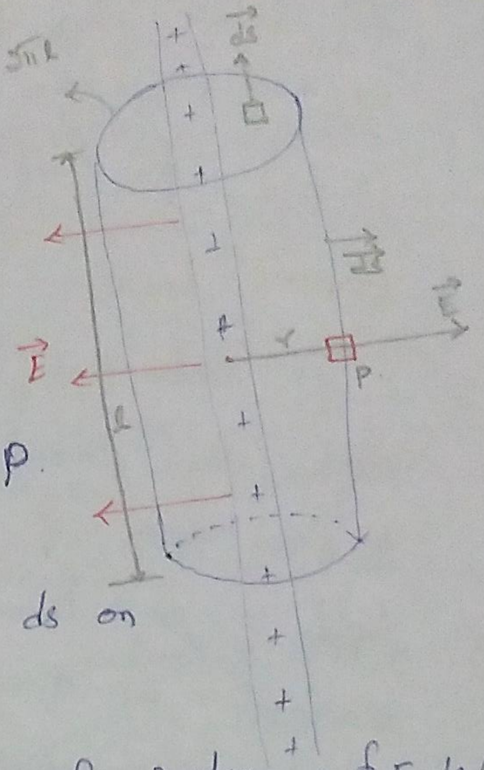
(or)

The law relates the flux through any closed surfaces and the net charge enclosed within the surface.

The Gauss's Law states that the total flux of the electric field E over any closed surface is equal to $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surfaces. $\phi = \frac{q}{\varepsilon_0}$

Application:

→ To find the electric field due to infinite long straight charge wire.



→ Uniformed charged wire of infinite length.

→ Constant linear charge density λ. (Charge per unit length)

→ Let 'p' be a point at a distance r from the wire, and E be the electric field at the point p.

→ Length l, and radius 'r'

→ Consider a very small area ds on the Gaussian surface

Electric flux (ϕ) through Curved surface $= \oint E.ds \cos\theta$

$\phi = \oint E.ds \cos\theta$ ($\because \theta = 0$; $\cos\theta = 1$)

$\phi = \oint E.ds = E(2\pi r l) \rightarrow (1)$

(The surface area of curved part is $2\pi r l$)

$\therefore$ Total flux through the Gaussian Surface, $\phi = E.(2\pi r l)$

The net charge enclosed by Gaussian surface is $q = \lambda l$.

By Gauss's Law, $\phi = \dfrac{\lambda l}{\varepsilon_0} \longrightarrow (2)$

Equating (1) and (2):

$$E(2\pi r l) = \frac{\lambda l}{\varepsilon_0} \quad \text{or} \quad \boxed{E = \frac{\lambda}{2\pi\varepsilon_0 r}}$$

The direction of electric field E is radially outward if line charge is positive and inward, if the line charge is negative.

Electric Current:-

"The current is defined as the rate of flow of charges across any cross sectional area of a conductor." If a net charge 'q' passes through any cross section of a conductor in time 't', then the current

$$I = q/t$$

, where q is in Coulomb and t is in second. The current I is expressed in 'ampere'.

Current is a scalar quantity. The direction of conventional current is taken as the direction of flow of positive charge or opposite to the direction of flow of electron. "Device = Ammeter"

Ohm's Law:

George Simon Ohm established the relationship between potential difference and current, which is known as Ohm's Law.

Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference across the two points of the conductor

$$I \propto V \quad \text{the} \quad I = \frac{V}{R}$$

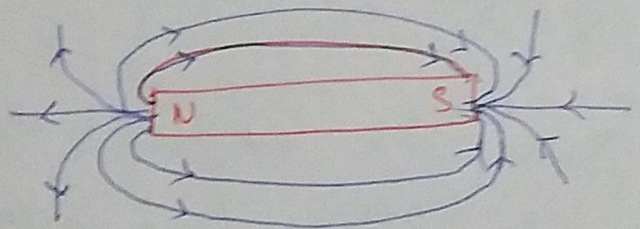
where I is the current through the conductor in units of amperes, V is the potential difference measured across the conductor in units of volts and 'R' is the Constant of proportionality, the resistance of the Conductor in units of ohms.

Law of Magnetism:-

Magnetic Lines of forces:-

A magnetic line of forces is defined as the Continuous Curve in a magnetic field, the tangent drawn at any point of which gives the direction of resultant intensity at that point.

→ Lines of forces travel externally in the magnet, i.e, the lines of forces travel from north to South poles.



→ Tangent to the lines of Induction at any point gives the direction of the B at that point.

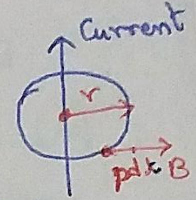
→ No. of the lines of force crossing through per unit area is proportional to the magnitude of the B.

Magnetic Field (B)

The space around a magnet or a Current carrying Conductor, where the magnetic effect is called magnetic field.

Ampere's Law:-

Ampere gave a relationship between the Current (I) and the magnetic field 'B', which is Known as Ampere's law. Mathematically we can write this law as :



$$\oint B.dl = \mu_0 I$$

where $\mu_0 \rightarrow$ Constant is called as permeability.

If we measure B for various distance r and for various current I in the wire, the experimental result show that

$$B \propto I \quad \& \quad B \propto \frac{1}{r}$$

$$B = k\frac{I}{r} \quad \text{or} \quad B = \frac{\mu_0 I}{2\pi r}$$

where $k = \frac{\mu_0}{2\pi}$

permeability.

$\mu_0 = 1.26 \times 10^{-6}$

$B \rightarrow$ teslas (T)

$$\therefore \quad B = \frac{\mu_0 I}{2\pi r}$$

$$B(2\pi r) = \mu_0 I \qquad \left(\text{Since } \oint B.dl = B\,2\pi r\right)$$

$$\oint B.dl = \mu_0 I$$

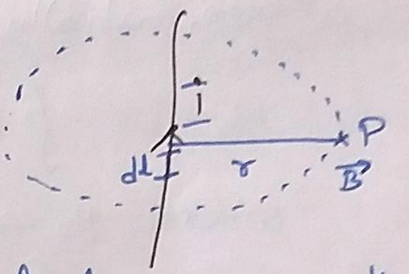
where $\oint dl$ is equal to the Circumference of the circle and equal to $2\pi r$.

which is Ampere's law. This law holds for any assembly of currents and for any closed surface.

Application of Ampere's Law :-

→ To determine the magnetic field of a infinitely long wire carring current 'i' at distance 'r' from it

Following steps are followed to find the magnetic field "B" due to wire carring current "i".



Steps - I : Constructs or image a closed loop around the wire

Steps - II : Take a closed surface. integration.

$$\oint B \cdot dl$$

where length element & magnetic field is $[\theta = 0]$

$$\oint B \cdot dl = B \oint dl$$

$$= B (2\pi r)$$

Steps - III :- $I_{enc} = I$

Steps - IV : Apply Ampere's circuit law:

$$\oint B \cdot dl = \mu_0 I_{enc}$$

$$B (2\pi r) = \mu_0 I$$

$$\boxed{B = \frac{\mu_0 I}{2\pi r}}$$

teslas. (T) = units

Biot Savart Law:-

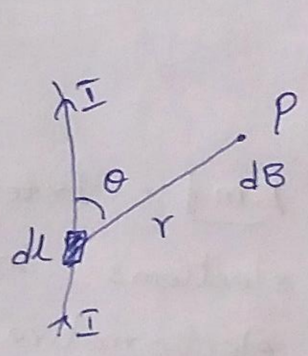
The ampere's law was modified to given better results by Biot and this modified law is Known as Biot savart law:- with the help of Biot-savart's law one can calculate magnetic field B at any point of space around a circuit in which a current is flowing.

Consider a wire carrying an electric current I and also consider an infinitely small length of a wire dl at a distance x from point A.

"The magnetic field dB' (intensity) induction at a point P due to current I flowing through a small element dl is,

1) Directly Proportional to current (I)
2) Directly Proportional to the length of the element (dl)
3) Directly Proportional to the sine of angle θ between the direction of current and the line joining the element, dl from point A.
4) Inversely Proportional to the square of the distance (x) of point A from the element dl.

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl \sin\theta}{r^2}$$



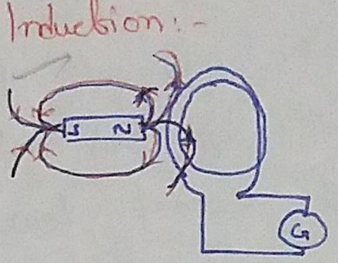
$$dB = K \frac{I\,dl \sin\theta}{r^2}$$

$$dB \propto \frac{I\,dl \sin\theta}{r^2}$$

K → Constant "permeability of free space or air".

$$\frac{\mu_0}{4\pi} = 4 \times 10^{-7}\ Wb/A\text{-}m.$$ "

Faraday's Law of Electromagnetic Induction:-



(The Faraday's Law is stated as follows:- (When the flux linkage of a magnetic field with a circuit is changing, an e.m.f is induced which is proportional to the rate of change of the flux linkage).

Let us Consider: a coil of N turns. Let it be linked with (initial flux "ϕ_1") and then in time "t" seconds it is linked with a (final flux 'ϕ_2') webers. i.e., (flux changes in the coil from ϕ_1 to ϕ_2 in times t seconds).

Change of flux/conductor $= (\phi_2 - \phi_1)$ wb.

∴ Rate of change of flux per Conductor

$$= \frac{d\phi}{dt} = \frac{\phi_2 - \phi_1}{t} \text{ wb/sec.}$$

Induced e.m.f. per Conductor $= -\frac{d\phi}{dt}$ V

$$e = -N\frac{d\phi}{dt} = -N\frac{\phi_2 - \phi_1}{t} \text{ V}$$

$$\boxed{e = -N\frac{\phi}{t} \text{ V}}$$

E.m.f:- External energy necessary to drive the free elections in a definite direction is called as electromotive force (emf). This emf is not a force, but it is the work done in moving a unit charge from one end to the other. This flow of free elections in a conductor constitutes electric currents.

Maxwell's Equations:

Some basic information needs to known, before going into the Maxwell's Equations:-

→ **Gradient of Scalar field:-**

$$\text{grad}\,\phi = \nabla\phi = \left(\frac{d\phi}{dr}\right)_{max} \cdot \hat{r} = \text{A Scalar quantity.}$$

→ **Divergence of a Vector field:-**

Total normal flux per unit volume through a closed surface drawn around a point, when the Volume enclosed by the surface tends to zero. is called the divergence of the field at that point.

$$\text{div}\,E = \nabla . E = \underset{V \to 0}{Lt} \left[\frac{1}{V} \oint_s E.ds\right] = \text{A Scalar quantity.}$$

→ **Curl of a Vector field:-**

Maximum value of circulation per unit area drawn around a point, when the area enclosed by the closed curve tends to zero, gives the magnitude of the curl of the vector field at that point, i.e.

$$\left[\text{Curl}\,\vec{B}\right]_{magnitude} = \left|\left[\nabla \times \vec{B}\right]\right| = \underset{S \to}{Lt} \left[\frac{1}{S} \oint_s B.\,dl\right].$$

The direction of curl $\vec{B}$ is same as direction of circulation i.e., same as direction of area vectorS.

→ Gauss's Divergence Theorem:-

It states that the surface integral of a vector field $\vec{E}$ over a closed surface S is equal to the volume integral of the divergence of the vector over the volume enclosed by the Gaussian Surface.

$$\oint_S \vec{E}\cdot\vec{ds} = \int_V (\vec{\nabla}\cdot\vec{E})\, dv$$

→ Stoke's Theorem:-

It states that the line integral of a vector field over a curved path C is equal to the surface integral of curl of the vector over the open surface bounded by the curve. C.

$$\oint_C \vec{E}\cdot\vec{dl} = \oint_S (\vec{\nabla}\times\vec{E})\cdot\vec{ds}$$

Some Vector algebric relations:-

a) div (curl $\vec{A}$) $=0$ ⇒ $\vec{\nabla}\cdot(\nabla\times\vec{A}) = 0$

b) Curl (grad ϕ) $=0$ ⇒ $\nabla\times(\vec{\nabla}\cdot\phi) = 0$ (ϕ is scalar)

c) $\nabla\times(\nabla\times A) = \nabla\cdot(\nabla\cdot A) - \nabla^2 A$

d) For irrotational vector $\vec{A}$, $\vec{\nabla}\times\vec{A} = 0$

e) For solenoidal vector $\vec{A}$, $\vec{\nabla}\cdot\vec{A} = 0$

Maxwell's Equations:- (Integral Form)

Entire theory of electromagnetic wave is contained in the equations (four) called maxwell's equations.

These four equations are as follows:-

J = current density
I = current
$\frac{d\phi}{dt}$ = Displacement current

Equation: (1) :-

$$\oint E \cdot ds = \frac{Q}{\varepsilon_0} \rightarrow (1)$$

This is Gauss's law in electrostatics. It states that the net electric flux through a closed surface S equals the total charge Q enclosed by the surface divide by ε_0.

E = Electric field strength
H = Magnetic field strength
D = Electric displacement Vector
B = Magnetic Induction
ε_0 = Permittivity of free space
μ_0 = permeability

Equation: (2) :-

$$\oint B \cdot ds = 0 \rightarrow (2)$$

This is Gauss's law in magnetostatics and states that the net magnetic flux through a closed surface is zero. i.e., the flux entering the surface is equal to the flux leaving it. Alternatively, we can say that law states that isolated magnetic monopoles do not exist.

$B = \mu H$ $\quad J = \sigma E$
$D = \varepsilon E$

Equation: (3) :-

$$\oint E \cdot dl = -\frac{d}{dt}\oint B \cdot ds = -\frac{d\phi_B}{dt} \rightarrow (3)$$

This is Faraday's law of electromagnetic induction and states that line integral of electric field around a closed path (or emf) is equal to the rate of change of magnetic flux through the surface bounded by the closed path.

Equation - (4) :-

$$\oint B \cdot dl = \mu_0 I + \mu_0 \varepsilon_0 \cdot \frac{d}{dt} \oint E \cdot ds \rightarrow (4)$$

$$\oint B \cdot dl = \mu_0 (I + I_D).$$

where $I_D = \varepsilon_0 \frac{d}{dt} \oint E \cdot ds.$

$= \varepsilon_0 \frac{d\phi_E}{dt}$

This is Ampeere - Maxwell's Law:

This shows the existence of displacement current and indicates that the magnetic field is produced by both the conduction current and displacement current.

Differential form of Maxwell's Equations:-

Equation - (1) :- Gauss's law is electrostatics.

$$\text{div } E = \nabla \cdot E = \frac{\rho}{\varepsilon_0}.$$

$$\text{div } D = \nabla \cdot D = \rho.$$

where $D = \varepsilon D$, is the electric displacement vector $\left(\frac{Q}{4\pi r^2}\right)$ and ρ is the charge density, i.e charge per unit volume enclosed by the closed surface

Equation - (2) :- Gauss's Law in magnetostatics.

$$\text{div } B = \nabla \cdot B = 0.$$

Equation - (3) :- Faraday's Law of electromagnetic Induction

$$\text{Curl } E = \nabla \times E = -\frac{\partial B}{\partial t}.$$

Equation – (4): Ampere – Maxwell's law

$$\text{curl } B = \nabla \times B = \mu_0 J + \mu_0 \varepsilon_0 \frac{\partial E}{\partial t}$$

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

$B = \mu_0 H$

$D = \varepsilon_0 E$

Maxwell's Equation in Free Space or Vacuum:-

In vacuum or free space there is no charge or current. Thus, for a region, $q = 0$ and $I = 0$.

from the integral form of maxwell's Equation:-

→ Eq:- (1):

$$\oint E \cdot ds = \frac{Q}{\varepsilon_0} \Rightarrow \oint E \cdot ds = 0.$$

→ Eq:- (2):

$$\oint B \cdot ds = 0 \Rightarrow \oint B \cdot ds = 0.$$

→ Eq: (3):-

$$\oint E \cdot dl = -\frac{d\phi_B}{dt} \Rightarrow \oint E \cdot dl = -\frac{d\phi_B}{dt}$$

Eq: (4):-

$$\oint B \cdot dl = \mu_0 I + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}.$$

$$\Rightarrow \oint B \cdot dl = \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}.$$

Sources

1) $\rho \rightarrow \vec{E}$

2) J & $\frac{\partial \vec{D}}{\partial t} \rightarrow \vec{H}$

3) $\frac{\partial E}{\partial t} \rightarrow \vec{B}$

4) $\frac{\partial B}{\partial t} \rightarrow \vec{E}$

Introduction - Polarization:

→ Polarized light has many important practical applications in industry and engineering.

→ Liquid Crystal displays — LCD

→ Waves — Transmission of energy thr. a medium in the form of disturbance.

- periodic motion of the particles abt their mean position.
- propagation of wave motion :- Transfer of energy from one particle to another without any actual transfer of the particle of the medium

→ Two types:-

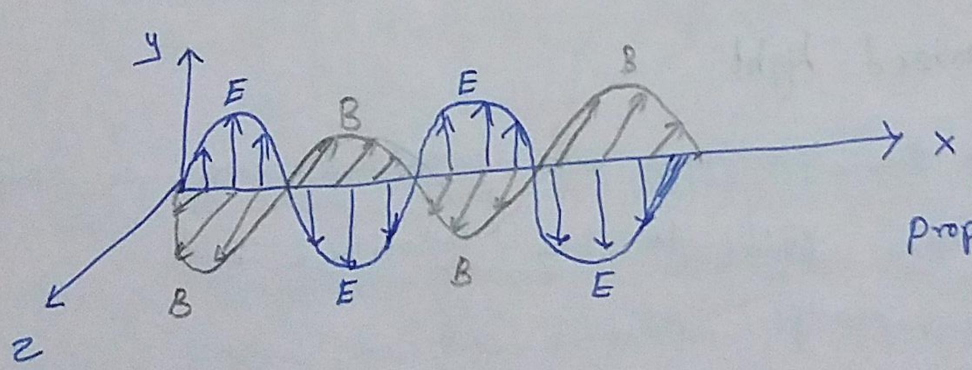
a) Transverse wave: Every particle of the medium oscillates up and down at right angles to the direction of wave propagation.

b) Longitudinal wave:- Every particle of the medium oscillates to and fro along the direction of wave propagation.

→ Electromagnetic Waves:-

→ An accelerated charge is a source of EM radiation.

→ Electric & magnetic field vectors are at right angle to each other and both are at right angles to the direction of propagation.



$\vec{E}$ = Y direction

$\vec{B}$ = Z direction

Propagation = +X direction

→ Characteristics of EM waves:-

⇒ Not require any material medium for propagation

⇒ Maxima & minima of both $\vec{E}$ & $\vec{B}$ occur simultaneously

⇒ In vacuum or free space - travels with velocity $3 \times 10^8 ms^{-1}$

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$ (μ_0 - permeability & ε_0 - permittivity of free space)

⇒ Energy - Equally divided b/w electric & magnetic field vectors.

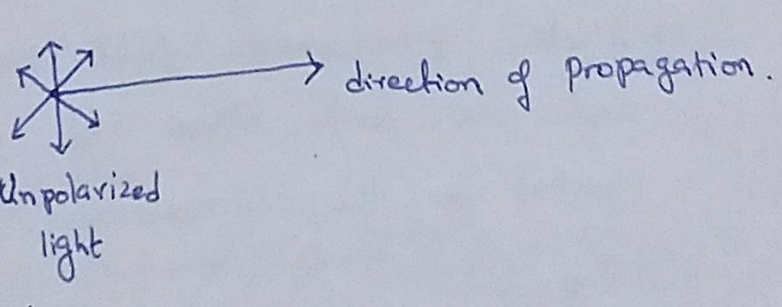
⇒ Being chargeless - not deflected by $\vec{E}$ & $\vec{B}$ field.

