I BSC SEMESTER-II

PHYSICS STUDY MATERIAL

2022-2023

Department of Physics

Sri Y.N.College (A)

Narsapur

B.Sc., First Year, SEMESTER - 2

PHYSICS

(WAVE OPTICS)

(STUDY MATERIAL

&

MODEL PAPERS)

SYLLABUS

B.Sc., First Year, SEMESTER - II
For Mathematics Combinations
(2020-21 Batch onwards)

PHYSICS : II Semester

Course-II : WAVE OPTICS

UNIT - I Interference of light

Introduction, Conditions for interference of light Interference of light by division of wave front and amplitude, Phase change on reflection-Stokes' treatiment, Lioyd's single mirror, Interference in thin films : Plane parallel and wedge-shaped films, colours in thin films, Newton's rings in reflected light-Theory and experiment, Determination of wavelength

UNIT - II Diffraction of light

Introduction, Types of diffraction : Fresnel and Fraunhoffer diffractions, Distinction between Fresnel and Fraunhoffer diffraction, Fraunhoffer diffraction at a single slit, plane diffraction grating, Determination of wavelength of light using diffraction grating, Resolving power of grating. Fresnel's half period zones, Explaration of rectilinear propagation of light, Zone plate, comparison of zone plate with convex lens.

UNIT - III Polarization of light

Polarized light : Methods of production of plane polarized light, Double refraction, Brewster's law, Malus law, Nicol prism, Nicol prism as polarizer and analyzer, Quarter wave plate, Half wave plate, Plane, Circularly and Elliptically polarized light production and detection, Optical activity, Laurent's half shade polarimeter : determination of specific rotation, Basic principle of LCDs.

UNIT - IV Aberrations and Fibre Optics

Monochromatic aberrations, Spherical aberration, Methods of minimizing spherical aberration, Coma, Astigmatism and Curvature of field, Distortion : Chromatic aberration-the achromatic doublet : Achromatism for two lenses i) in contact and ii) separated by a distance.

Fibre optics : Introduction to Fibers, different types of fibers, rays and modes in an optical fiber, Principles of fiber communication (qualitative treatment only), Advantages of fiber optic communication.

UNIT - V Lasers and Holography

Lasers : Introduction, Spontaneous emission, stimulated emission, Population Inversion, Laser principle, Einstein coefficients. Types of lasers-He-Ne laser : Ruby laser, Applications of lasers ; Holography : Basic principle of holography, Applications of holography.

PHYSICS (WAVE OPTICS) PRACTICALS

Minimum of 6 experiments to be done and recorded

1. Determination of radius of curvature of a given convex lens-Newton's rings.
2. Resolving power of grating.
3. Study of optical rotation - polarimeter.
4. Dispersive power of a prism.
5. Determination of wavelength of light using diffraction grating-minimum deviation method.
6. Determination of wavelength of light using diffraction grating-normal incidence method.
7. Resolving power of a telescope.
8. Refractive index of a liquid-hallow prism.
9. Determination of thickness of a thin wire by wedge method
10. Determination of refractive index of liquid-Boy's method.

SHORT ANSWER QUESTIONS

1. What is polarisation of Light? Explain plane of vibration and plane of polarisation.
2. State and prove Brewster's Law.
3. Law of Malus.
4. Explain Huygen's theory of double refraction.
5. Explain Quarter wave and half wave plates ?

UNIT - IV : ABBERATIONS AND FIBRE OPTICS

LONG ANSWER QUESTIONS

1. What is meant by spherical aberration ? Explain how we minimized the spherical aberration?
2. State and explain chromatic aberration and derive equation for longitudinal chromatic aberration.
3. Explain the defect "Coma" in a lens. How is it reduced?
4. What is an Optical fibre ? Describe construction and working principle of Optical Fibre.
5. Explain the system for fibre optics communication ?