→ Different Regions of EM waves:-

Gamma rays — Long waves.

→ Light as a Waves:

Unpolarized Light:
Ordinary Light :- ~~propagation~~ of ~~waves~~ or Vibrations take place along all possible directions or randomly and its is perpendicular to the direction of propagation of light.



Polarized Light:

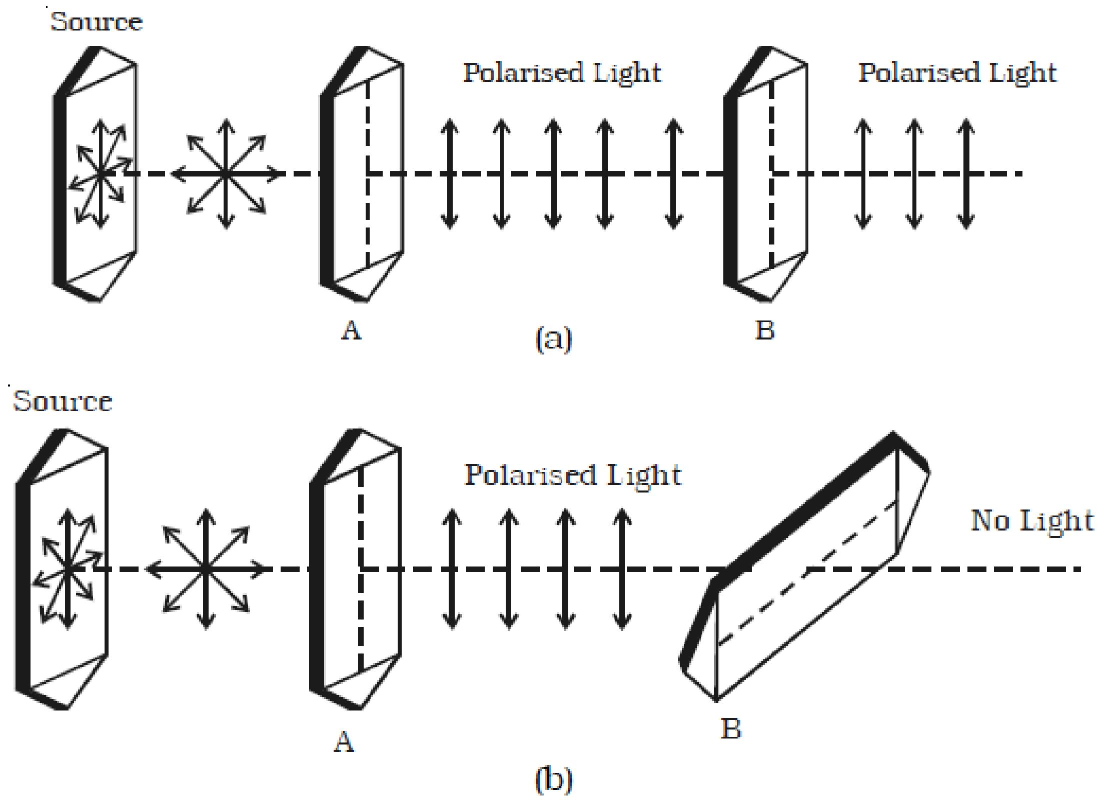
When the Vibrations are confined along a single direction are said to be polarized light.

POLARISATION

Introduction to Polarisation:

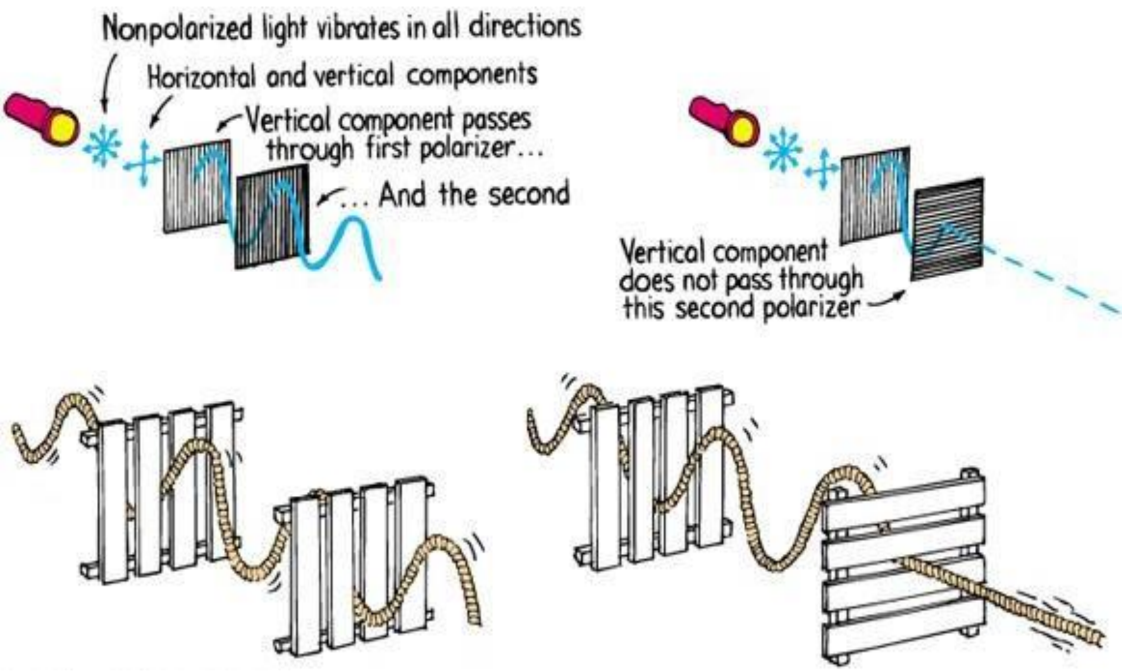
The phenomenon of restricting the vibration of light in a particular direction perpendicular to the direction of wave motion is called as polarisation.

To explain the phenomenon of polarisation let us consider the two tourmaline crystal with their optics axis placed parallel to each other.When an ordinary light is incident normally on the two crystal plates the emergence light shows a variation in intensity as T2 is rotated.



The intensity is maximum when the axis of T2 is parallel to that of T1 and minimum when they are at right angle. This shows that the light emerging from T1 is not symmetrical about the direction of propagation of light but its vibration are confined only to a single line in a plane perpendicular to the direction of propagation, such light is called as polarised light.

Example:



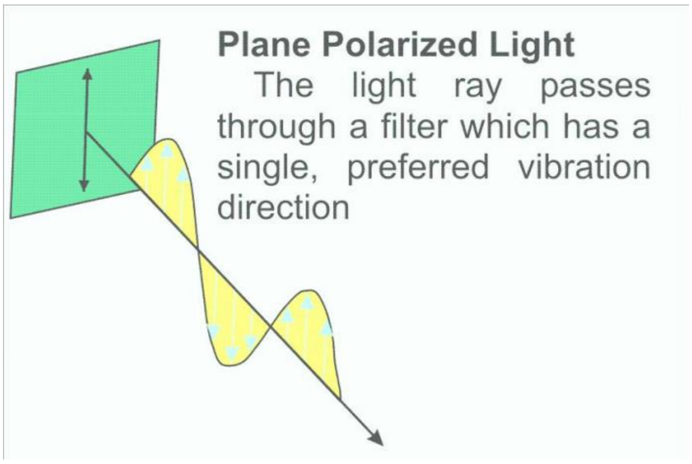
Difference between Polarised and ordinary light:

Polarised light	**Ordinary light**
1. The vibrations are confined in a particular direction.	1. The vibrations of light particle are not confined in a particular direction.
2. The probability of occurrence of vibration along the axis of crystal is not same in all position of crystal	2. The probability of occurrence of vibration along the axis of the crystal is not symmetries for all position of the crystal.
3. The intensity of light plate is not same in all position of the crystal plate.	3. The intensity of light plate is same in all position of the plate.

The resultant light wave in which the vibrations are confined in a particular direction of propagation of light wave, such light waves are called Polarised light. Depending on the mode of vibration in a particular direction, the polarised light is three types

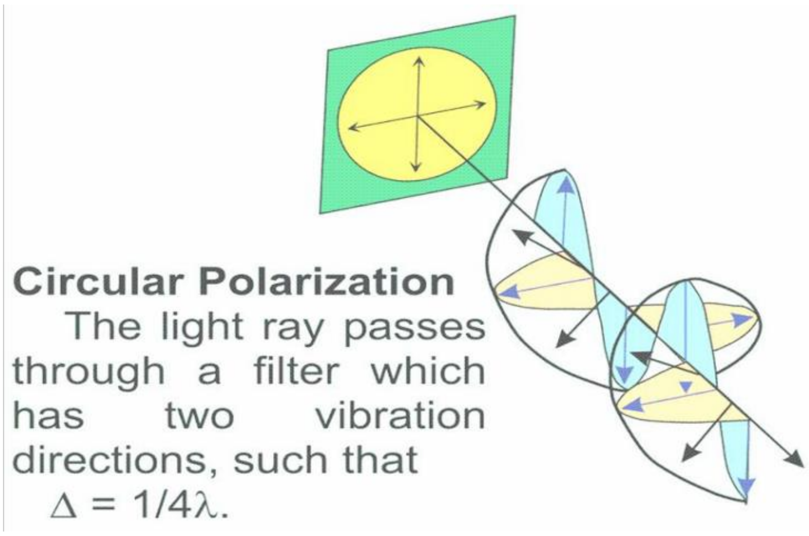
Linearly Polarised /Plane polarised:

When the vibrations are confined to a single linear direction at right angles to the direction of propagation, such light is called Plane polarised light.



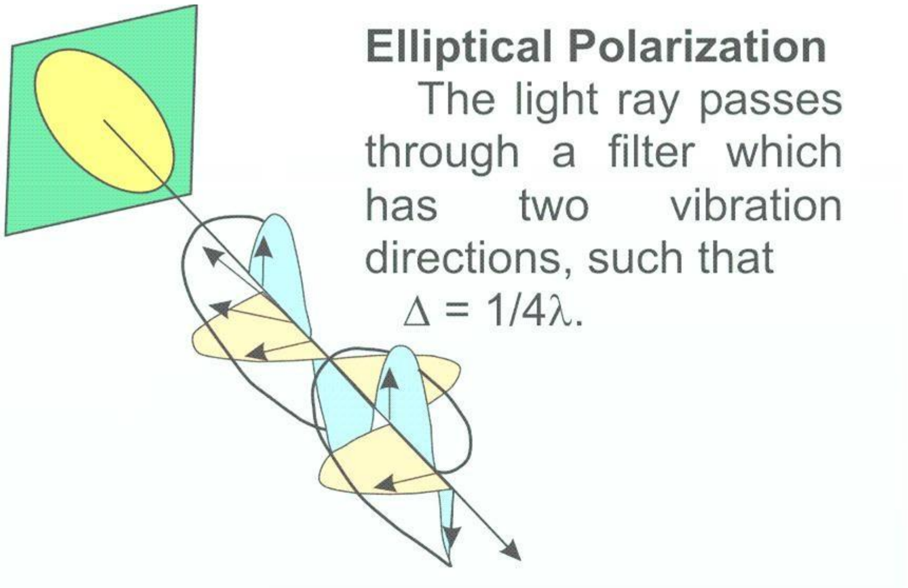
Circularly polarised light:

When the two plane polarised wave superpose under certain condition such that the resultant light vector rotate with a constant magnitude in a plane perpendicular to the direction of propagation and tip of light vector traces a circle around a fixed point such light is called circularly polarised light.



Elliptically polarised light:

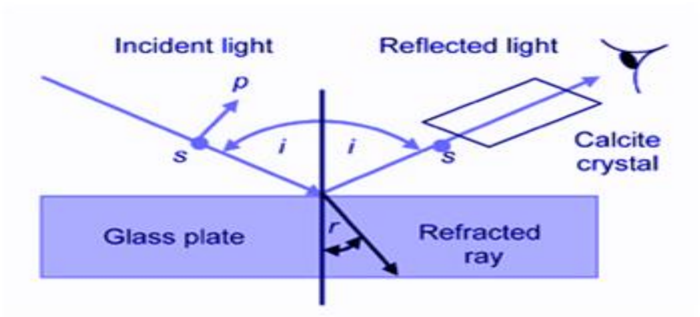
When two plane polarised light are superpose in such a way that the magnitude of the resultant light vector varies periodically during its rotation then the tip of the vector traces an ellipse such light is called elliptically polarised light.



Brewster's Law

Brewster's law is a relationship of light waves at the maximum polarization angle of light. This law is named after Sir David Brewster, a Scottish physicist, who proposed the law in the year 1811. The law states that the p-polarized rays vanish completely on different glasses at a particular angle.

Further, the polarization angle is also called as Brewster's angle. It is an angle of incidence where the ray of light having a p-polarization transmitted through a dielectric surface that is transparent without any reflection. While, the unpolarized light at this angle is transmitted, the light is reflected from the surface.



Brewster was able to determine that the refractive index of the medium is numerically equal to the tangent angle of polarization. Know more about the Brewster's Law Formula.

$$\mu = \tan i$$

Where,

μ = Refractive index of the medium.

i = Polarization angle.

From Snell's Law:

$$\mu = \frac{\sin i}{\sin r} \quad \text{.........................(1)}$$

From Brewster's Law:

$$\mu = \tan i = \frac{\sin i}{\cos i} \quad \text{..................(2)}$$

Comparing both formulas: (1) and (2)

$$\cos i = \sin r = \cos\left(\frac{\Pi}{2} - r\right)$$

$$i = \left(\frac{\Pi}{2} - r\right), \text{ or } i + r = \frac{\Pi}{2}$$

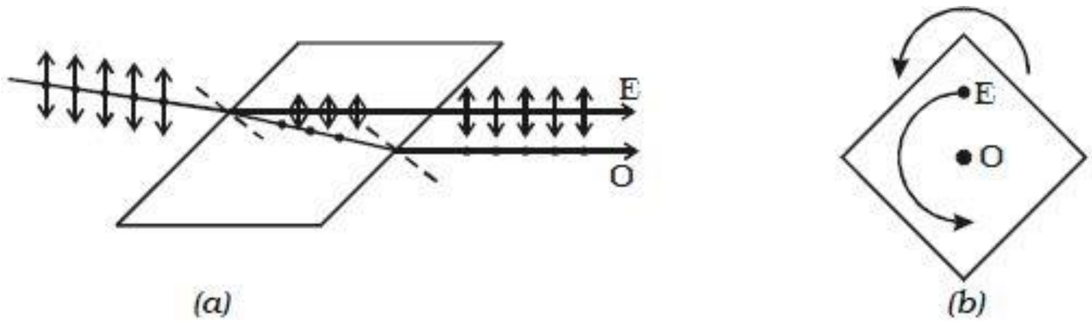
As, $i+r = \frac{\Pi}{2}$. Therefore, the reflected and the refracted rays are at right angles to each other.

Application of Brewster's Law

One general example for the application of Brewster's law is polarized sunglasses. These glasses use the principle of Brewster's angle. The polarized glasses reduce glare that is reflecting directly from the sun and also from horizontal surface like road and water. Photographers also use the same law to reduce the reflection from reflective surfaces by using polarizing filter for the lens.

Double Refraction

Bartholinus discovered that when a ray of unpolarised light is incident on a calcite crystal, two refracted rays are produced. This phenomenon is called **double refraction**. Hence, two images of a single object are formed. This phenomenon is exhibited by several other crystals like quartz, mica etc.



When an ink dot on a sheet of paper is viewed through a calcite crystal, two images will be seen (Fig: b). On rotating the crystal, one image remains stationary, while the other rotates around the first. The stationary image is known as the ordinary image (O), produced by the refracted rays which obey the laws of refraction. These rays are known as ordinary rays. The other image is extraordinary image (E), produced by the refracted rays which do not obey the laws of refraction. These rays are known as extraordinary rays.

Inside a double refracting crystal the ordinary ray travels with same velocity in all directions and the extra ordinary ray travels with different velocities along different directions.

A point source inside a refracting crystal produces spherical wavefront corresponding to ordinary ray and elliptical wavefront corresponding to extraordinary ray.

Inside the crystal there is a particular direction in which both the rays travel with same velocity. This direction is called optic axis. The refractive index is same for both rays and there is no double refraction along this direction.

Optical birefringence is an inherent property of a material, which causes double refraction of a ray of light resulting in polarization of the light wave. Birefringence is seen in crystallographic materials that have different refractive indices with respect to different crystallographic directions. Birefringence occurs when light passes through a transparent, molecularly ordered material, which exhibits orientation-dependent differences in refractive indices.

Birefringence is caused by the anisotropic forces that bind the atoms of a crystal. Anisotropy refers to the non-uniform distribution of properties in different directions. Some mineral crystals have two different refractive indices and, hence, show birefringence. Examples of minerals that exhibit birefringence are quartz, tourmaline, and calcite.

Occurrence of Birefringence

Calcite crystals show some of the strongest birefringence effects. Light passing through a calcite crystal is split into two rays by refraction. Refraction of the light waves occurs in such a way that two refracted rays are mutually perpendicular and, also, perpendicular to the direction of wave propagation. The two rays are termed as slow and fast rays. The wave having greater refractive index is called the slow ray.

Types of Birefringence and its measurement

Birefringence is classified as intrinsic or stress-induced birefringence.

- Intrinsic Birefringence – This type of birefringence is caused by the anisotropy present in the crystals. The atomic arrangement of the crystal itself is the source of birefringence. Examples are calcite, tourmaline, etc
- Stress-Induced Birefringence – This type of birefringence is caused due to the stresses imposed on the material. Materials such as glass or plastics show strain birefringence

Birefringence can be quantified by measuring the changes in polarization of light waves. This method of measurement is called polarimetry. A special method, called dual polarization interferometry, is used to measure birefringence of lipid bilayers.

Applications of Birefringence

Birefringence finds use in the following applications:

- Polarizing prisms and retarder plates
- Liquid crystal displays
- Medical Diagnostics

UNIT IV

DIELECTRICS AND MAGNETIC PROPERTIES OF MATERIALS

INTRODUCTION

Solids which have an energy gap of 3 eV or more are termed as insulators. In these materials, it is almost not possible to excite the electrons from the valence band to the conduction band by an applied field. Generally, dielectrics are also called as insulators, thereby poor conductors of electricity. However, they allow some of the electrons at abnormally high temperatures, causing a small flow of current.

Dielectrics are non-metallic materials of high specific resistance ρ, negative temperature coefficient of resistance (-α) and large insulation resistance. Insulation resistance will be affected by moisture, temperature, applied field and age of dielectrics.

FUNDAMENTAL DEFINITIONS AND PROPERTIES

1. Electric polarization

The process of producing electric dipoles inside the dielectrics by an external electric field is called polarization in dielectrics.

2. Polarization vector (*P*)

If the strength of the electric field E is increased the strength of the induced dipole also increases. The induced dipole moment is proportional to the intensity of the electric filed.

$$\mu = \alpha E$$

where, α is the constant of proportionality, called the Polarizability.

If μ is the average dipole moment per molecule and N is the number of molecules per unit volume, the polarization vector *P* is defined as dipole moment per unit volume of the dielectric material.

$$P = N\ \mu$$

3. Electric Displacement Vector (D)

Electric Displacement Vector or electric induction (D) is a quantity which is used for analyzing electrostatic fields in the presence of dielectrics, which is given by

$$D = \frac{Q}{4\pi r^2} \qquad \ldots(1)$$

We know electric field intensity

$$E = \frac{Q}{4\pi \epsilon r^2} \qquad \ldots(2)$$

From (1) and (2) we get

$$D = \epsilon\ E$$

$$D = \epsilon_o \epsilon_r\ E \qquad \ldots(3)$$

$$\mathbf{D} = \epsilon_{\mathbf{o}} \, (\mathbf{1} + \boldsymbol{\chi}_{\mathbf{e}})$$

Since $\epsilon_r = 1 + \chi_e$ Where, χ_e is the electrical susceptibility.

4. Relation between P and E

We know $D = \epsilon_o E + \epsilon_o \chi_e E$

Since P=$\epsilon_o \chi_e E$, we have

$$D = \epsilon_o E + P \qquad \text{... (4)}$$

Equating (3) and (4)

$$\epsilon_o \epsilon_r E = \epsilon_o E + P$$

$$\frac{\boldsymbol{P}}{\boldsymbol{E}} = \epsilon_{\boldsymbol{o}} \, (\epsilon_{\boldsymbol{r}} - \mathbf{1}) \qquad \text{…(5)}$$

5. Electrical Susceptibility (χ_e)

The polarization vector (P) is proportional to the applied electric field (E), for field strengths that are not too large. So we can write

$$P \propto E$$

$$P = \epsilon_o \chi_e E \qquad \text{…(1)}$$

χ_e is a characteristic of every dielectric and which is called electrical susceptibility.

$$\chi_e = \frac{P}{\epsilon_o E}$$

Since $\frac{\mathrm{P}}{\mathrm{E}} = \epsilon_o (\epsilon_r - 1)$

Therefore,

$$\chi_e = \frac{\epsilon_{\mathrm{o}} (\epsilon_{\mathrm{r}} - 1)}{\epsilon_{\mathrm{o}}}$$

$$\boldsymbol{\chi_e} = \epsilon_{\boldsymbol{r}} - \mathbf{1} \qquad \text{…(2)}$$

6. Dielectric constant (ε_r)

Dielectric constant (ε_r) is the measure of the polarization produced in the material. It is the ratio between absolute permittivity (ε) and the permittivity of free space (ε_0).

i.e., $\epsilon_r = \frac{\epsilon}{\epsilon_o}$

ϵ_r is a dimensionless quantity and it is a measure of polarization in the dielectrics. The value of $\epsilon_r = 1$ for air or vaccum.

For solids, $\epsilon_r > 1$, for glass it is 4 to 7, for diamond is 5.68, for silicon it is 12, for germanium it is 16, for ethanol it is 24.3 and for water at 0˚C $\epsilon_r = 87.8$.

ACTIVE AND PASSIVE DIELECTRICS

Active Dielectrics

Dielectrics which can be easily adapt itself to store the electrical energy in it is called active dielectrics. Ex: Piezo electrics, Ferro electrics, Pyro electrics.

It is used in production of Ultrasonics.

Passive Dielectrics

Dielectrics which restrict the flow of electrical energy in it are called passive dielectrics. Ex: Glass, mica, plastic

It is used in production of sheets, pipes etc.

POLAR AND NON-POLAR MOLECULES

POLAR MOLECULES

The molecules have permanent dipole moments even in the absence of an applied field is called polar molecules. These molecules do not have symmetrical structure and do not have centre of symmetry.

Ex: H_2O, N_2O, HCl, NH_3 etc.

Effect of electric field

In the absence of electric field

In the absence of electric field the polar molecule posses some dipole moment. since, these dipoles are randomly oriented they cancel each other and the net dipole moment will be very less (app zero).

In the presence of electric field

When an external electrical field is applied the dipoles in the dielectrics will align themselves parallel to the field direction and produces a net dipole moment.

NON POLAR MOLECULES

The molecules which do not have permanent dipole moments is called Non Polar molecules. These molecules have symmetrical structure and they have centre of symmetry

Ex: N_2, H_2, O_2, CH_4, CO_2

Effect of electric field

When a non-polar molecule is placed in an external electric field, a force is exerted on each charged particle within the molecule. (i.e.,) the positive particles are pushed along the field direction and the negative charges are pushed opposite to the field direction. Hence the positive and negative charges are separated by some distance from their equilibrium positions, creating a dipole and therefore a net dipole moment will be produced in non-polar molecules.

INTERNAL FIELD OR LOCAL FIELD AND DEDUCTION OF CLAUSIUS MOSOTTI EQUATION

When a dielectric material is kept in an external field it exerts a dipole moment in it. Therefore two fields are exerted, viz.,

I. Due to external field

II. Due to dipole moment.

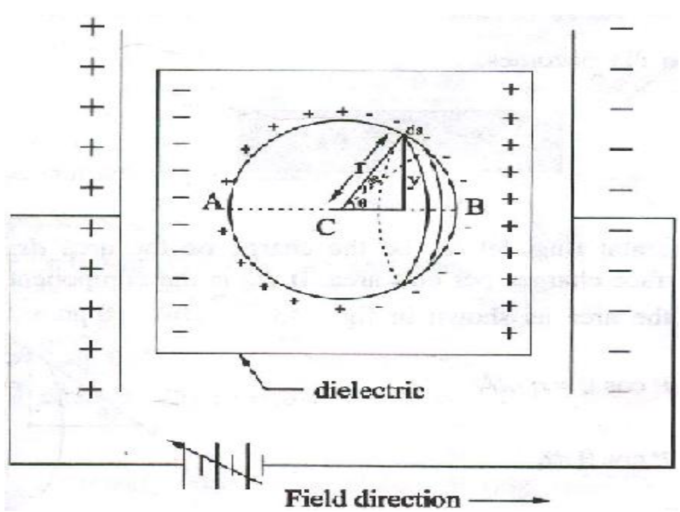
This long range of coulomb forces which is created due to the dipoles is called as internal field or local field. This field is responsible for polarizing the individual atoms or molecules.

Lorentz Method for Finding Internal Field

Let us assume a dielectric material kept in an external electric field. Consider an imaginary sphere in the solid dielectric of radius 'r'.

Here the radius of the sphere is greater than the radius of the atoms. i.e., there are many atomic dipoles within the sphere.

A small elemental ring is cut with thickness ds. Let y be the radius of the small ring as shown in figure.



The electric field at the centre of the sphere is called internal field, which arises due to the following four factors.

$$E_{int} = E_1 + E_2 + E_3 + E_4 \qquad \text{……..(1)}$$

Where,

E_1- Field due to the charge on the plates.(externally applied)

E_2- Field due to p[olarization charges on the plane surface of the dielectric.

E_3- Field due to polarized charges induced at the spherical surface.

E_4- Field due to atomic dipoles inside the sphere considered.

Macroscopically, we can take $E = E_1+E_2$ (i.e.). The field externally applied (E_1) and the field induced on the plane surface of the dielectric (E_2) as a single field (E).

If the dielectric is highly symmetric then the dipoles will cancel with each other therefore we can take $E_4=0$

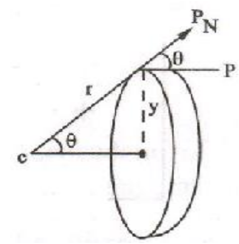
Equation (1) becomes

$$E_{int} = E+E_3 \quad \text{……..(2)}$$

To find E_3

In the elemental ring, let "q" be the charge on the area ds. Polarization is defined sa the surface charges per unit area.

If P_N is the component of polarization perpendicular to the area as shown in figure.



Here $P_N=P\cos\theta = -q'/ds$

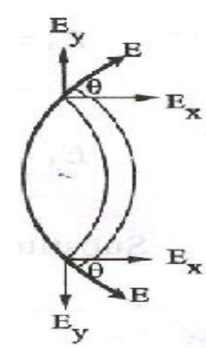
(or) $q'=P \cos\theta \, ds$

Electric field intensity at 'C' due to charge q' is given by

$$E = \frac{q'}{4\pi\varepsilon_o r^2}$$

$$= \frac{P\cos\theta}{4\pi\varepsilon_o r^2} \quad \text{…….(3)}$$

The above intensity is along the radius 'r'. Resolving the intensity into two components as shown in figure.



Component Parallel to the field direction $E_x = E \cos\theta$

$$\therefore E_x = \frac{P\cos^2\theta ds}{4\pi\varepsilon_o r^2}$$

Component Perpendicular to the field direction $Ey=E \sin\theta$

$$E_x = \frac{P\cos\theta \sin\theta ds}{4\pi\varepsilon_o r^2}$$

The perpendicular components are in the opposite directions and hence cancel each other. So the parallel components are alone taken into consideration.

If the total surface area of the ring is considered as dA then

$$E_x = E = \frac{P\cos^2\theta dA}{4\pi\varepsilon_o r^2} \quad \text{…….(4)}$$

Where, dA = circumference x thickness

$$dA = 2\pi y \times dS$$

Since y= r sin θ and dS = r d θ, we can write

$$dA = 2\pi\, r \sin\theta \times r\, d\theta$$

(Or) $$dA = 2\pi\, r^2 \sin\theta\, d\theta \quad \text{......(5)}$$

Substitute eqn (5) in (4) we get

Electric field intensity due to the elemental ring

$$= \frac{P\cos^2\theta\sin^2\theta d\theta}{2\varepsilon_o} \quad \text{......(6)}$$

∴ Electrical field intensitydue to the whole sphere can be derived by integrating eqn (6) within the limits 0 to π.

$$E_3 = \int_0^{\pi} \frac{P\cos^2\theta\sin^2\theta d\theta}{2\varepsilon_o}$$

$$E_3 = \frac{2}{3}\cdot\left(\frac{P}{2\varepsilon_o}\right) \qquad \because \int_0^{\pi} \cos^2\theta\sin^2\theta d\theta = \frac{2}{3}$$

$$E_3 = \left(\frac{P}{3\varepsilon_o}\right) \quad \text{........(7)}$$

Substituting eqn (7) in (2) we get

$$\therefore \mathbf{E_{int}} = \mathbf{E} + \frac{\mathbf{P}}{\mathbf{3\varepsilon_o}} \quad \text{.........(8)}$$

Where, E_{int} is called internal field or Lorentz field.

Clausius – Mosotti Relation

We know $$D = \varepsilon E = \varepsilon_o E + P$$

(Or) $$E(\varepsilon - \varepsilon_o) = P$$

$$E = \frac{P}{\varepsilon - \varepsilon_o} \quad \text{.........(9)}$$

Substituting eqn (9) in eqn (8), we get

$$E_{int} = \frac{P}{\varepsilon - \varepsilon_o} + \frac{P}{3\varepsilon_o}$$

Rearranging we get

$$E_{int} = \frac{P(2\varepsilon_o + \varepsilon)}{3\varepsilon_o(\varepsilon - \varepsilon_o)} \quad \text{........(10)}$$

We know polarization $P = N\alpha E_i$

$$\therefore E_{int} = \frac{P}{N\alpha} \quad \text{.......(11)}$$

Comparing eqn (10) & (11) we get

$$\frac{P}{N\alpha} = \frac{P(2\varepsilon_o + \varepsilon)}{3\varepsilon_o(\varepsilon - \varepsilon_o)}$$

$$\frac{N\alpha}{3\varepsilon_o} = \frac{\varepsilon - \varepsilon_o}{2\varepsilon_o + \varepsilon}$$

$$\frac{N\alpha}{3\varepsilon_o} = \frac{\varepsilon_o(\frac{\varepsilon}{\varepsilon_o} - 1)}{\varepsilon_o(\frac{\varepsilon}{\varepsilon_o} + 2)}$$

$$\frac{N\alpha}{3\varepsilon_o} = \frac{\varepsilon_r - 1}{\varepsilon_r + 2} \quad \text{......(12)}$$

The above equation is called **Clausius – Mossotti Relation.**

APPLICATIONS OF DIELECTRIC MATERIALS

The dielectric materials has three major applications

- It is used as a dielectric medium in capacitors.
- It is used as insulating materials in transformers.
- It is used in industries and dielectric heating.

DIELECTRICS IN CAPACITORS

For dielectrics to be used in capacitors, it should posses the following properties.

Properties:

- It must have high dielectric constant.
- It should posses high dielectric strength.
- It should have high specific resistance.
- It should have low dielectric loss.

Uses

- Thin sheets of papers filled with synthetic oils are used as dielectrics in the capacitors.
- Tissue papers and polypropylene flims filled with dielectrol are used in power capacitors.
- Mica is used as dielectrics in discrete capacitors.
- An electrolytic solution of sodium phosphate is used in wet type electrolytic capacitors.
- An electrolytic paste made up of ammonium tetraborate and glycol is used in Dry type electrolytic capacitors.
- Ceramic materials such as Barium titanate and calcium titanate are used in disc capacitors and high frequency capacitors respectively.

INSULATING MATERIALS IN TRANSFORMERS

For dielectrics to act as insulating materials, it should posses the following properties.

Properties

- It should have low dielectric constant.
- It should posses low dielectric loss.
- It must have high resistance.
- It must posses high dielectric strength.
- It should have adequate chemical stability.

- It must have high moisture resistance etc.

Uses

- Ceramics and polymers are used as insulators.
- Paper, rubber, plastics, waxes etc are used to form thin films, sheet tapes, rods etc.
- PVC (Poly Vinyl Chloride) is used to manufacture pipes, batteries, cables etc.
- Glass, mica, asbestos, alumina are used in ceramics.
- Porcelain is used in high voltage power lines.
- Liquid dielectrics such as petroleum oils, silicone oils are widely used in transformers, circuit breakers etc.
- Mineral insulating oils obtained from crude petroleum by distillation is used as transformer oil, because of high resistive to oxidation and fire hazards.
- Synthetic oils such as askarels, sovol etc are used as a coolant and insulant in high voltage transformers.
- Gases such as vaccum, air, nitrogen, sulphur hexa fluoride are used in X-ray tubes, switches, high voltage gas filled pressure cables, coolants respectively.

MAGNETIC PROPERTIES OF MATERIALS

INTRODUCTION

Magnetic materials are the materials which can be made to behave as magnets. When these materials are kept in an external magnetic field, they will create a permanent magnetic moment in it. Diamagnetic, Paramagnetic, Ferromagnetic, Antiferromagnetic and Ferromagnetic materials are the magnetic materials type.

Magnetism originates from the magnetic moment of the magnetic materials due to the rotational motion of the changed particles. When an electron revolves around the positive nucleus, orbital magnetic arises and due to the spinning of electrons, spin magnetic moment arises. Let us see some of the basic definitions in magnetism.

BASIC DEFINITIONS

Magnetic dipole moment

A system having two opposite magnetic poles separated by a distance'd' is called as a magnetic dipole. If *'m'* is magnetic pole strength and *'l'* is the length of the magnet, then its dipole moment is given by

$$M = ml$$

Magnetic moment can also be defined as $M = ia$, where i is the electric current that flows through a circular wire of an area of cross section *'a'*.

Bohr Magneton

The total magnetic moment and the spin magnetic moment of an electron in an atom can be expressed in terms of atomic unit of magnetic moment called Bohr magneton.

$$1 \text{ Bohr magneton} = e\hbar/2m = 9.27 \times 10^{-24} \text{ Am}^2$$

Magnetic field

The space around the magnet or the current carrying conductor where the magnetic effect is felt is called magnetic field.

Magnetic lines of force

Magnetic field is assumed to consist of lines of magnetic forces. These lines of forces travel externally from North Pole to South Pole as shown in figure. Hence a magnetic line of force is defined as the continuous curve in a magnetic field. The tangent drawn at any point on the curve gives the direction of the resultant magnetic intensity at that point.

Magnetic induction (or) Magnetic flux density (B)

It is defined as the number of magnetic lines of force passing normally through unit area of cross section at that point.

Magnetic field intensity (H)

It is defined as the force experienced by a unit North Pole placed at the given point in a magnetic field

Magnetisation (or) Intensity of Magnetisation (I)

The magnetization is the process of converting a non-magnetic material into a magnetic material. It measures the magnetization of the magnetized specimen. It also defined as the magnetic moment per unit volume

Magnetic susceptibility (χ_m)

It is defined as the ratio between intensity of magnetization (I) and the magnetic field intensity (H)

$$\chi_m = \frac{I}{H}$$

Magnetic permeability (μ)

It is defined as the ratio between the magnetic flux density (B) and the magnetic field intensity (H)

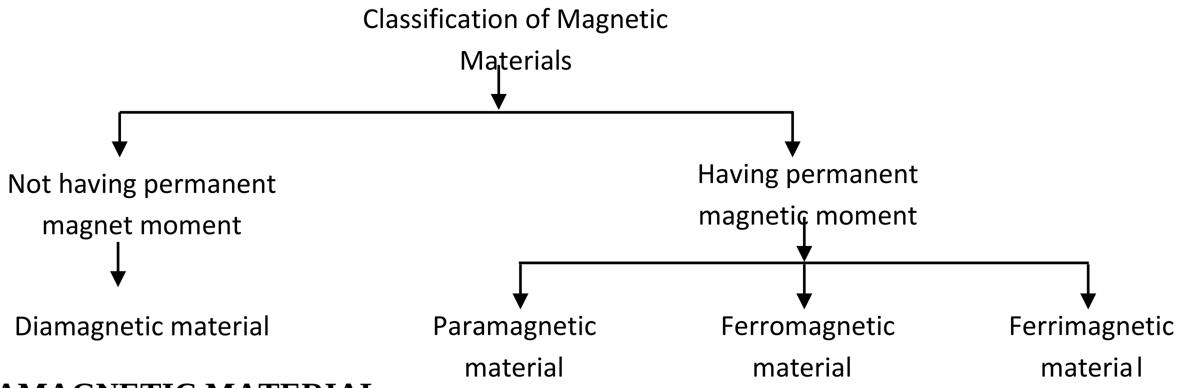
$$\mu = \frac{B}{H}$$

CLASSIFICATION OF MAGNETIC MATERIALS ON THE BASIS OF MAGNETIC MOMENT

Magnetic materials are classified according to the presence or absence of the permanent magnetic dipoles. Generally, every two electrons in an energy state of an atom will form a pair with opposite spins. Thus the resultant spin magnetic moment is zero. Hence they don't have permanent magnetic moments and they are called as diamagnetic materials.

Example: Gold, germanium, silicon, etc.

But in some magnetic materials like iron, cobalt, etc., there exists unpaired electrons. The spin magnetic moment of these unpaired electrons interact with the adjacent atoms unpaired electron spin magnetic moment in a parallel manner resulting in enormous permanent spin magnetic moment. These materials are classified into para, ferro and ferromagnetic materials with respect to the electron spins.



DIAMAGNETIC MATERIAL

Ina diamagnetic material, the electron orbits are more or less random, and mostly all the magnetic moments are cancelled. Similarly all the spin moments are almost paired i.e., they have even number of electrons and has equal number of electrons spinning in two opposite directions. Hence the net magnetic moment in the diamagnetic material is zero. Therefore most of the materials do not have magnetism in the absence of magnetic field.