SHORT ANSWER QUESTIONS

1. Write a note on "Astigmatism".
2. Explain about curvature ? (or) Write a short note on Curvature ?
3. Write a short note on distortion ?
4. How is the chromatic aberration minimised in achromatic doublet?
5. Derive the condition for minimum chromatic aberration when two lenses made up of same material are co-axially separated by a distanced.
6. Explain the types of optical fibres ?
7. Explain Ray and optic representation of optical fibre ?
8. What are the applications of Fibre optics?

UNIT - V : LASERS AND HOLOGRAPHY

LONG ANSWER QUESTIONS

1. Derive the relation between Einstein coefficients.
2. Describe the construction and working of Ruby Laser ?
3. Describe the construction and working of He-Ne laser ?
4. Write an essay on Holography ?

SHORT ANSWER QUESTIONS

1. State and explain spontaneous and stimulated emission of radiation.
2. Distinguish between spontaneous and stimulated emission.
3. Give a brief note on Population inversion.
4. Explain the principle of Laser ?
5. What are the applications of Laser?

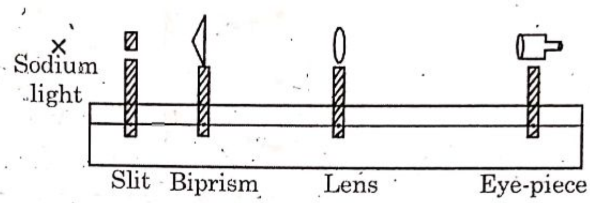
UNIT - I
INTERFERENCE OF LIGHT

LONGANSWER QUESTIONS

Q. 1. Describe Fresnel's biprism method for producing interference finger and determining the wavelength of light ?

Ans : Fresnel's experimental arrangement consists of an optical bench carrying three or four stands, the first for an adjustable slit, second for bi-prism and the third for a micrometer eye-piece. These stands can be moved along and as well as in lateral directions.

A biprism is having two acute base angles and the abtuse angle of the prism is about 179^0. The action of biprism is to produce two coherent virtual sources of light from single source of light.



The slit is illuminated by monochromatic light. This light from slit falls on the bi-prism. At the biprism the beam is divided into two coherent beams. They appear as if they are coming from two virtual sources S_1 and S_2. Thus S_1 and S_2 act as coherent sources and the distance between them is '$2d$'. The interference fringes are obtained in the overlaping region and can be seen by eye-piece. Proper adjustments are done for clear and sustained interference pattern.

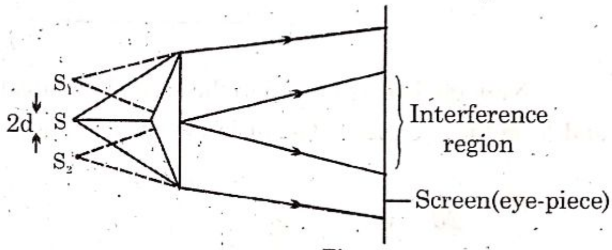


Fig.

The wavelength, λ can be determined by the following formula, $\lambda = \frac{\beta.2d}{D}$

When the eye–piece is at a distance, D_1 corresponding bandwidth is β_1. Similarly when the eye-piece is at D_2. The band width is β_2.

Then $\lambda = \frac{\beta_1.2d}{D_1}$

$$\lambda = \frac{\beta_2.2d}{D_2}$$

From the above equations,

$$\lambda = \frac{2d(\beta_2 - \beta_1)}{(D_2 - D_1)}$$

In order to determine the wavelength of light, the following measurements are made.

To measure bandwidth (β_1 & β_2) : The vertical cross wire of the eye-piece is adjusted on any bright fringe and the reading on the scale of eyepiece R_1 is noted. The eye-piece screw is slowly rotated so that N–number of fringes cross the vertical wire and again scale reading R_2 is noted. Now the width of each band $\beta = \frac{R_1 \sim R_2}{N}$ is calculated. In this way the eye-piece is placed at a distance D_1 and corresponding bandwidth β_1 is calculated. Again the eye-piece is moved to the second position D_2 and the bandwidth, β_2 is calculated.

To measure the value of '2d' : Lens displacement method is used to measure the distance between two coherent sources, $2d$. The distance between the source, S and the eye-piece is fixed. A convex lens of focal-length, f is placed between biprism and the eye-piece. The position of the lens is adjusted so that clear and magnified images of S_1 and S_2 are seen in the eye-piece.