Effect of external field

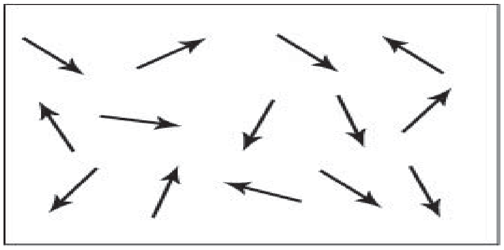
When an external magnetic field is applied, the electrons reorient in such a way that they align perpendicular to the field direction and their magnetic moments opposes the external magnetic field. This will reduce the magnetic induction present in the specimen.

Properties

1. They repel the magnetic lines of force
2. Susceptibility is negative and it is independent of temperature and applied magnetic field strength
3. Permeability is less than 1
4. There is no permanent dipole moment, so they are called weak magnets
5. When temperature is less than critical temperature diamagnetic become normal material
   Examples: Gold, Germanium, Silicon, etc.,

PARAMAGNETIC MATERIALS

In the case of paramagnetic materials, the spins in two opposite directions will not be equal. There exist some unpaired electrons which gives rise to spin magnetic moment. Hence the resultant magnetic will not be equal to zero.



However in the absence of external field the magnetic moments are oriented randomly. Due to its random orientation some magnetic moments get cancelled and the materials possess very less magnetization in it.

Effect of external field

When an external field is applied, the magnetic moments of individual molecules reorient itself along the direction of the magnetic field and the material is magnetized.

Properties

1. The magnetic lines of force pass through the material
2. Magnetic susceptibility is positive and it is given by
3. Permeability is greater than one
4. They possess permanent dipole moment
5. When the temperature is less than Curie temperature, paramagnetic materials becomes diamagnetic material.

   Examples: CuSO4, MnSO4, Platinum etc.

FERROMAGNETISM

In a ferromagnetic material the numbers of unpaired electrons are more. Most of these spin magnetic moments point in one direction as shown in figure.

Hence even in the absence of external field, the magnetic moments align themselves parallel to each other and give rise to magnetic field.

Effect of magnetic field

To these materials even if a small external magnetic field is applied, the magnetic moments which are already aligned parallel, reorient itself along the direction of the magnetic field and they become very strong magnets.

Properties

1. Since some magnetization is already existing in these materials, all the magnetic lines of force passes through it
2. They have permanent dipole moment. So they act as strong magnets.

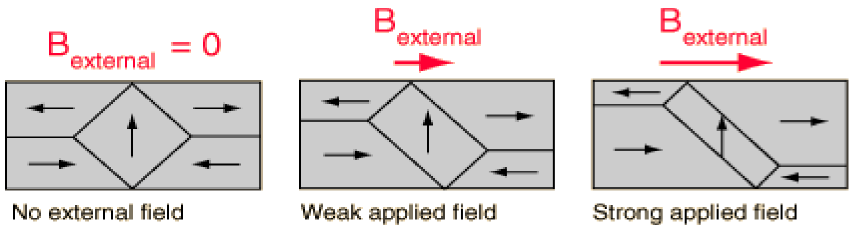
3. They exhibit magnetization even in the absence of external field. This property is called Spontaneous magnetization.
4. Its susceptibility is positive and high and it is given by
5. When the temperature is greater than Curie temperature, ferromagnetic material becomes paramagnetic material.
6. Permeability is very much greater than 1

   Examples: Ni, Co, Fe, etc.,

FERROMAGNETIC DOMAINS

We can observe that a ferromagnetic material such as iron does not have magnetization unless they have been previously placed in an external magnetic field. But according to Weiss theory, the molecular magnets in the ferromagnetic material are said to be aligned in such a way that, they exhibit a magnetization even in the absence of an external magnetic field. This is called spontaneous magnetization. i.e., it should have some internal magnetization due to quantum exchange energy.

Thus according to Weiss hypothesis, a single crystal of ferromagnetic material is divided into large number of small regions called domains. These domains have spontaneous magnetization due to the parallel alignment of spin magnetic moments in each domain. But the directions of spontaneous magnetization vary from domain to domain and are oriented in such a way that the net magnetization of the specimen is zero as shown in figure.



Due to this reason the iron does not have any magnetization in the absence of an external field.

Now, when the magnetic field is applied, then the magnetization occurs in the specimen by two ways

1. By the movement of domain walls
2. By rotation of domain walls

(i) By the movement of domain walls

The movement of domain walls takes place in weak magnetic fields. Due to this weak field applied to the specimen the magnetic moment increases and hence the boundaries of domains are displaced, so that the volume of the domains changes as shown in figure.

(ii) By rotation of domain walls

The rotation of domain walls takes place in strong magnetic fields. When the external field is high (strong) then the magnetization changes by means of rotation of the direction of magnetization towards the direction of the applied field as shown in figure.

DOMAIN THEORY OF FERROMAGNETISM

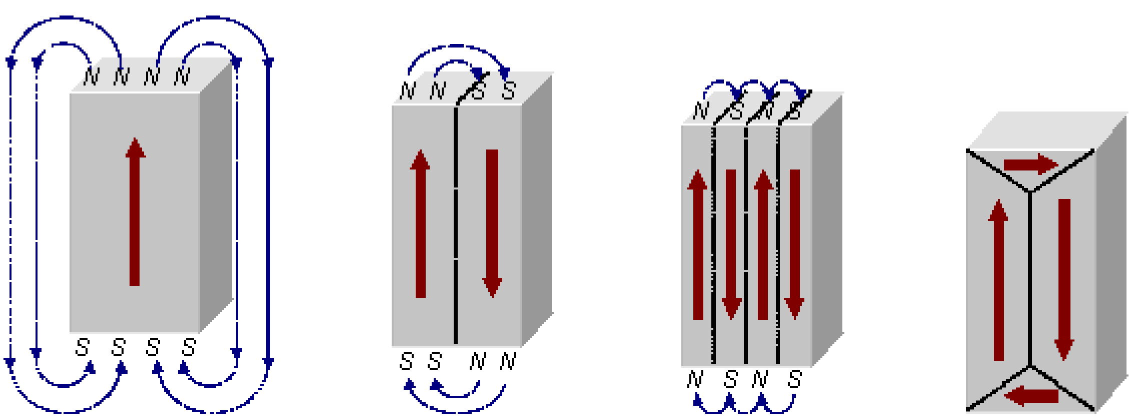
The domain in ferromagnetic solid is understandable from the thermo dynamical principle, (i.e.,) in equilibrium the total energy of the system is minimum. For this, first we consider the total energy of the domain structure and then how it is minimized. The total energy of the domain comprises the sum of following energies. Viz,

1. Exchange energy
2. Anisotropy energy
3. Domain wall energy
4. Magneto-strictive energy

(i) Exchange energy (or) magnetic field energy (or) magneto-static energy

The interaction energy which makes the adjacent dipoles to align themselves is known as exchange energy (or) magnetic field energy. The exchange energy has established a single domain in a specimen of ferromagnetic and it is shown in figure.

Because of the development of the free poles at the domain, an external field will be produced around it and the configuration will have a high value of magnetic field energy. In other words it is the energy required in assembling the atomic magnets into a single domain and this work done is stored as potential energy.



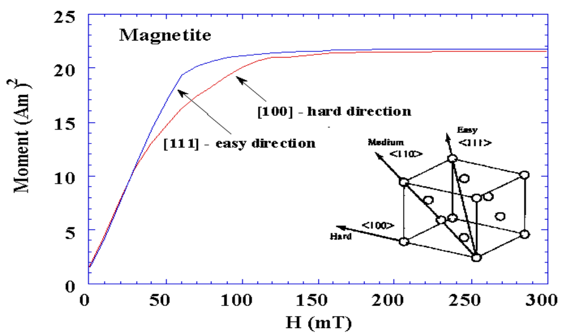
The magnetic energy can be reduced by dividing the specimen into two domains as shown in figure. The process of subdivision may be carried further, until the reduction of magnetic energy is less than the increase in energy to form another domain and its boundary. This boundary is called as domain wall (or) Block wall.

(ii) Anisotropy energy

In ferromagnetic crystals there are two direction of magnetization, viz,

(i) Easy direction (ii) Hard direction

In easy direction of magnetization, weak field can be applied and in hard direction of magnetization, strong field should be applied. For producing the same saturation magnetization along both the hard and easy direction, strong fields are required in the hard direction than the easy direction.



For example in Iron easy direction is [100], medium direction is [110] and the hard direction is [111] and it is as shown in figure. From the figure we can see that very strong field is required to produce magnetic saturation in hard direction [111] compared to the easy direction [100].

Therefore the excess of energy required to magnetize the specimen along hard direction over that required to magnetize the specimen along easy direction is called crystalline anisotropy energy.

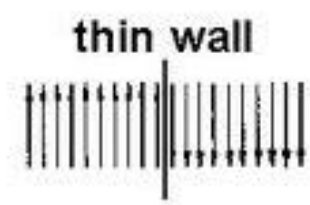
(iii) Domain wall energy (or) Bloch wall energy

Bloch wall is a transition layer which separates the adjacent domains, magnetized in different directions. The energy of domain wall is due to both exchange energy and anisotropic energy.

Based on the spin alignments, two types of Bloch walls may arise, namely

(i) Thick wall (ii) Thin wall

Thick wall: When the spins at the boundary are misaligned and if the direction of the spin changes **gradually** as shown in figure, it leads to a thick Bloch wall. Here the misalignments of spins are associated with exchange energy.



Thin wall: When the spins at the boundaries changes **abruptly**, then the anisotropic energy becomes very less. Since the anisotropic energy is directly proportional to the thickness of the wall, this leads to a thin Bloch wall.

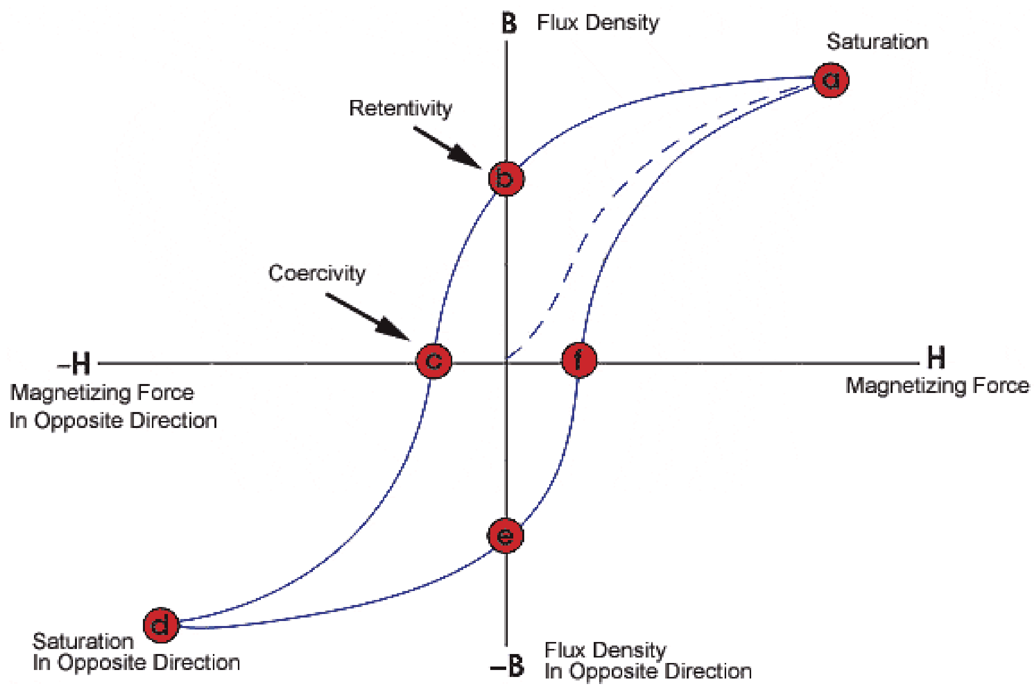
(iv) Magnetostrictive energy

When the domains are magnetized in different directions, they will either expand (or) shrink. Therefore there exists a deformation (i.e.,) change in dimension of the material, when it is magnetized. This phenomenon is known as magnetostriction and the energy produced in this effect is known as magnetostriction energy.

The deformation is different along different crystal directions and the change in dimension (increase or decrease) depends upon the nature of the material. For example in Ni the length decreases; and in permalloy the length increases. But both the increase (and) decrease is due to the mechanical stress generated by domain rotation.

HYSTERESIS

When a ferromagnetic material is made to undergo through a cycle of magnetization, the variation of B with respect to H can be represented by a closed hysteresis loop (or) curve. i.e., it refers to the lagging of magnetization behind the magnetizing field.



If a magnetizing field H is applied to a ferromagnetic material and if H is increased to H_{max} the material acquires the magnetism. So the magnetic induction also increases, represented by *'oa'* in the figure.

Now if the magnetic field is decreased from H_{max} to zero, the magnetic induction will not fall rapidly to zero, but falls to *'b'* rather than zero. This shows that even when the applied field is zero or removed, the material still acquires some magnetic induction *(ob)* which is so called Residual magnetism or Retentivity.

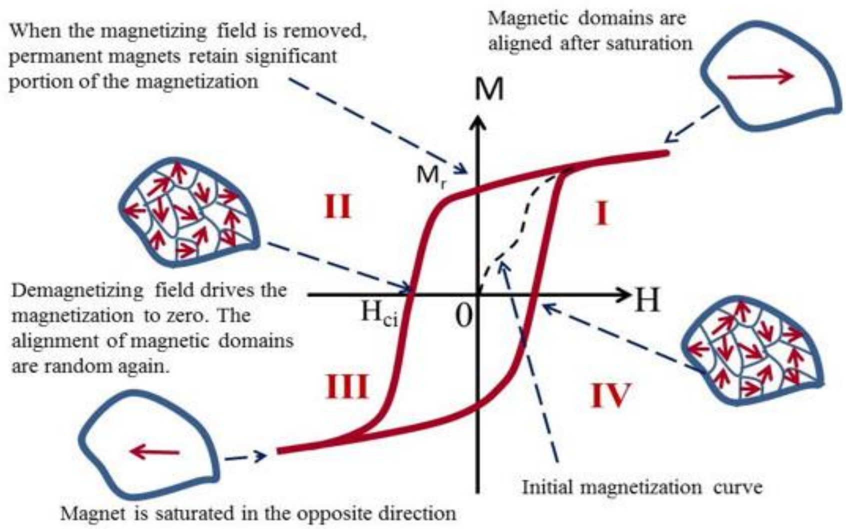
Now, to remove this residual magnetism, the magnetic field strength is reversed and increased to $-H_{max}$ represented as *'oc'* so called coercivity and hence we get the curve *'bcd'*. Then the reverse field (-H) is reduced to zero and the corresponding curve *'de'* is obtained and by further increasing H to H_{max} the curve *'efa'* is obtained.

EXPLANATION OF HYSTERESIS ON THE BASIS OF DOMAINS

We know when the ferromagnetic material is subjected to external field, there is an increase in the value of the resultant magnetic moment due to two process, viz.,

1. The movement of domain walls
2. Rotation of domain walls

When a small external field is applied, the domains walls are displaced slightly in the easy direction of magnetization. This gives rise to small magnetization corresponding to the initial portion of the hysteresis curve (OA) as shown in figure.



Now, if the applied field is removed, then the domains returns to its original state, and is known as reversible domains.

When the field is increased, large number of domains contributes to the magnetization and thus the magnetization increases rapidly with H.

Now, even when the field is removed, because of the displacement of the domain wall to a very large distance, the domain boundaries do not come back to their original position. This process is indicated as AB in figure and these domains are called irreversible domains.

At point 'B' all the domains have got magnetized along the easy direction. Now, when the field is further increased, the domains starts rotating along the field direction and the anisotropic energy is stored in the hard direction, represented as BC in the figure.

Thus the specimen is said to attain the maximum magnetization. At this position, even after the removal of external field the material possess maximum magnetization, called residual magnetization or retentivity, represented by OD in figure.

Actually after the removal of the external field, the specimen will try to attain the original configuration by the movement of Bloch wall. But this movement is stopped due to the presence of impurities, lattice imperfections etc. Therefore to overcome this, a large amount of reverse magnetic field is applied to the specimen. The amount of energy spent to reduce the magnetization to zero is called as coercivity represented by 'OE' in the figure.

Hysteresis loss

It is the loss of energy in taking a ferromagnetic specimen through a complete cycle of magnetization and the area enclosed is called hysteresis loop.

Based on the area of the hysteresis loop, the magnetic materials are classified into soft and hard magnetic materials.

APPLICATIONS OF FERRITES

(i) They are used to produce ultrasonincs by magneto-striction principle.

(ii) Ferrites are used in audio and video transformers.

(iii) Ferrites rods are used in radio receivers to increase the sensitivity.

(iv) Since the ferrites have low hysteresis loss and eddy current loss, they are used in two port devices such as gyrator, circulator and isolator.

Gyrator: It transmits the power freely in both directions with a phase shift of π radians.

Circulator: It provides sequential transmission of power between the ports.

Isolator: It is used to display differential attenuation.

(i) They are also used for power limiting and harmonic generation.

(ii) Ferrites are used in parametric amplifiers so that the input can be amplified with low noise figures.

(iii) They are used in computers and data processing circuits.

(iv) Ferrox cubes are used in switching circuits and in matrix storage devices of computers.

(v) Ferrites are not metals, but their resistivity lies in the range of insulator or semiconductor. Thus, the power losses due to eddy currents are reduced in this type of materials and hence they are used in microwave frequency applications.

(vi) Ferrites are used in storage devices such as magnetic tapes, floppy discs, hard discs, ferrite core memories and in bubble memories.

UNIT V

QUANTUM MECHANICS

INTRODUCTION TO QUANTUM THEORY

Laws of thermodynamics and classical laws of electricity and magnetism provide the basis for explanation of all phenomena in classical physics. It was general belief of the scientists that these laws would suffice to account for any subsequent discovered phenomena. Classical mechanics successfully explained the motion of the objects, which are directly observable. When the objects are not observable, then the concept of classical mechanics cannot be applied.

The phenomena in the realm of the atoms, nuclei and elementary particles are commonly referred to as quantum phenomena and subject matter containing all these phenomena constitutes what is known as Quantum Physics.

Inadequacy of classical mechanics:

According to the classical mechanics, if we consider the case of an electron moving round the nucleus, its energy should decrease (because the accelerated charged particle loses energy in the form of electromagnetic waves) and therefore its velocity should decrease continuously. The ultimate result is that the electron comes closer and closer to the nucleus until it collapses. This shows the instability of the atom; it is in contradiction to the observed fact of the stability of an atom. Thus the classical mechanics fails to explain the stability of an atom.

The classical mechanics also failed to explain the spectrum of the hydrogen atom. According to the classical theory, the excited atoms of hydrogen emit electromagnetic radiations of all wavelengths continuously, while it is observed that they emit the radiation of certain wavelengths only.

Difficulties with classical theories of Black Body Radiation and Origin of Quantum Theory of Radiation:

We know that when bodies radiate energy, their temperature falls until the loss of energy is compensated by an external source. In case of heat radiation, we can obtain the thermal equilibrium by maintaining the body at a fixed temperature with the help of some heat-giving source. In this case the body gives as much radiation as it receives. If the body absorbs all the incident radiation, then it is called Black Body radiation. In actual practice, it is not possible to realize a perfectly black body, but an enclosure provided with a small opening serves the purpose because the radiation entering the enclosure will be reflected many times inside the enclosure and ultimately absorbed.

BLACK BODY RADIATION

Perfect black body:

A perfect black body is one which absorbs and emits in all the radiations (corresponding to all wavelengths) that fall on it. The radiation given out by a perfect black body is called Black body radiation.

Kirchoff's law:

Ratio of emissive power to the coefficient of absorption of any given wavelength is the same for all bodies at a given temperature and is equal to the emissive power of the black body at that temperature.

$$E_\lambda = \frac{e_\lambda}{a_\lambda}$$

Experiment:

In practice a perfect black body is not available. Therefore let us consider a hollow sphere coated with lamp black on its inner surface.

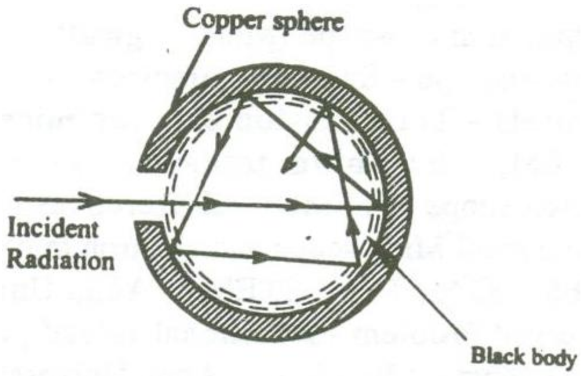


Fig 3.1

A fine hole is made for radiations to enter into the sphere as shown in the fig 3.1.

Now when the radiations are made to pass through the hole it undergoes multiple reflections and are completely absorbed. Thus the black body acts as a perfect absorber. Now when the black body is placed in a temperature bath of fixed temperature, the heat radiations will come out only through the hole in the sphere and not through the walls of the sphere.

Therefore, we can conclude that the radiations are emitted from the inner surface of the sphere and not from the outer surface of the sphere. Thus a perfect black body is a perfect absorber and also a perfect radiator of all wavelengths.

Energy spectrum:

When a perfect black body is allowed to emit radiations at different temperatures, then the distribution of the energy for different wavelengths at various temperatures is obtained as shown in the fig 3.2.

From figure the following results are formulated.

i. The energy distribution is not uniform for a given temperature.

ii. The intensity of radiation (E) increases with respect to the increase in wavelength at particular wavelength in becomes maximum (λ_m) and after this it starts decreasing with respect to the increase in wavelength.

iii. When the temperature is increased, the maximum wavelength (λ_m) decreases.

iv. For all the wavelengths an increase in its temperature causes increase in energy.

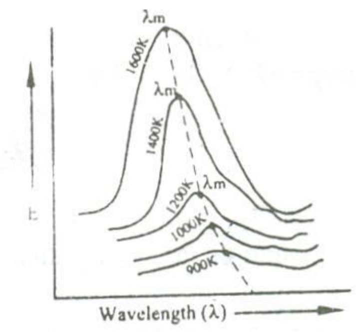


Fig 3.2

v. The total energy emitted at any particular temperature can be calculated from the area under that particular curve.

PHOTON AND ITS PROPERTIES:

According to the Quantum theory of radiation, we know that the exchange of energy values between the light radiation and particles have discrete energy values.

Photon

The discrete energy values in the form of small packets (or) bundles (or) quantas of definite frequency or wavelength are called photon. These photons are propagates like a particle like a particle but with the speed of light ($3x10^8$m/s).

Properties of photon:

- Photons are similar to that of electrons.
- We know for electrons the definite quantities are ‘e’ and ‘m’. Similarly for photons the definite quantities are ‘h’ and ‘c’.
- Photons will not have any charge. They are neutral and hence they are not affected by magnetic (or) electric fields.
- They do not ionize gases.
- The energy of the photon is given by E = hν, which varies with respect to the type of radiation frequencies.
- The momentum of photon is given by p = mc, where ‘m’ is the mass of the photon and ‘c’ is the velocity of light.
- The relation between energy and the momentum of the photon is given by E = pc.

  [i.e., $E = mc^2 = mc(c) = pc$].

DUAL NATURE OF RADIATION (LIGHT) AND MATTER (PARTICLES) – MATTER WAVES

De- Broglie concept of dual nature:

The universe is made of radiation (light) and matter (particles). The light exhibits the dual nature (ie.) it can behave both a wave (interference, diffraction, phenomenon) and as a particle (Compton Effect, photo electric effect etc.)

Since the nature loves symmetry, in 1923 Louis debroglie suggested that an electron or any other material particle must exhibit wave like properties in addition to particle nature.

The waves associated with a material particle are called as matter waves.

De-Broglie wavelength:

From the theory of light, considering a photon as a particle the total energy of the photon is given by

$$E = mc^2 \qquad ---(1)$$

Where, 'm' is the mass of the particle and 'c' is the velocity of light.

Considering the photon as a wave, the total energy is given by

$$E = h\nu \qquad --- (2)$$

Where, 'h' is the Planck's constant and 'ν' is the frequency of the radiation.

From equations (1) and (2)

$$E = mc^2 = h\nu \qquad --- (3)$$

We know Momentum = Mass × velocity

$$p = mc$$

∴ Equation (3) becomes $h\nu = pc$

$$p = \frac{h\nu}{c}$$

Since $\lambda = \frac{c}{\nu}$ we can write $p = \frac{h}{\lambda}$

(or) The wavelength of a photon $\lambda = \frac{h}{p}$ --- (4)

de-Broglie suggested that the equation 3 can be applied both for photons and material particles. If m is the mass of the particle and v is the velocity the particle, then

Momentum $p = mv$

∴ de-Broglie wavelength $\lambda = \frac{h}{mv}$ --- (5)

De-Broglie wavelength in terms of energy:

We know kinetic energy $E = \frac{1}{2}mv^2$

Multiplying by 'm' on both sides we get

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

$$2Em = m^2v^2$$

(or) $mv = \sqrt{2mE}$

∴ de-Broglie wavelength $\lambda = \frac{h}{\sqrt{2mE}}$ --- (6)

De-Broglie wavelength in terms of Voltage

If a charged particle of charge 'e' is accelerated through a potential difference 'v', Then the Kinetic Energy of the particle = $\frac{1}{2}mv^2$ --- (7)

Also we know energy = eV --- (8)

Equating (7) and (8), we get,

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

Multiplying by 'm' on both sides we get

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

$$m^2v^2 = 2meV$$

(or) $mv = \sqrt{2meV}$ --- (9)

Substituting equation (9) in equation (5), we get

∴ de-Broglie wavelength $\lambda = \frac{h}{\sqrt{2meV}}$ --- (10)

De-Broglie wavelength in terms of Temperature:

When a particle like neutron is in thermal equilibrium at temperature T, then they possess Maxwell distribution of velocities.

∴ Their kinetic energy $E_k = \frac{1}{2}mv_{rms}^2$ --- (11)

Where, 'v_{rms}' is the Root mean square velocity of the particle.

Also, we know energy = $\frac{3}{2}K_BT$ --- (12)

Where, 'K_B' is the Boltzmann constant.

Equating (11) and (12) we get

$$\frac{1}{2}mv^2 = \frac{3}{2}K_BT$$

Multiplying by 'm' on both sides we get

$$\frac{1}{2}m^2v^2 = \frac{3}{2}mK_BT$$

$$m^2v^2 = 3mK_BT$$

(or) $mv = \sqrt{3mK_BT}$

∴ De-Broglie wavelength $\lambda = \frac{h}{\sqrt{3mK_BT}}$

PROPERTIES OF MATTER WAVES:

- Matter waves are not electromagnetic waves.
- Matter waves are new kind of waves in which due to the motion of the charged particles, electromagnetic waves are produced.
- The wave and particle aspects cannot appear together.
- Locating the exact position of the particle in the wave is uncertain.
- Lighter particles will have high wavelength.

- Particles moving with less velocity will have high wavelength.
- The velocity of matter wave is not a constant; it depends on the velocity of the particle.
- The velocity of matter wave is greater than the velocity of light.

UNCERTAINITY PRINCIPLE

According to classical ideas, it is possible for a particle to occupy a fixed position and have a definite momentum. Hence we can predict exactly its position and momentum, at any time.

But according to quantum mechanics, there is an inherent uncertainity in the determination of the position and momentum of the particle. According to Heisenberg's principle the position and momentum of a particle cannot be determined simultaneously to any degree of accuracy.

Statement

It is impossible to determine precisely and simultaneously the values of both the position and momentum of a particle.

Example

Considering the position and momentum as a pair of physical variables. These quantiTIes are related as

$$\Delta x \Delta p \approx \frac{h}{2\pi}$$

where Δx is the error in determining position

Δp is error in determining momentum of the particle.

Similarly we have

$$\Delta E \Delta t \approx \frac{h}{2\pi}$$

$$\Delta J \Delta \theta \approx \frac{h}{2\pi}$$

where ΔE and Δt is the error in determining energy and time respectively and ΔJ and $\Delta\theta$ are the error in determining the angular momentum and angle respectively.

SCHROEDINGER WAVE EQUATION:

Schroedinger wave equation describes the wave nature of a particle in the mathematical form. It is the basic equation of motion of matter waves.

If the particle has wave properties, then there should be some sort of wave equation to describe the behavior of that particle.

Schrodinger connected the expression of de-Broglie's wavelength with the classical wave equation for a moving particle and he obtained a new wave equation

FORMS OF SCHROEDINGER WAVE EQUATION

There are two forms of Schroedinger wave equation. They are

a. Time independent wave equation

b. Time dependent wave equation

SCHROEDINGER TIME INDEPENDENT WAVE EQUATION:

Consider a wave associated with a moving particle.

Let x, y, z be the coordinates of the particle and ψ wave function for de – Broglie's waves at any given instant of time't'.

The classical differential equation for wave motion is given by

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

Here, 'v' is wave velocity.

The eqn (1) is written as

$$\nabla^2\psi = \frac{1}{v^2}\frac{\partial^2\psi}{\partial t^2} \qquad \text{--- (2)}$$

Where, $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$ is a Laplacian's operator.

The solution of eqn (2) gives ψ as a periodic variations in terms of 't',

$$\psi(x, y, z, t) = \psi_0(x, y, z)\, e^{-i\omega t} \qquad \text{--- (3)}$$

Here, $\psi_0(x, y, z)$ is a function of x, y, zonly, which is the amplitude at the point considered. 'ω' is angular velocity of the wave.

Differentiating eqn (3) with respect to 't', we get

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

Again differentiating with respect to 't', we have

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

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

$$\frac{\partial^2\psi}{\partial t^2} = -\omega^2\psi \text{ --- (4)}$$

Where, $i^2 = -1$ and $\psi = \psi_0 e^{-i\omega t}$

Substituting eqn (4) in eqn (2), we have

$$\nabla^2\psi = -\frac{\omega^2}{v^2}\psi$$

$$\nabla^2\psi + \frac{\omega^2}{v^2}\psi = 0 \qquad \text{--- (5)}$$

We know that angular frequency $\omega = 2\pi\nu$

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

Where, $\nu = \frac{v}{\lambda}$, ν is the frequency and v is the wave velocity

$$\frac{\omega}{v} = \frac{2\pi}{\lambda} \quad \text{--- (6)}$$

Squaring the eqn (6) on both sides, we get

$$\frac{\omega^2}{v^2} = \frac{2^2\pi^2}{\lambda^2}$$

$$\frac{\omega^2}{v^2} = \frac{4\pi^2}{\lambda^2} \quad \text{--- (7)}$$

Substituting eqn (7) in eqn (5), we get

$$\nabla^2\psi + \frac{4\pi^2}{\lambda^2}\psi = 0 \quad \text{--- (8)}$$

On substituting, $\lambda = \frac{h}{mv}$ in eqn (8), we get

$$\nabla^2\psi + \frac{4\pi^2}{\left(\frac{h}{mv}\right)^2}\psi = 0$$

$$\nabla^2\psi + \frac{4\pi^2}{\frac{h^2}{m^2v^2}}\psi = 0$$

$$\nabla^2\psi + \frac{4\pi^2 m^2 v^2}{h^2}\psi = 0 \quad \text{--- (9)}$$

If 'E' is the total energy of the particle, 'V' is potential energy and $\frac{1}{2}mv^2$ is kinetic energy, then

Total energy = Potential energy + Kinetic energy

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

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

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

Multiplying by 'm' on both sides, we have

$$2m\,(E - V) = m^2v^2 \quad \text{--- (10)}$$

Substituting eqn (10) in eqn (9), we get

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

$$\nabla^2\psi + \frac{8\pi^2 m}{h^2}(E - V)\psi = 0 \quad \text{--- (11)}$$

The eqn (11) is known as Schroedinger time independent wave equation.

Let us know introduce $\hbar = \frac{h}{2\pi}$ in eqn (11),

$$\hbar^2 = \frac{h^2}{2^2\pi^2}$$

$$\hbar^2 = \frac{h^2}{4\pi^2} \quad \text{--- (12)}$$

where, 'ħ' is a reduced Planck's constant.

The eqn (11) is modified by substituting ħ,

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

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

$$\nabla^2\psi + \frac{2m\,(E - V)}{\frac{h^2}{4\pi^2}}\psi = 0 \qquad \text{--- (13)}$$

On substituting eqn (12) in eqn (13), Schroedinger time independent wave equation is written as,

$$\nabla^2\psi + \frac{2m}{\hbar^2}(E - V)\,\psi = 0 \qquad \text{--- (14)}$$

Special case:

If we consider one dimensional motion i.e., particle moving along only X-direction, then Schroedinger time independent wave equation (14) reduces to

$$\frac{\partial^2\psi}{\partial x^2} + \frac{2m}{\hbar^2}(E - V)\,\psi = 0 \qquad \text{--- (15)}$$

SCHROEDINGER TIME DEPENDENT WAVE EQUATION:

Schoredinger time independent wave equation is derived from Schroedinger time independent wave equation.

The solution of classical differential equation of the wave motion is given by

$$\psi(x, y, z, t) = \psi_0(x, y, z)\, e^{-i\omega t} \qquad \text{--- (1)}$$

Differentiating eqn (1) with respect to 't', we get

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

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

Where, $\omega = 2\pi\,\nu$

$$\frac{\partial\psi}{\partial t} = -i(2\pi\nu)\psi \qquad \text{--- (3)}$$

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

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

Where, $E = h\nu$ (or) $\nu = \frac{E}{h}$

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

We know that $\hbar = \frac{h}{2\pi}$

$$\therefore\ \frac{\partial\psi}{\partial t} = -i\,\frac{E}{\hbar}\,\psi \qquad \text{--- (4)}$$

Multiplying 'i' on both sides in eqn (4), we get

$$i\,\frac{\partial\psi}{\partial t} = -i^2\,\frac{E}{\hbar}\,\psi$$

We know that $i^2 = -1$

$$\therefore\ i\,\frac{\partial\psi}{\partial t} = -(-1)\,\frac{E}{\hbar}\,\psi$$

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

$$i\hbar\,\frac{\partial\psi}{\partial t} = E\psi \qquad \text{--- (5)}$$

Schroedinger time independent wave equation is given by

$$\nabla^2\psi + \frac{2m}{\hbar^2}(E - V)\,\psi = 0$$

$$\nabla^2\psi + \frac{2m}{\hbar^2}(E\psi - V\psi) = 0 \qquad \text{--- (6)}$$

Substituting eqn (5) in eqn (6), we get

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

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

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

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

$$\left(-\frac{\hbar^2}{2m}\nabla^2 + V\right)\psi = i\hbar\frac{\partial\psi}{\partial t} \qquad \text{--- (7)}$$

$$\text{(or) } H\psi = E\psi \qquad \text{--- (8)}$$

Where, H = $\left(-\frac{\hbar^2}{2m}\nabla^2 + V\right)$ is Hamiltotnian operator and E = $i\hbar\frac{\partial}{\partial t}$ is energy operator

The eqn (8) is known as Schroedinger time dependent wave equation

PHYSICAL SIGNIFICANCE OF WAVE FUNCTION:

Wave function:

It is the variable quantity that is associated with a moving particle at any position (x, y, z) and at any time‘t’ and it relates the probability of finding the particle at that point and at that time.

- It relates the particle and the wave statistically (i.e.,) $\psi = \psi_0 e^{-i\omega t}$
- Wave function gives the information about the particle behavior.
- Ψ is a complex quantity and individually it does not have any meaning.
- $|\psi|^2 = \psi^*\psi$ is real and positive, it has physical meaning. This concept is similar to light. In light, amplitude may be positive (or) negative but the intensity, which is square amplitude, is real and is measurable.
- $|\psi|^2$ represents the probability density (or) probability of finding the particle per unit volume.
- For a given volume dτ, the probability of finding the particle is given by
  Probability (P) = $\iiint |\psi|^2 d\tau$
  Where, dτ = dx.dy.dz
- The probability will have any value between zero and one. (i.e.,)
  i. If P = 0 then there is no chance for finding the particle (i.e.,) there is no particle, within the given limits.
  ii. If P = 1 then there is 100% chance for finding the particle (i.e.,) the particle is definitely present, within the given limits.

iii. If P = 0.7 then there is 70% chance for finding the particle and 30% there is no chance for finding the particle, within the given limits.

Example:

If a particle is definitely present within a one dimensional box (x-direction) of length 'l', then the probability of finding the particle can be written as

$$P = \int_0^l |\psi|^2 \, dx = 1$$

PARTICLE IN A ONE DIMENSIONAL BOX:

Let us consider particle (electron) of mass 'm' moving along the x - axis, enclosed in a one dimensional potential box as shown in the figure 3.10.

Since the walls are of infinite potential the particle does not penetrate out from the box.

Also, the particle is confined between the length 'l' of the box and has elastic collisions with the walls. Therefore, the potential energy of the electron inside the box is constant and can be taken as zero for simplicity.

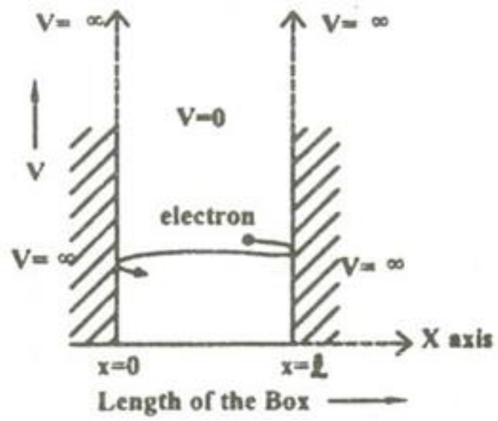


Fig 3.10

∴ We can say that the Outside the box and on the wall of the box, the potential energy V of the electron is 'α'.

Inside the box the potential energy (V) of the electron is zero.

In other words we can write the boundary condition as

$$V(x) = 0 \text{ when } 0 < x < l$$

$$V(x) = \alpha \text{ when } 0 \geq x \geq l$$

Since the particle cannot exist outside the box the wave function $\psi = 0$ when $0 \geq x \geq l$.

To find the wave function of the particle within the box of length 'l', let us consider the Schroedinger one dimensional time independent wave equation(i.e.,)

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

Since the potential energy inside the box is zero [i.e.V = 0], the particle has kinetic energy alone and thus it is named as a free particle (or) free electron

∴ For a free particle (electron), the Schroedinger wave equation is given by

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

Or $$\frac{\partial^2\psi}{\partial x^2} + k^2E\psi = 0 \qquad \text{--- (1)}$$

Where, $$k^2 = \frac{2mE}{\hbar^2} \qquad \text{--- (2)}$$

Equation (1) is a second order differential equation; therefore, it should have solution with two arbitrary constants.