The distance between the images of S_1 and S_2 is measured as d_1 in the eye-piece.

Then, $$\frac{d_1}{2d} = \frac{\upsilon}{u} \qquad \text{-----(1)}$$

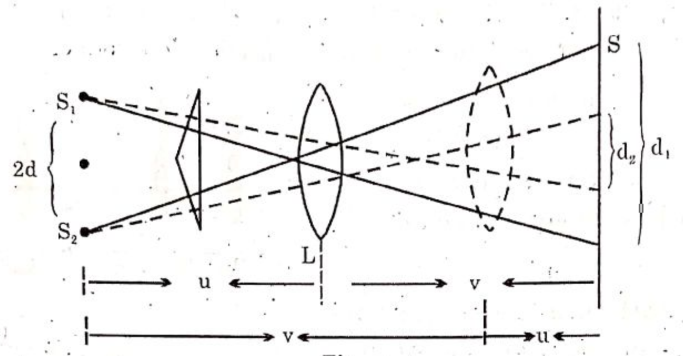


Fig.

Now the lens is moved to the second conjugate position. Again we see the diminished images of S_1 and S_2 in the eye-piece. The distance between them is measured as d_2 in the eye-piece.

Then $$\frac{d_2}{2d} = \frac{u}{\upsilon} \qquad \text{-----(2)}$$

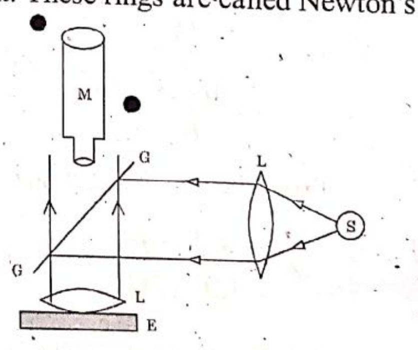
From (1) and (2)

$$2d = \sqrt{d_1 d_2}$$

Substituting the values of 2d, β_1, β_2, D_1 and D_2 in the formula, wavelength of given monochromatic source can be determined.

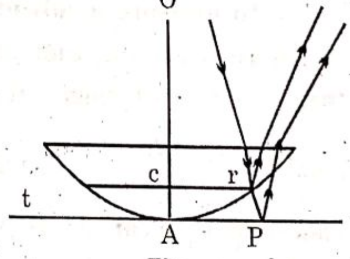
Q. 2. Describe Newton ring's experiment and explain how to measure wavelength of given light.

Ans : When a convex lens of large radius of curvature is placed on a plane glass plate, an air film is formed between the upper surface of the plate and the lower surface of the lens. If this film is illuminated by a monochromatic light falling normally to the film then a system of alternate bright and dark concentric rings are observed in the reflected light and also in the transmitted light. These rings are called Newton's rings.



Fig

In the experiment to observe Newton's rings a convex lens L is kept in contact with the plane glass plate E. The light from a monochromatic source S is rendered parallel by a lens L_1 and is made to fall normally on the convex lens with the help of a plane glass plate GG. After passing through the lens the light gets reflected at the lower surface of the lens L and at the upper surface of the glass plate E. These two reflected waves interfere with each other and the interference pattern can be observed with a travelling microscope M. Since the surface of the lens is spherical, the thickness of the air film will be constant over a circle whose centre is the point of contact and we will obtain concentric dark and bright rings.



Fig

The intensity at a point depends upon the path difference t between the rays reflected from the upper and lower surfaces of the film at that point. Let t be the thickness of the air film at a point. Then the path difference is given by

$$\delta = 2nt\cos\theta^{1} + \frac{\lambda}{2}$$

Since one of the reflection is at a denser medium $\frac{\lambda}{2}$ is added. For normal incidence the angle of refraction $\theta^{1} = 0$ and for air n = 1.

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

(At the point of contact, t = 0. i.e., at the point, A dark spot will be formed)

If this path difference

$$2t + \frac{\lambda}{2} = m\lambda \text{ or } t = (2m-1)\frac{\lambda}{4} \quad \text{-----(2)}$$

a bright ring is formed or if

$$2t + \frac{\lambda}{2} = \left(m + \frac{1}{2}\right)\lambda \text{ or } t = \frac{m\lambda}{2} \quad \text{-----(3)}$$

a dark ring is formed.

Diameter of the rings :

Let the radius of curvature of the convex surface *PAQ* be *R* and let *r* be the radius of the ring *PQ* with centre *C*. Let '*t*' be the thickness of the air film at this ring.

Fig.

Geometrically,

$$AC \times CB = PC \times CQ$$

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

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

As t is small, t^2 can be neglected

$$\therefore 2Rt = r^2$$

$$\therefore t = \frac{r^2}{2R} \quad \text{------(4)}$$

From (2) for a bright ring

$$\frac{r^2}{2R} = (2m-1)\frac{\lambda}{4}$$

$$\therefore r^2 = (2m-1)\frac{R\lambda}{2}$$

$$r = \sqrt{\frac{R\lambda}{2}}\left(\sqrt{2m-1}\right)$$

This give the radius of the mth bright ring

$$\therefore r_m = \sqrt{\frac{R\lambda}{2}}\sqrt{2m-1}$$

The diameter (D_m) of the mth bright ring is given by

$$D_m = \sqrt{2R\lambda}\,\sqrt{2m-1} \qquad \text{-----(5)}$$

From (3) for a dark ring

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

$$\therefore r = \sqrt{R\lambda}\,\sqrt{m}$$

The diameter (D_m) of the mth dark ring.

$$D_m = \sqrt{4R\lambda}\,\sqrt{m} \qquad \text{----(6)}$$

i.e $D_m \propto \sqrt{m}$

Thus the diameters of the dark rings are proportional to their natural numbers.

Wavelength of light : Let D_m and D_n be the diameters of mth and nth dark rings. Then from (6)

$$D_m^2 = 4\,R\lambda m$$

$$D_n^2 = 4\,R\lambda n$$

$$\therefore D_m^2 - D_n^2 = 4\,R\lambda(m-n)$$

i.e., $(D_m - D_n)(D_m + D_n) = 4R\lambda(m-n)$

If D_m and D_n are two consequent bright bands, then "$D_m - D_n$" is the bright band width and $\frac{(D_m + D_n)}{2}$ gives the distance of the bright band from the centre.

i.e., $D_m + D_n = 2D$.

$$\therefore \text{Bandwidth, } \beta = D_m - D_n = \frac{4R\lambda}{2D}$$

$$\text{i.e., } \beta = \frac{2R\lambda}{D}$$

Thus, as the distance of the band from the centre, D increases, the band width, β decreases.

If we draw a graph between the number of the ring m, on the x-axis and square of corresponding ring diameter D^2 on a straight line will be obtained.

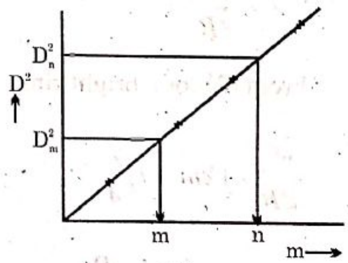


Fig.

From the graph, squares of diameters of two rings, say D_m^2 and D_n^2 corresponding to mth and nth rings are noted and substituted in the formula.

$$\lambda = \frac{D_n^2 - D_m^2}{4(n-m)R}$$

Wavelength of the given monochromatic light source can be determined.

Q. 3. *Describe the Working principle of Michelson Interferometer and explain its uses.*

Ans : Interferometers are the instruments based on the principle of interference. Prof.A.A.Michelson designed the interfero-meter and used to determine monochromatic wavelength, thickness and refractive index of thin transparent film, standardisation of meter and so on.