∴ The solution for equation (1) is given by

$$\Psi(x) = A \sin kx + B \cos kx \qquad \text{--- (3)}$$

Where, A and B are called Arbitrary constants, which can be found by applying the boundary conditions.

(i.e.,) $V(x) = \alpha$ when $x = 0$ and $x = l$

Boundary condition (i) at x=0 Potential energy $V = \alpha$. ∴ There is no chance for finding the particle at the walls of the box, ∴ $\psi(x) = 0$

∴ Equation (3) becomes

$$0 = A \sin 0 + B \cos 0$$

$$0 = 0 + B(1)$$

∴ **B = 0**

Boundary condition (ii) at $x = l$ Potential energy $V = \alpha$. ∴ There is no chance for finding the particle at the walls of the box, ∴ $\psi(x) = 0$

∴ Equation (3) becomes

$$0 = A \sin kl + B \cos kl$$

Since B = 0 (from the first boundary condition), we have

$$0 = A \sin kl$$

Since $A \neq 0$; $\sin kl = 0$

We know $\sin n\pi = 0$

Comparing these two equations,

We can write $kl = n\pi$

Where, n is an integer.

$$\text{(or) } k = \frac{n\pi}{l} \qquad \text{--- (4)}$$

Substituting the value of B and k in equation 3 we can write the wave function associated with the free electron confined in a one dimensional box as

$$\Psi_n(x) = A \sin \frac{n\pi}{l} \qquad \text{--- (5)}$$

Energy of the particle (Electron)

We know from equation (2),

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

Where, $\hbar^2 = \frac{h^2}{4\pi^2}$

$$k^2 = \frac{2mE}{\left(\frac{h^2}{4\pi^2}\right)}$$

$$\text{(or)} \qquad k^2 = \frac{8\pi^2 mE}{h^2} \qquad \text{--- (6)}$$

Squaring eqn (4), we get

$$k^2 = \frac{n^2\pi^2}{l^2} \quad \text{--- (7)}$$

Equating (6) and (7), we can write

$$\frac{8\pi^2 mE}{h^2} = \frac{n^2\pi^2}{l^2}$$

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

∴ Energy of the particle (electron) $E_n = \frac{n^2h^2}{8ml^2}$ --- (8)

∴ From equations (8) and (5) we can say that, for each value of 'n', there is an energy level and the corresponding wave function.

Thus we can say that, each value of E_n is known as Eigen value and the corresponding value of ψ_n is called Eigen function.

Energy levels of an electron

For various values of 'n' we get various energy values of the electron. The lowest energy value or ground state energy value can be got by substituting n = 1 in equation (8)

∴ When n= 1 we get $E_1 = \frac{1^2h^2}{8ml^2} = \frac{h^2}{8ml^2}$

Similarly we can get the other energy values

When n= 2, we get $E_2 = \frac{2^2h^2}{8ml^2} = \frac{4h^2}{8ml^2} = 4E_1$

When n = 3, we get $E_3 = \frac{3^2h^2}{8ml^2} = \frac{9h^2}{8ml^2} = 9E_1$

When n = 4, we get $E_4 = \frac{4h^2}{8ml^2} = \frac{16h^2}{8ml^2} = 16E_1$

∴ In general we can write the energy Eigen function as

$$\mathbf{E_n = n^2E_1} \quad \text{--- (9)}$$

It is found that from the energy levels E_1, E_2, E_3 etc the energy levels of an electron are discrete.

This is the great success which is achieved in Quantum Mechanics than classical mechanics, in which the energy levels are found to be continuous.

The various energy Eigen values and their corresponding Eigen functions of an electron enclosed in a one dimensional box is as shown in the fig 3.11.

Thus we have discrete energy values.

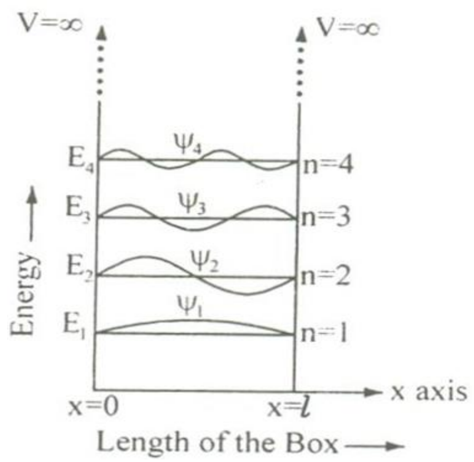


Fig 3.11

Normalization of the wave function:

Normalization:

It is the process by which the probability (P) of finding the particle (electron) inside the

$$A = \sqrt{\frac{2}{l}}$$

Substituting the Value of A in equation (5),

The normalized wave function can be written as

$$\Psi_n = \sqrt{\frac{2}{l}} \sin \frac{n\pi}{l}$$

The normalized wave function and their energy values are as shown in the fig 3.12

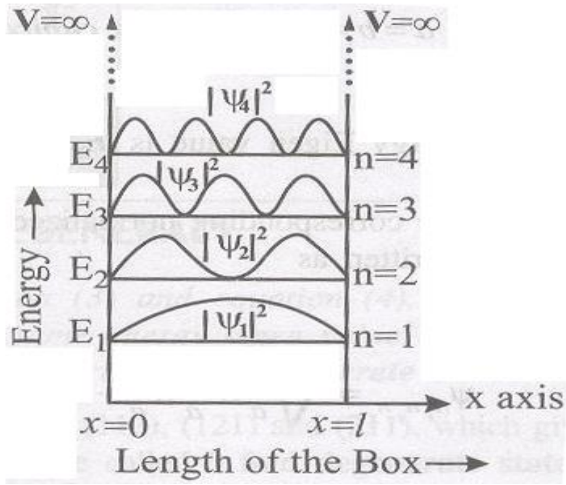


Fig 3.12

box can be done.

We know that the total probability (P) is equal to 1 means then there is a particle inside the box. Therefore, for a one dimensional potential box of length 'l' the probability

$$P = \int_0^l |\psi|^2\, dx = 1 \qquad \text{--- (10)}$$

(Since the particle is present inside the well between the length 0 to 'l' the limits are chosen between 0 to l)

Substituting equation (5) in equation (10), we get

$$P = \int_0^l A^2 \sin^2 \frac{n\pi}{l}\ dx = 1$$

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

$$A^2\left[\frac{x}{2} - \frac{1}{2}\frac{\sin\left(\frac{2n\pi x}{l}\right)}{\left(\frac{2n\pi}{l}\right)}\right]_0^l = 1$$

$$A^2\left[\frac{l}{2} - \frac{1}{2}\frac{\sin\left(\frac{2n\cancel{l}\pi}{\cancel{l}}\right)}{\left(\frac{2n\pi}{l}\right)}\right] = 1$$

$$A^2\left[\frac{l}{2} - \frac{1}{2}\frac{\sin(2n\pi)}{\left(\frac{2n\pi}{l}\right)}\right] = 1$$

We know $\sin n\pi = 0 \therefore \sin 2n\pi$ is also $= 0$

$\therefore$ Equation 11 can be written as

$$A^2\left[\frac{l}{2}\right] = 1$$

$$A^2 = \frac{2}{l}$$

DEGENERACY AND NON-DEGENERACY:

Degeneracy:

It is seen from equation (3) and equation (3), for several combination of quantum numbers we have same energy Eigen value but different Eigen functions. Such states and energy levels are called Degenerate state.

The three combinations of quantum numbers (112), (121) and (211) which gives same Eigen value but different Eigen functions are 3 fold degenerate state.

Non –degeneracy:

For various combinations of quantum number if we have same energy value and same (one) Eigen function then such states and energy levels are called Non – degenerate state.

BASICS OF A MICROSCOPE:

A microscope is a device which is used to view the magnified image of a smaller object, which cannot be clearly seen through a naked eye.

In general we can classify the microscope as simple and compound microscope. A simple microscope is made up of a single biconvex magnifying lens held in a simple frame. A compound microscope is made up of two lenses (or) system of lenses for better magnification.

Depending on the field of application, many other microscopes such as phase contrast microscope, UV microscope, metallurgical microscope, electron microscope, etc are designed. These types of microscopes give a stereoscopic vision and reduce the strain of our eyes.

Magnifying power:

The magnifying power (M) of a microscope is defined as the ratio between the angle subtended by the final image at the eye (β) to the angle subtended by the object at the eye (α), placed at the near point.

$$M = \frac{\beta}{\alpha}$$

Resolving power:

It is the ability of an optical instrument to form a distinct and separable image of the two point objects which are close to each other.

If'd' is the least distance between two close point objects, then we can write

$$d = \frac{\lambda_0}{2\,NA}$$

∴ Resolving power = $\frac{I}{d} = \frac{2NA}{\lambda_0}$

Where, NA be the numerical aperture of the objective of the microscope and λ_0 be the wavelength of light through vacuum.

Therefore the resolving power of a microscope can be increased by decreasing the value of λ_0. Thus, by using UV light and quartz lenses, the resolving power can be increased.

ELECTRON MICROSCOPE

It is a type of microscope in which instead of light beam, a beam of electrons are used to form a large image of very small object. These microscopes are widely used in the field of engineering and medicine.

Principle:

A stream of electrons is passed through the object and the electron which carries the information about the object are focused by electric and magnetic fields.

Since the resolving power is inversely proportional to the wavelength, the electron microscope has high resolving power because of its shorter wavelength.

Construction:

An electron microscope is similar to that of an optical microscope. Here the focusing of electrons can be done either by magnetic lens or by electrostatic lens. Normally in electron microscope magnetic lenses are used for focusing.

In general, the magnetic lenses are made of two coils C1 and C2 enclosed inside the iron cases which have one hole as shown in fig 3.13. When the holes face each other, the magnetic field in space between the two coils focuses the electrons emerging out from the electron gun. Similarly the divergence of the electrons can also be made by adjusting the position of the holes in the iron cases.

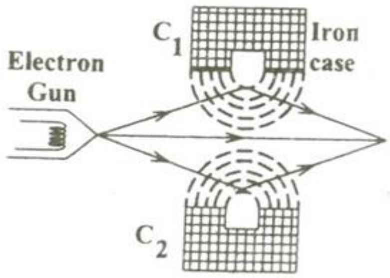
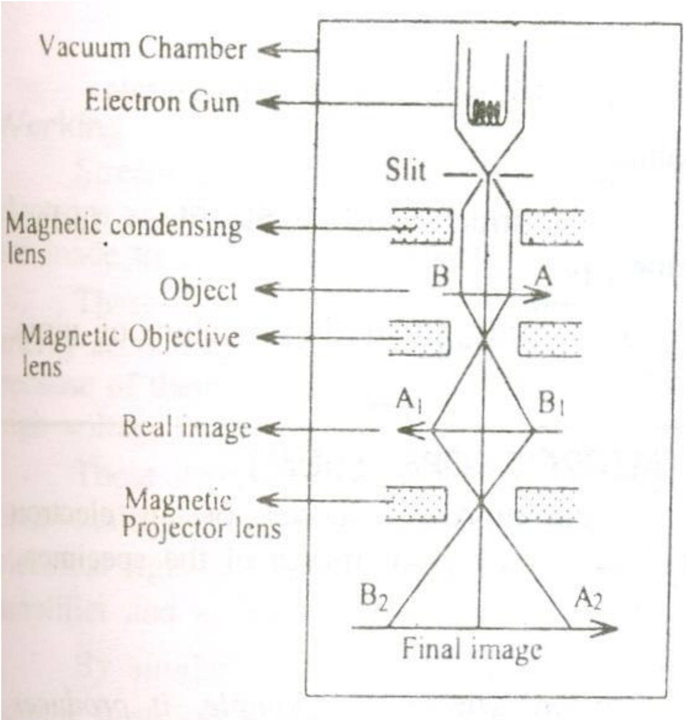


Fig 3.13

The essential parts of an electron microscope are as shown in the fig 3.14 and for comparison an optical microscope is also shown in fig 3.15.



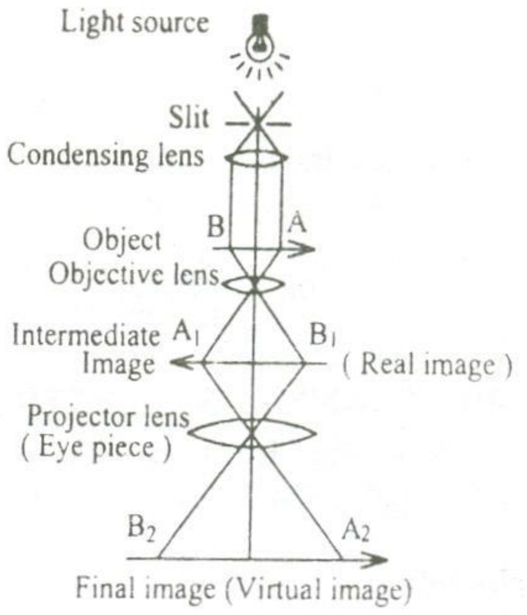


Fig 3.14 Fig 3.15

The electron microscope consists of an electron gun to produce the stream of electrons. Similar to the condensing lens, objective and eye piece in an optical microscope here three magnetic lenses are used.

- Magnetic condensing lens
- Magnetic objective lens
- Magnetic projector lens

The whole arrangement is kept inside a vacuum chamber to allow the passage of electron beam.

Working:

Stream of electrons are produced and accelerated by the electron gun. The electron beam is made to pass through the center of the doughnut shaped magnetic condensing lens. These electrons are made as parallel beam and are focused on to the object AB (fig 3.14). The electrons are transmitted more in the less dense region of the object and is transmitted less (i.e.,) absorbed by the denser region of the object. Thus the transmitted electron beam on the falling over the magnetic objective lens, resolves the structure of the object to form a magnified real image of the object. Further the image can be magnified by the magnetic projector lens and the final image is obtained on the fluorescent screen.

In order to make a permanent record of the image of the object, the final image can also be obtained on a photographic plate.

Advantages:

- It can produce magnification as high as 1, 00,000 times as that of the size of the object.

- The focal length of the microscopic system can be varied.

Applications:

It has a very wide area of applications (Eg.) in biology, metallurgy, physics, chemistry, medicine, engineering etc.

- It is used to determine the complicated structure of the crystals.
- It is used in the study of the colloids.
- In industries it is used to study the structure of textile fibers, surface of metals, composition of paper, paints etc.
- In the medical field it is used to study about the structure of virus, bacterial etc which are of smaller size.

SCANNING ELECTRON MICROSCOPE

Scanning electron microscope is an improved model of an electron microscope. SEM is used to study the three dimensional image of the specimen.

Principle:

When the accelerated primary electron strikes the sample, it produces secondary electrons. These secondary electrons are collected by a positive charged electron detector which in turn gives a 3- dimensional image of the sample.

Construction:

It consists of an electron gun to produce high energy electron beam. A magnetic condensing lens is used to condense the electron beam and a scanning coil is arranged in-between magnetic condensing lens and the sample.

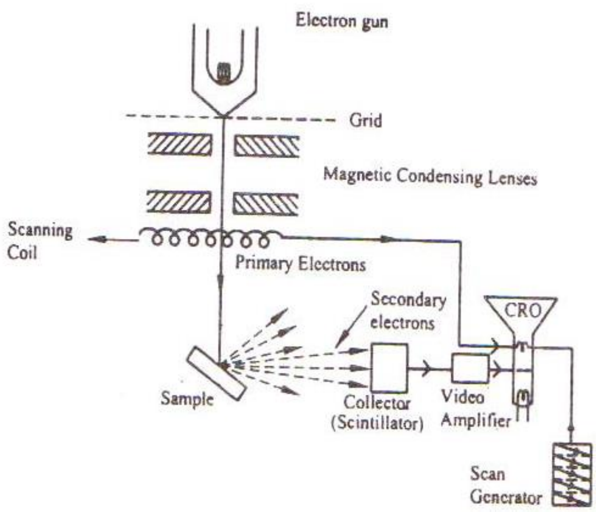


Fig 3.16

The electron detector (Scintillator) is used to collect the secondary electrons and can be converted into electrical signal. These signals can be fed into CRO through video amplifier as shown in fig 3.16.

Working:

Stream of electrons are produced by the electron gun and these primary electrons are accelerated by the grid and anode. These accelerated primary electrons are made to be incident on the sample through condensing lenses and scanning coil.

These high speed primary electrons on falling over the sample produce low energy secondary electrons. The collections of secondary electrons are very difficult and hence a high voltage is applied to the collector.

These collected electrons produce scintillations on to the photo multiplier tube are converted into electrical signals. These signals are amplified by the video amplifier and are fed to the CRO.

By similar procedure the electron beam scans from left to right and again right to left etc., similar to we read a book (fig 3.17) and the whole picture of the sample is obtained in the CRO screen.

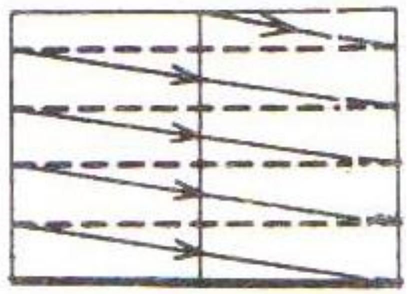


Fig 3.17

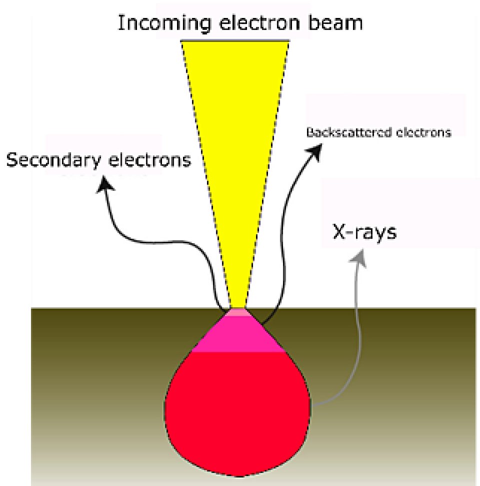
Electrons Interaction;

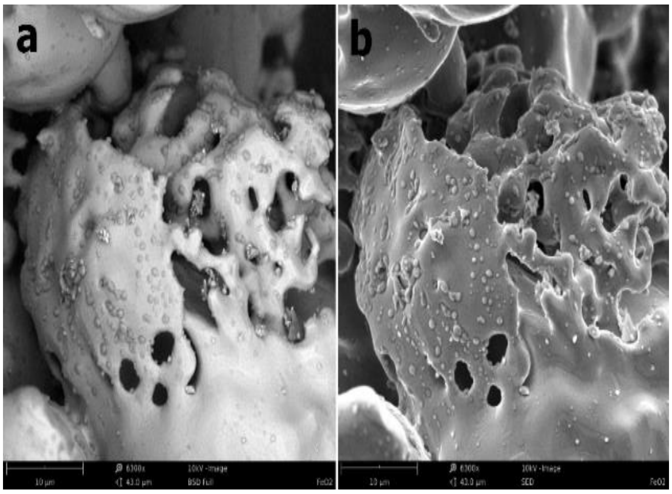
The interaction of electrons with a sample can result in the generation of many different types of electrons, photons or irradiations. In the case of SEM, the two types of electrons used for imaging are the backscattered (BSE) and the secondary electrons (SE).

Backscattered electrons belong to the primary electron beam and are reflected back after elastic interactions between the beam and the sample. On the other hand, secondary electrons originate from the atoms of the sample: they are a result of inelastic interactions between the electron beam and the sample.