Description :

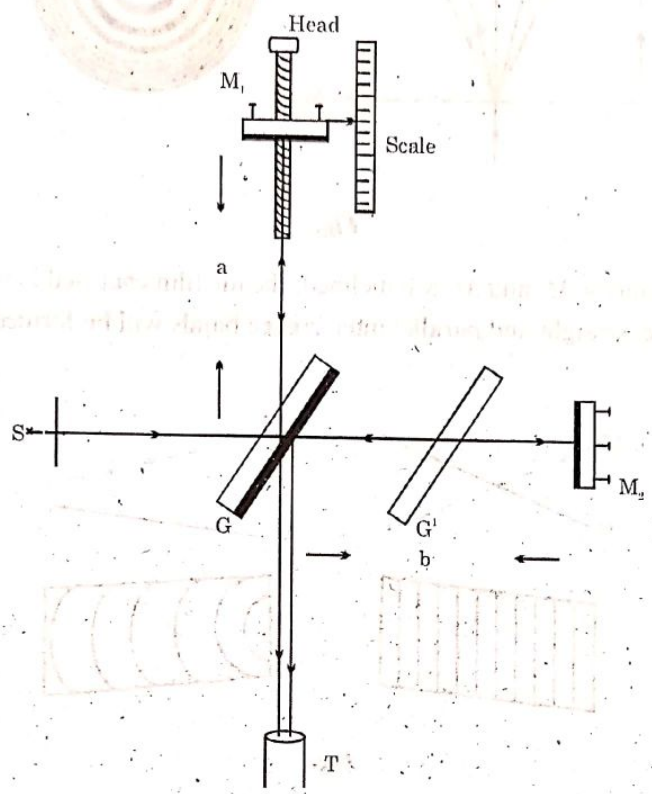


Fig. .

Interferometer consists of two plane mirrors M_1 and M_2 arranged perfectly perpendicular at distances of a and b respectively from semi transparent mirror G. M_2 is fixed while M_1 can be moved on a vertical scale.

Compensating glass plate, G^1 is parallel to 'G'. The interference fringes will be observed through Telescope, T.

Working : The light from extended source, s falls on the semi silvered mirror G. At G_1 the incident beam gives rise to reflected and transmitted beams of nearly equal intensity. These two beams incident on M_1 and M_2 mirrors respectively and then get reflected from them. These two beams recombine at G and enter the telescope T. These two beams are coherent and so produce interference pattern. The beam is reflected from the rear surface of the mirror, G it passes twice through the mirror, G. Thus if the ray acquires extra optical path. This extra optical path is compensated by the glass plate 'G^1' placed between G and M_2.

When we observe through Telescope, the image M_2^1 of mirror M_2 will be formed parallel to M_1. Hence the system is optically equivalent to the interference from an air film.

From the orientation of mirrors M_1 and M_2 two cases arise.

Case i) When mirrors M_1 and M_2 are perfectly perpendicular to each other, there M_1 and the image of M_2 are parallel to each other. The air film between M_1 and M_2^1 is a uniform film of thickness t i.e., $a \sim b = t$

The path difference between two beam will be $2t \cos\theta$

For a particular value of 'θ' , if $2t \cos\theta = n\lambda$ bright circular ring will be formed. Thus the interference pattern will be a concentric circular rings.

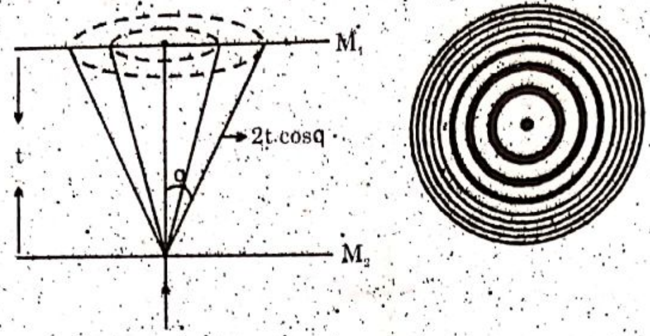


Fig.

Case ii) When the mirror M_1 and M_2 are inclined, the air film enclosed is wedge shaped. When the air film is a perfect wedge, straight and parallel interference bands will be formed. In other positions, the fringes are curved.