BSE come from deeper regions of the sample (Figure 2), while SE originate from surface regions. Therefore, BSE and SE carry different types of information. BSE images show high sensitivity to differences in atomic number: the higher the atomic number, the brighter the material appears in the image.

SEM imaging can provide more detailed surface information — something you can see in Figure 3. In many microscopes, detection of the X-rays, which are generated from the electron-matter interaction, is also widely used to perform elemental analysis of the sample. Every material produces X-rays that have a specific energy; X-rays are the material's fingerprint. So, by detecting the energies of X-rays that come out of a sample with an unknown composition, it is possible to identify all the different elements that it contains.





Different types of signals used by a SEM and the area from which they originate

a) BSE and b) SE image of the FeO_2 particles

Detection of Surface morphology of the particles using electrons detected;

The types of electrons mentioned above are detected by different types of detectors. For the detection of BSE, solid state detectors are placed above the sample, concentrically to the electron beam, in order to maximize the BSE collection.

On the other hand, for the detection of SE, the **Everhart-Thornley detector** is mainly used. It consists of a scintillator inside a Faraday cage, which is positively charged and attracts the SE. The scintillator is then used to accelerate the electrons and convert them into light before reaching a photomultiplier for amplification. The SE detector is placed at the side of the electron chamber, at an angle, in order to increase the efficiency of detecting secondary electrons. These secondary electrons are used to form a 3D-image of the sample, which is shown on a PC monitor.

SEM: magic but meticulous

As you can see, there are different processes that the electrons must go through before an image can be shown on your monitor - Figure 4. Of course, you don't have to wait for the electrons to finish their journey; the whole process is almost instantaneous, in the range of nanoseconds (10-9 seconds). However, every "step" of an electron inside the column needs to be pre-calculated and controlled with precision in order to obtain a high-quality image. Scanning electron microscopes are continuously improved, and new applications are still arising, making them fascinating instruments with lots of undiscovered capabilities.

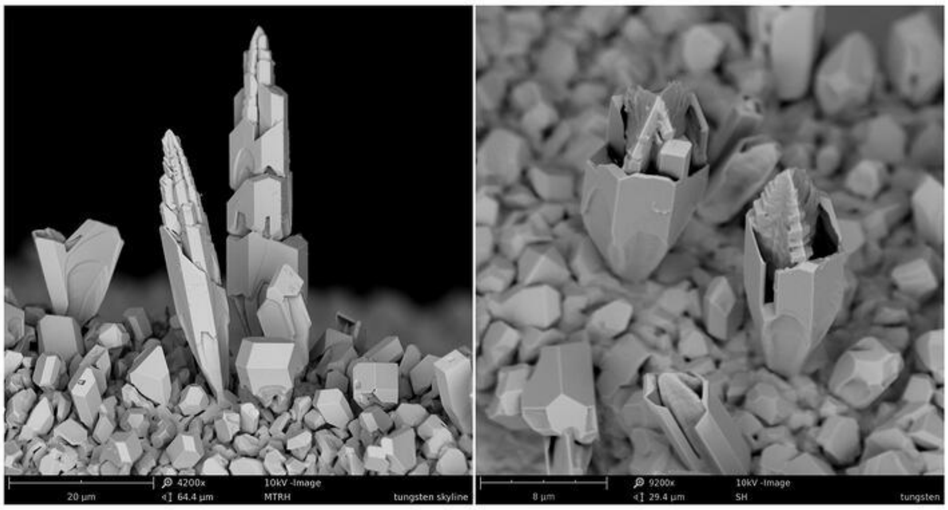


Figure 4: Backscattered electron image of Tungsten particles

Advantages:

- It can be used to examine specimens of large thickness.
- It has large depth of focus.
- It can be used to get a three dimensional image of the object.
- Since the image can be directly viewed in the screen, structural details can be resolved in the precise manner.
- The magnification may be upto 3, 00,000 times greater than that of the size of the object.

Disadvantages:

The resolution of the image is limited to about 10-20 nm, hence it is very poor.

Applications:

- It is used to examine the structure of very large specimens in a three dimensional view.
- Similar to the application of electron microscope this SEM also has applications over various fields such as Biology, Industries, Engineering, Physics, Chemistry, etc.

PROBLEMS

1. **Calculate de-Broglie wavelength associated with a proton moving with a velocity equal to $\frac{1}{20}^{th}$ of the velocity of light.**

   Mass of proton = 1.675 x 10^{-27}kg

   Given data:

   Mass of proton m = 1.675 x 10^{-27}kg

   Velocity of proton v = $\frac{1}{20}$ x velocity of light

   $v = \frac{1}{20} \times 3\times10^{8}$

   $v = 15 \times 10^{6}$ m/s

   Solution:

   de-Broglie wavelength $\lambda = \frac{h}{mv}$

   $$\lambda = \frac{6.63\times10^{-34}}{1.675\times10^{-27}\times15\times10^{6}}$$

   $\boldsymbol{\lambda = 2.64 \times 10^{-14}}$ **m**

2. **Calculate the de-Broglie wavelength of an electron of energy 100 eV.**

   Given data:

   Energy of electron (E) = 100 eV =100 x 1.6 x 10^{-19} Joules

   E = 1.6 x 10^{-17} Joules

   Solution:

   de-Broglie wavelength $\lambda = \frac{h}{\sqrt{2mE}}$

   $$\lambda = \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-17}}}$$

   $\lambda = 1.227 \times 10^{-10}$ m

   $\boldsymbol{\lambda = 1.227}$**A°**

3. **An electron is accelerated by a potential of 150 V. what is the wavelength of that electron wave?**

   Given data:

   Accelerated potential of an electron (V) = 150 V

   Solution:

   de-Broglie wavelength $\lambda = \frac{h}{\sqrt{2meV}}$

   $$\lambda = \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}\times150}}$$

   $\lambda = 1.0018 \times 10^{-10}$m

   $\boldsymbol{\lambda = 1}$ **A°**

4. **Calculate the de-Broglie wavelength corresponding to the root mean square velocity of hydrogen molecules at 27°C.**

   Given data:

Temperature T = 27˚C = 300K

Mass of hydrogen = mass of proton = 1.678×10^{-27}kg

Solution:

de-Broglie wavelength $\lambda = \frac{h}{\sqrt{3mK_BT}}$

$$\lambda = \frac{6.63\times10^{-34}}{\sqrt{3\times1.678\times10^{-27}\times1.38\times10^{-23}\times300}}$$

λ = 1.451 A˚

5. An electron is confined to a one dimensional box of side 10^{-10}m. Obtain the first two Eigen values of the electron.

Given data:

Length of one dimensional box 'l' = 10^{-10}m

Solution:

1st Eigen value,

Eigen Energy of the particle (electron) $E_1 = \frac{1^2(6.63\times10^{-34})^2}{8\times9.1\times10^{-31}\times(10^{-10})^2}$

$E_1 = 6.022 \times 10^{-18}$J

(or) $\boldsymbol{E_1 = \frac{6.022\times10^{-18}}{1.6\times1.6^{-19}}}$ **= 37.63 eV**

2nd Eigen value,

Eigen Energy of the particle (electron) $\boldsymbol{E_2 = 2^2 E_1}$ **= 2.408 x 10^{-17}J = 150 eV**

(or) $E' = \frac{7.8002\times10^{-14}}{1.6\times10^{-19}}$

$$\mathbf{E' = 0.4875 \times 10^6\ eV}$$

6. Calculate the magnifying power of a microscope. Give that the angle subtended by the final image (β) is 40˚ at eye and the angle subtended by the object at the eye kept at the near point (α) is 10˚.

Given data:

β = 40˚; α = 10˚

Solution:

Magnifying power $M = \frac{\beta}{\alpha}$

Or $M = \frac{tan\beta}{tan\alpha}$

$= \frac{tan40°}{tan10°}$

∴ M**agnifying power M = 4.758**

QUESTIONS	OPTION 1	OPTION 2	OPTION 3	OPTION 4	ANSWERS
For destructive interference, path difference is	odd number of half	Even number of half wavelengths	whole number of half wavelengths	even whole number of half wavelengths	odd number of half wavelengths
Constructive interference happens when two waves are	out of phase	zero amplitude	in phase	in front	in phase
Two waves with phase difference 180° have resultant of amplitude	one	zero	same as the single wave	doubles as the single wave	zero
If two waves are in phase and have same amplitude then resultant wave has	half of amplitude of	same amplitude of single wave	twice of amplitude of single wave	thrice of amplitude of single wave	twice of amplitude of single wave
Extra distance travelled by one of waves compared with other is called	Path	displacement	phase difference	path difference	path difference
Interference of light is evidence that	the speed of light is very	light is a transverse wave	light is electromagnetic in	light is a wave phenomenon	light is a wave phenomenon
Scattering of white light in to constitute colours is called	Diffraction	Refraction	Reflection	Dispersion	Dispersion
With diffraction grating, angles are	small	Greater	Zero	close to zero	Greater
Effect of diffraction is greatest if waves pass through a gap with width equal to	Frequency	Wavelength	amplitude	none of the above	Wavelength
Spreading of wave as it passes through a gap (or) around an edge is called as	Diffraction	Refraction	Reflection	Superposition	Diffraction
When a thin film of oil (or) soap bubbles is illuminated with white light, multiple colours appears this is due to	Diffraction	Refraction	Reflection	Dispersion	Diffraction
In Fresnel bi prism experiment the central fringe is	Dark	Bright	black	White	Bright
Interference pattern is caused by superposition of -------------- waves.	One	Two	Three	none of the above	Two
Interference pattern all maxima have	same wavelength	same intensity	same frequency	coherence	same intensity
In fraunhofer diffraction, the diffraction wavefront is	Circle	spherical	elliptical	plane	plane
For interference pattern	width of dark and bright	width of dark and bright bands are not	width of dark bands only	width of bright bands only	width of dark and bright bands are equal
In Fresnel diffraction, the diffraction wave front is	planar	spherical	cylindrical	none of the above	cylindrical
Fringes are referred to as	minima	maxima	nodes	normal points	maxima
Color depends on what characteristic of light?	its frequency	its wavelength	both of these	neither of these	both of these

Diffraction is a result of	Refraction	Reflection	Dispersion	Interference	Interference
Waves diffract the most when their wavelength is	short	long	both diffract the same	very short	long
The effect in which white light separates into different colors is called	Magnification	Reflection	Dispersion	Refraction	Dispersion
Which principle explains the phenomenon of diffraction?	Principle of Simultaneity	Pascal's Principle	Archimedes' Principle	Huygen's principle	Huygen's principle
Which of the following explains the concept of diffraction loss?	Fresnel zone	Principle of Simultaneity	Pascal's Principle	Archimedes' Principle	Fresnel zone
Diffraction allows radio signals to propagate around	Continuous surface	Smooth surface	Curved surface of Earth	Does not allow propagation	Curved surface of Earth
The penetration of waves into the regions of the geometrical shadow is	interference	Dispersion	polarisation	diffraction	diffraction
Superposition of crest and trough results in	Constructive interference	Destructive interference	polarisation	diffraction	Destructive interference
Interference due to reflected light is also called _________ law	. sine law	cosine law	Tangent law	cotangent law	cosine law
Which of the following changes in interference of light?	Velocity	intensity	frequency	wavelength	velocity
Diffraction appears if the size of obstacle in path of rays is the order of	1mm	2mm	4mm	0	1mm
Interference of light is evidence that	The speed of light is very	light is a transverse wave	light is electromagnetic in	Light is a wave phenomenon	. Light is a wave phenomenon
In Fresnel diffraction	source of light is kept at infinite distance from	source of light is kept at finite distance from the aperture	Convex lens used	aperture width is selected so that it can acts as a point source	source of light is kept at finite distance from the aperture
The dark lines constituting the absorption spectrum exhibited by sunlight are frequently called	Fresnel lines	Fraunhofer lines	Fermi lines	Franklin lines	Fraunhofer lines
Colors in thin films are because of	Dispersion	. Interference	Compton effect	diffraction	Interference
For single slit Diffraction, the path difference between the two ends of the slit is	$\Delta = a \sin \theta$	$\Delta = a \cos \theta$	$\Delta = \cos \theta$	$\Delta = 0$	$\Delta = a \cos \theta$
Light travels fastest	In a vacuum	through water	Through glass	through diamond	In a vacuum
The grating used to observe, diffraction of visible light can have approximately __________.	300 lines per cm	3000 lines per cm	15000 lines per cm	30 lines per cm	15000 lines per cm
X-ray diffraction can be observed by using __________.	Diffraction Grating	Rock salt crystal	Convex lens	Michelson's interferometer	Diffraction Grating
There are two types of diffraction Fresnel and __________.	Michelson	Fraunhofer	Huygens	De Broglie	Fraunhofer
Why are diffraction gratings used instead of single slit or double slits to measure the wavelength of light?	Gratings provide a much wider	Gratings provide equal spacing between the maxima and minima	narrow diffraction maxima which can be	Gratings provide a much small diffraction maxima	narrow diffraction maxima which can be accurately
For diffraction gratings, 'd' represents	Spaces between antinodes in a diffraction pattern	Width of each one of the slits in the grating	The distance between the grating and the screen	Distance between each one of the slits in the grating	Width of each one of the slits in the grating
when white light is incident on a diffraction grating, the light that light will be deviated from central image	yellow	red	Violet	green	Red
dispersive power of a grating can be defined as	the increase in the angle of refraction corresponding to a change in wavelength	the increase in the angle of diffraction corresponding to a change in wavelength	the increase in the angle of incidence corresponding to a change in wavelength	the increase in the angle of interference corresponding to a change in wavelength	the increase in the angle of diffraction corresponding to a chnge in wavelength
a diffraction pattern is obtained using a beam of red light. What happens if the red light is replaced by blue light	no change	diffraction bands become narrower and crowded together	bands become broader and apart	bands is disappear	diffraction bands become narrower and crowded together

QUESTIONS	OPTION 1	OPTION 2
The radiation emission process can occur in ----------	One	Two
Which process gives the laser its special properties as	dispersion	Absorption
The lower energy level contains more atoms than	isothermal	Population inversion
Light amplification in the laser occurs when photon colliding with an excited	First photon	Second photon
Method of pumping used in Co_2 laser is	Optical pumping	directelectron excitation
The term "monochromatic" means	In phase	single wavelength
The population inversion takes place in	active center	active medium
The optical fibers have____________ band	Low	High
Active medium of homo junction semiconductor	silicon	P-type semiconductor
The term "coherence" means	in phase with same frequency	single wavelength
The path of light propagation in graded index	Zigzag	straight line
The principle of optical fiber communication is	Refraction	Diffraction
The dispersion will not occur in	Single mode fibers	Multimode fiber
What is the typical value of refractive index for an ethyl	1	1.36
If a light travels in a certain medium and it gets reflected off an optically denser	External Reflection	Internal Reflection
In an optical fiber, the concept of Numerical aperture is applicable in	Light Collection	Light Scattering
In Kerr effect, induced index change has its	square of electric field	cube of electric field
Which among the following is regarded as an inelastic	Kerr Effect	Raman Effect
In the fiber optic link, power transfer from one fiber to another and from	maximum	stable
In spontaneous emission, the light source in an	Moderate energy	Higher energy
Which among the following is a key process for light	Spontaneous Emission	Stimulated Emission
In the structure of fiber, the light is guided through the	Reflection	Refraction

In the structure of a fiber, which component provides additional strength and	Core	Cladding
With respect to single mode and graded index fibers, which parameter specifies the propagation of	Mode field diameter	Birefringence
What is the other name for maximum external incident	Optical angle	Total internal reflection angle
A single mode fibre has _________ intermodal	Low	high
How does the refractive index vary in Graded Index	Tangentially	Radially
Which of the following has more distortion?	Single step-index fibre	Graded index fibre
In which of the following there is no distortion?	Graded index fibre	Multimode step-index fibre
Which of the following loss occurs inside the fibre?	Radiative loss	Scattering
When more than one mode is propagating, how is it	Dispersion	Inter-modal dispersion
The loss in signal power as light travels down the fiber.	Attenuation	Scattering
It refers to the dielectric material of an optical fiber	cladding	shield
The core of an optical fiber has	medium index of refraction	medium with a lower index of refraction
Which of the following is a unique property of laser?	Directional	Speed
Which of the following is an example of optical	Ruby laser	Helium-Neon laser
Which of the following can be used for generation of	Ruby laser	Carbon dioxide laser
What is the need to achieve population inversion?	To excite most of the atoms	To bring most of the atoms to ground state
Principle of laser is	spontaneous absorption	stimulated emission
Laser light is intense because	it has very less number of Photons that in phase	it has very less number of Photons that are not in phase
The process of population inversion is to increase the	excited state	ground state
The number of atoms in the excited state becomes much greater than the number of	normal population	population inversion
The light from a laser source is monochromatic	are in phase	have same energy
In normal population, the number of atoms in the	excited state is more	ground state is more

In Ruby laser the atoms are excited by	ruby rod	flash tube
What does LASER stand for?	Light Amplification by Stimulated Emission of Radiation	Light Applied Scientifically to Super Rangers
What direction does a LASER move in	a straight light	backwards
what is laser made from	photons	energy
Which of the following is a property of LASERS?	coherence	Reflection
LASER travels at speed of	Sound	Cars
When electrons return to their ground state, the	Photons	Sound
Which process gives the laser its special properties as	Dispersion	Stimulated absorption
A semiconductor laser crystal of length 5 cm, refractive index 1.8 is used	2.8 GHz	1.2 GHz
Which of the following laser have high efficiency	Ruby	Semiconductor
A semiconductor diode Laser is also called as	Four level	Three level
Bending mode of vibration of the CO2 molecule gives	10° 0	01 °0,02° 0
Gallium Arsenide acts as optical resonator in homojuction semiconductor	.high refractive index	low refractive index

OPTION 3	OPTION 4	ANSWERS
Three	Four	Two
Spontaneous emission	stimulated emission	stimulated emission
Thermal equilibrium	Pumping	Thermal equilibrium
Third photon	Fourth photon	Second photon
direct conversion	chemical method	directelectron excitation
directional	intense	single wavelength
optical resonator	vacuum	active medium
Zero	Very narrow	High
N-type semiconductor	P-N junctiondiode	P-N junctiondiode
less angular speed	intense	in phase with same frequency
circle	helical	helical
Total internal reflection	Reflection	Total internal reflection
Step index fiber	Graded index fiber	Single mode fibers
2.6	3.4	1.36
Both a and b	Reflection	External Reflection
Light Dispersion	Light Polarization	Light Collection
cube root of electric field	one-fourth power of electric field	square of electric field
Hall Effect	Miller Effect	Raman Effect
minimum	unpredictable	maximum
Lower energy	Very Lower energy	Lower energy
Both a and b	Absorption	Stimulated Emission
Diffraction	Dispersion	Reflection

Buffer Coating	Core with Cladding	Buffer Coating
Fiber beat length	Spot Size	Birefringence
Refraction angle	Wave guide acceptance angle	Wave guide acceptance angle
Very high	Very low	Low
Longitudinally	Transversely	Radially
Multimode step-index fibre	Glass fibre	Multimode step-index fibre
Single step-index fibre	Glass fibre	Graded index fibre
Absorption	Attenuation	Scattering
Material dispersion	Waveguide dispersion	Inter-modal dispersion
Propagation	Absorption	Attenuation
cover	Buffer Coating	cladding
a lower index of refraction than the cladding	a higher index of refraction than the cladding	medium with a lower index of refraction
Coherence	Wavelength	Coherence
Semiconductor laser	Dye laser	Ruby laser
Helium-Neon laser	Nd- YAG laser	Nd- YAG laser
To achieve stable condition	To reduce the time of production of laser	To excite most of the atoms
Absorption	stimulated and induced emission	stimulated and induced emission
it has very large number of Photons that are in phase	it has very large number of Photons that are not in phase	it has very large number of Photons that are in phase
intermediate state	excited state and ground state	excited state
stimulated emission	spontaneous emission	population inversion
have same amplitude	are in the same direction	have same energy
ground state is zero	excited state is equal to the ground state	ground state is more

silvered mirror	semi-transparent mirror	flash tube
Local Access Service & Equipment Records	Light Amplification by Stimulated Energy of Radiation	Light Amplification by Stimulated Emission of Radiation
a wave	Vertical	a straight light
light	wind	light
Refraction	Deflection	coherence
light	Planes	light
LASER	Fusion	Photons
Spontaneous emission	Stimulated emission	Stimulated emission
1.6 GHz	2 GHz	1.6 GHz
He- Ne	Co2	Co2
Two level	one level	Two level
00 °1	00° 2,01° 0	01 °0,02° 0
high conductivity	high reflecting property	high refractive index

QUESTIONS	OPTION 1	OPTION 2
The ability of a material to remain magnetized after removal of the magnetizing	Retentivity	permeability
When the current through the coil of an electromagnet reverses, the	magnetic field collapses	magnetic field expands
An electromagnetic field exists only when there is	current	voltage
The Biot-savart's law is a general modification of	Kirchhoffs law	Lenz's law
The benefit of Maxwell equation is that	Any parameter can be calculated	Antenna can be designed
………….waves travels with the same velocity in all	O	E
…………….waves travels with the different velocity in	O	E
The curl of the electric field intensity is	Conservative	Rotational
Maxwell second equation is based on which law?	Ampere law	Faraday law
The first Maxwell law is based on which law?	Faraday and Lenz law	Ampere law
Resistivity of a wire depends on	length	material
Ampere second could be the unit of	power	conductance
Coulomb law is employed in	Electrostatics	Magnetostatics
Coulomb is the unit of which quantity?	Field strength	Permittivity
Coulomb law is only true for point charges whose sizes are	medium	very large
The Ampere law is based on which theorem?	Green's theorem	Gauss divergence theorem
Which of the following phenomena suggest that light	Reflection	Polarisation
In optics, when the vibrations of light are limited to a single two dimensional	Polarised	Plane polarised
Brewster's law in terms of refractive index can be	μ = sinip	μ = cosip
Which one is the example of uniaxial crystal?	Calcite & Tourmaline & Quartz	Piezo crystal
What happen if the ordinary unpolarised light is passed through a Uniaxial crystal	light is split into two rays	Light remain unaffected
Zone plate has some similarities as well as some	Plano convex lens	Concave lens
What happen to O and E rays if they travel along the optic Axis?	Both ray travel with the same velocity	O ray travels faster than E ray
Electric field vector vibrates in only one plane and perpendicular to the direction	plane polarised	unpolarised

The plane in which the electric field vector of plane polarised light vibrates is	Plane of vibration	Plane of Polarisation
The plane in which the magnetic field vector of plane polarised light vibrates	Plane of vibration	Plane of Polarisation
Plane of vibration is defined only for	plane polarised	unpolarised
If the light is made incident on any transparent medium at the polarising angle , the	unpolarised	plane polarised
If the light is made incident on any transparent medium at the polarizing angle , the	unpolarised	Plane polarised
The waves forming ordinary image are……….	unpolarised	Plane polarised
Principle planes in calcite crystals are……………	squares	rhombus
The shape of O -wave front is-----------	plane	spherical
The shape of E -wave front is-----------	Plane	spherical
The property of rotating the plane of vibration of plane	double refraction	optical activity
Which is the following used to convert Unpolarised light	Nicol Prism	Calcite prism
In double refraction, the vibrations of E ray are confined in	Plane perpendicular to the principle section	Principle section
If Ve the velocity of E-ray and Vo is the velocity of O ray in a negative crystal they	Vo > Ve	Vo < Ve
The Nicol prism based on the action of	reflection	Double refraction
O and E waves travel with the same velocity --------------	parallel to the surface	Perpendicular to the surface
If the light is incident on a transparent material at the polarizing angle of 600	45 degree	60 degree
If the cross-sectional area of a magnetic field increases, but the flux remains the	Doubles	Increases
When the north poles of two bar magnets are brought	no force	a downward force
The direction of a magnetic field within a magnet is	front to back	from north to south

OPTION 3	OPTION 4	ANSWERS
hysteresis	Spontaneous Magnetisation	Spontaneous Magnetisation
direction of the magnetic field remains unchanged	direction of the magnetic field reverses	direction of the magnetic field reverses
decreasing current	an increasing current	current
Ampere’s law	Faraday’s laws	Ampere’s law
Polarisation of the wave can be calculated	Transmission line constants can be found	Any parameter can be calculated
O and E	Neither O nor E	O
O and E	Neither O nor E	E
Divergent	Static	Rotational
Lenz law	Coulomb law	Ampere law
Coulomb law	Lenz law	Faraday and Lenz law
cross section area	Thickness	material
energy	charge.	charge.
Electromagnetics	Maxwell theory	Electrostatics
Force	charge.	charge.
very small	small	very small
Stoke’s theorem	Maxwell theorem	Stoke’s theorem
Photoelectric effect	Diffraction	Polarisation
Partially polarised	Unpolarised	Polarised
μ = tanip	μ = cotip	μ = tanip
Zinc	Led	Calcite & Tourmaline & Quartz
light is split into more than two rays	Reflection	light is split into two rays
grating	Convex lens	Convex lens
E ray travel faster than O ray	E ray travel very faster than O ray	Both ray travel with the same velocity
both plane polarised & unpolarised	neither plane polarised & nor unpolarised	plane polarised

principal Plane	Plane of Refraction	Plane of vibration
Principal Plane	None of above	Plane of Polarisation
both plane polarised & unpolarised	neither plane polarised & nor unpolarised	plane polarised
partially Polarised	Polarised	plane polarised
partially Polarised	Circularly Polarized	partially Polarised
Circularly Polarized	partially Polarised	plane polarised
triangles	parallelograms	parallelograms
elliptical	cylindrical	spherical
elliptical	cylindrical	elliptical
polarization	Dichroism	optical activity
Tourmaline crystal	None of the above	Nicol Prism
at an angle θ to the principle section	keeps on changing orientation	Principle section
Vo = Ve D	None of the above	Vo < Ve
refraction	scattering	Double refraction
along optic axis	none of the above	along optic axis
30 degree	90 degree	30 degree
decreses	remains the same	decreses
a force of attraction	a force of repulsion	a force of repulsion
back to front	from south to north	from south to north

QUESTIONS	OPTION 1	OPTION 2	OPTION 3
_____________molecules have permanent dipole moment even in the absence of an applied field	non-polar	polar	dielectric
______________ molecules do not have permanent dipole moment.	non-polar	polar	dielectric
The properties of dielectric materials is _________	large insulation resistance	low insulation resistance	very low insulation resistance
The induced dipole moment (μ) is ℓ __________	charge × displacement	charge ×voltage	voltage×displacement
w is called as ______	angular frequency	dipole moment	mass
The another name of the internal field is ___________	Clausius-Mosotti	lorentz field	electric field
The ferro-electrics are used in ________	SONAR	LASER	MASER
The dielectric strength is ____________	dielectric voltage/thickness of dielectric	thickness of dielectric/ dielectric voltage	dielectric current/ thickness of dielectric
For solids the dielectric constant is -------	Less than one	greater than one	equal to one
Example for polar molecule is -------	CHCl3	CCl4	H2
The following molecules will not have centre of symmetry.	Polar	non polar	symmetric molecules
Polar molecules have ------ dipole moments.	induced	permanent	temporary
The relaxation times are -------- for different kinds of polarisations	same	different	remains constant

The materials which have negatve temperature co-efficient of resistance is known as------	Dielectrics	insulators	conductors
Dielectric constant for water at 0 ° C is -------	87.8	88.7	787.8
Monoatomic gases exhibit ----- type of polarisation.	Ionic	Space charge	electronic
Dielectric loss occurs in ------	only in direct voltage	only in alternating voltage	Both in alternating & direct voltages
Ferroelectrics are ----- crystals	isotropic	Anisotropic	isomorphic
which of the following material have spontaneous polarisation?	ferromagnetic	paramagnetic	ferroelectric
The dielectric constant reaches a maximum value at --------	curie temperature	neel temperature	absolute temperature
The materials which are used to produce ultrasonics is -----	ferro magnetic	antiferromagnetic	ferro electric
The domain structure of ferro electric is similar to --------- material.	ferro magnetic	dia magnetic	para magnetic
Dielectrics follows --------- effect	piezo electric	inverse piezo electric	magnetostriction
Dielectrics are ------ materials .	non metallic	metallic	semiconducting
Dielectrics are also called as ----- .	conductors	semiconductors	insulators
The ratio between absolute permitivity to the permitivity of free space is known as	dielectric	dielectric constant	relative permeability
The material which restricts the flow of electrical energy is known as--------	dielectrics	active dielectrics	passive dielectrics

The following molecules will have centre of symmetry.	Polar	non polar	symmetric molecules
The polarisation of polar molecules is highly -------- dependent.	temperature	pressure	volume
The following molecules are not having absorption or emission in the infrared range.	polar molecules	non polar molecules	infrared molecules
The presence of parallel alignment of magnetic dipole moment is given by which materials?	Diamagnetic	Ferromagnetic	Paramagnetic
The magnetic materials follow which law?	Faraday's law	Ampere law	Lenz law
In which materials the magnetic anisotropy is	Diamagnetic	Ferromagnetic	Paramagnetic
Piezoelectric effect is analogous to which	Electrostriction	Magnetostriction	Anisotropy
Te materials having very small	Antiferromagnetic	Diamagnetic	Ferromagnetic
The susceptibility is independent of	Anti Ferromagnetic	Diamagnetic	Ferromagnetic
A permeable substance is one	which is a goo d conductor	which is a bad conductor	which is a strong magnet
The materials having low retentivity are	weak magnets	temporary magnets	permanent magnets
A magnetic field exists around	iron	copper	aluminium
Ferrites are materials	paramagnetic	Diamagnetic	Ferromagnetic
The direction of magnetic lines of force	from south pole to north pole	from north pole to south pole	from one end of the magnet to another
Which of the following is a vector quantity ?	Magnetic potential	Relative permeability	Magnetic field intensity
A material which is slightly repelled by a	Diamagnetic	Ferromagnetic material	Paramagnetic material
The ratio of intensity of magnetisation to the	flux density	susceptibility	relative permeability
The unit of relative permeability is	henry per metre	henry	hentry per square meter
Materials subjected to rapid reversal of	large area of B-H loop	high permeability and low hysteresis loss	high co-ercivity and high retentivity

The main constituent of permalloy is	cobalt	chromium	nickel
Ferrites are a sub-group of	non-magnetic materials	ferro-magnetic materials	paramagnetic materials
Which of the following is expected to have the maximum permeability ?	Brass	Copper	Zinc
Magnetic moment is a	pole strength	universal constant	scalar quantity
The magnetic materials exhibit the property of magnetisation because of	orbital motion of electrons	spin of electrons	spin of nucleus
For which of the following materials the net magnetic moment should be zero ?	Diamagnetic	Ferromagnetic material	Paramagnetic material
Paramagnetic materials have relative permeability	slightly less than unity	equal to unity	slightly more than unity
Ferromagnets contain all of the following except:	Nickel	Cobalt	Gold

OPTION 4	ANSWERS
dipole moment	polar
dipole moment	non-polar
very large insulation resistance	large insulation resistance
voltage×current	charge × displacement
current	angular frequency
magnetic field	lorentz field
Capacitor	SONAR
thickness of dielectric/ dielectric current	dielectric voltage/thickness of dielectric
equal to zero	greater than one
CO_2	$CHCl_3$
insulating	Polar
unstable	permanent
fixed value	different

resistors	Dielectrics
71.8	87.8
orientation	electronic
Neithear ac nor dc	Both in alternating & direct voltages
symmetric	Anisotropic
Diamagnet	ferroelectric
fixed tekperature	curie temperature
Diamagnet	ferro electric
anti ferromagnetic	ferro magnetic
magnetostatic	inverse piezo electric
conducting	non metallic
resistors	insulators
relative permitivity	dielectric constant
none of the above.	passive dielectrics

insulating	non polar
shape	temperature
visible	polar molecules
Anti Ferromagnetic	Ferromagnetic
Curie Weiss law	**Curie Weiss law**
Anti Ferromagnetic	Ferromagnetic
Magnetization	Magnetostriction
Paramagnetic	Antiferromagnetic
Paramagnetic	Diamagnetic
through which the magnetic lines of force can pass very easily	through which the magnetic lines of force can pass very easily
strong magnet	temporary magnets
moving charges	moving charges
Antiferromagnetic	Ferromagnetic
none of the above.	from north pole to south pole
Flux density	Magnetic field intensity
conducting material	Diamagnetic material
none of the above.	susceptibility
it is dimensionless	it is dimensionless
high co-ercivity and low density	high permeability and low hysteresis loss

tungsten	nickel
ferri-magnetic materials	ferri-magnetic materials
Ebonite	Ebonite
vector quantity	vector quantity
all of the above	spin of nucleus
Antiferromagnetic materials	Antiferromagnetic materials
equal to that ferromagnetic mate rials	slightly more than unity
Iron	Gold

QUESTIONS	OPTION 1	OPTION 2	OPTION 3
Waves associated with electrons are referred to as	plasma waves	UV waves	gamma rays
Frequency below which no electrons are emitted from metal surface is	minimum frequency	angular frequency	maximum frequency
Loss of energy of an electron results in	absorption of photon	emission of photon	destruction of photon
According to Newton, light travels as	particles	waves	both A and B
In electron diffraction, rings behave as	particles	waves	both A and B
Energy absorbed by electron is used in	escaping the metal	increasing kinetic energy	both A and B
Diffraction of slow moving electrons is used to estimate	arrangement of atoms in metals	nature of atoms	number of atoms in metals
Energy of photon is directly related to the	wavelength	wave number	frequency
When a charged particle is accelerated through a	decreases	remains same	increases
Energy of an electron in an atom is	quantized	continuous	radial
In dark, LDR has	low resistance	high current	high resistance
Electrons show diffraction effects because their de Broglie	spacing between atomic layers	no. of atomic layers	nature of atomic layers
Plank's constant has units	J	s	J /s
Gas atoms that exert negligible electrical	molecules	compounds	isotopes
Quantum of electromagnetic energy	particles	photons	waves
In photoelectric effect, electrons should be removed from the	inner shells	surface	from core
Light interacts with matter as	wave	particle	both A and B
When white light is passed through cool gases, spectra observed is called	line spectra	continuous spectra	emission line spectra

Wavelength of ultraviolet region of electromagnetic spectrum is	121 nm	120 nm	119 nm
In an insulator, valence band is	fully occupied	fully empty	half filled
Most energetic photons are	alpha	beta	gamma
Which of the following colors is associated with the lowest temperature of a black body radiator?	Violet	Blue	Green
Classical physics could not explain the behavior of a black body radiator at very short wavelengths. What was this problem called?	Absorption failure	Ultraviolet Explosion	Wavelength decrease
What did Max Planck propose to solve the black body radiator problem?	Radiation is made up of waves.	Light changes its speed in different media.	Light comes in packets of energy.
The energy of a photon depends on its:	Amplitude	Speed	Temperature
How does the energy of a photon change if the wavelength is doubled?	Doubles	Quadruples	Stays the same
How does the momentum of a photon change if the wavelength is halved?	Doubles	Quadruples	Stays the same
The photoelectric effect was explained by Albert Einstein by assuming that:	light is a wave.	light is a particle.	an electron behaves as a wave.
The kinetic energy of photoelectrons depends on the:	speed of light.	angle of illumination.	intensity of the light.
When an electron falls from an orbit where n = 2 to n = 1:	A photon is emitted.	A photon is absorbed.	No change in atomic energy.

When an electron jumps from an orbit where n = 1 to n = 4, its energy in terms of the energy of the ground level (E_1) is:	E1/9	2 E 0	2 E1
The Compton Effect supports which of the following theories?	Special Theory of Relativity.	Light is a wave.	Thomson model of the atom.
Which one of the following objects, moving at the same speed, has the greatest de Broglie wavelength?	Neutron	Electron	Tennis ball
Which theory explains the interaction of photons with matter (electrons)?	Quantum Chromodynamics	The Standard Model	String Theory
Which theory explains the attraction between protons and neutrons?	Quantum Chromodynamics	The Grand Unified Theory	The Standard Model.
How much of the universe is comprised of matter and energy that is explained by current Physics theory?	95 percentage	75percentage	50percentage
A perfect black body is one which _________________ all the radiations.	absorbs	emits	absorbs and emits
The classical theory was not able to explain the________	diffraction	interference	emission of black body radiation
The wave nature associated with a material particle is called as ___________	standing wave	progressive wave	transverse wave
The relation between energy and the momentum of the photon is________	P is equal to EC	Eis equal toP/C	C is equal toEP

According to de-broglie wave equation, when velocity of the particle increases wavelength will be____________.	doubles	increases	decreases
A particle in one dimensional box at the walls of the box, the wave function will be____________.	zero	increases	decreases
A perfect black body is a perfect absorber and radiator of____________ radiation.	monochromatic	all wavelengths of the given	coherent
The source used in the SEM is ____________.	electrical source	chemical source	neutron gun
For a free particle, the potential energy is____________.	0	1	2
According to ____________ theory, the hydrogen spectrum is a discrete spectrum.	classical	electromagnetic	quantum
The equation of motion of matter wave was derived by	Heisenberg	Bohr	de Broglie

OPTION 4	ANSWERS		
matter waves	matter waves		
threshold frequency	threshold frequency		
formation of photon	emission of photon		
dust	particles		
rays	waves		
increasing frequency	both A and B		
position of atoms in metalloids	arrangement of atoms in metals		
amplitude	frequency		
varies depending on resistance of wire	increases		
randomized	quantized		
both A and B	high resistance		
positioning of atomic layers	spacing between atomic layers		
J s	J s		
isolated atoms	isolated atoms		
energy	surface		
the nucleus	surface		
rays	particle		
absorption line spectra	absorption line spectra		

130 nm	121 nm
half charged	fully occupied
x-rays	gamma
Red	Red
Photoelectric Effect	Ultraviolet Explosion
Light has a continuous energy profile.	Light comes in packets of energy.
Frequency	Frequency
Is cut to one-half	Is cut to one-half
Is cut to one-half	Doubles
an electron behaves as a particle.	light is a particle.
photon frequency.	photon frequency.
The atomic energy increases.	A photon is emitted.

16 E1	16 E1
Light is a particle.	Light is a particle.
Bowling ball	Electron
Quantum Electrodynamics	Quantum Electrodynamics
String Theory	Quantum Chromodynamics
5 percentage	5 percentage
reflects	absorbs and emits
diffraction and interference	emission of black body radiation
matter wave	matter wave
E is equal to PC	E is equal toPC

zero	decreases
Infinity	zero
polychromatic	all wavelengths of the given
electron gun	electron gun
3	0
wave	quantum
Schrodinger	Schrodinger