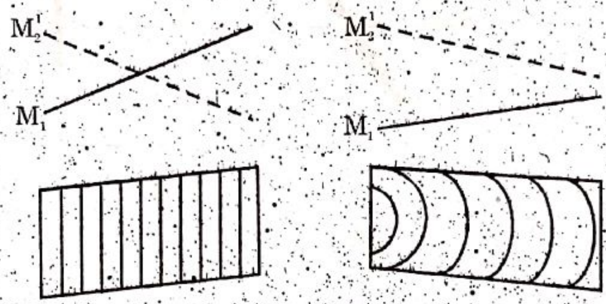


Fig.

Uses : Michelson interferometer has been used for a variety of purposes.

i) Wavelength measurement ; The mirrors M_1 and M_2 are adjusted so that circular fringes are seen in the field of view. The condition for interference is

$2t \cos\theta = n\lambda$. or $(2n\pm 1)\,\lambda/2$

The position of mirror M_1 is noted as R_1. When the mirror M_1 is moved through a distance, $\lambda/2$, next interference spot (Bright or dark) appears at the centre. The mirror is moved so that N–bright or dark spots appear at the centre and its position R reading R_2 is noted.

There $N.\frac{\lambda}{2} = R_2 \sim R_1 = x$

$\therefore \lambda = \frac{2x}{N}$

ii) Determination of Thickness of Thin film ; In the interferometer cross wire is set on bright fringe. The given transparent film of thickness 't' and refractive index, μ is inserted in the path of one of the interfering beams. This film increases the path by $2(\mu\text{-}1)t$. As a result, the fringe pattern is shifted. The mirror M_1 is moved through a distance 'x' so that the fringes are brought back to their initial position.

$\therefore\ 2x = 2\,(\mu-1)t$

And also, $x = N\frac{\lambda}{2}$, where N is no.of fringes shifted.

$\therefore x = (\mu - 1)t$

or $N.\frac{\lambda}{2} = (\mu - 1)t$

From above equations, if μ is known, t can be calculated.

iii) Standardisation of meter : The 'meter' can be standardised in terms of wavelength of cadmium red light. The mirror M_1 is moved through a standard 1 cm and the number of fringes crossing . The field of view is noted. And thus the number of fringes can be estimated for 1 meter. Thus the meter is standardised.

Q. 4 . Describe an experimental arrangement for calculating wavelength of light using LIOYd's mirror ? What are differences between Lloyd's mirror and Fresnel's biprism producing interference finger.

Ans : **LIOyd's mirror :** The experimental arrangement of LIOyd's mirror is shown in fig.

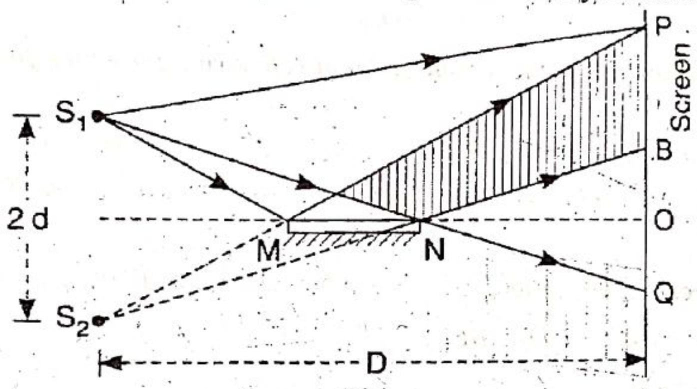


Fig.

It consists of a plane mirror MN polished on the front surface and blackened at the back to avoid multiple reflections. Light from a narrow slot S_1, illuminated by a monochromatic source of light, is allowed to incident on mirror almost at grazing angle. The reflected beam appears to diverge from S_2, which is virtual image of S_1. Thus S_2 and S_1 act as two coherent sources. The direct care of light PS_1Q and reflected cone of light PS_2 B Super impose over each other and produces interference finger in overlapping region PB of the screen.

Determination of wavelength : LIOYd's mirror is mounted vertically on an uplight of an optical bench and placed along the length of the bench on another uplight, a narrow vertical slit is mounted which is illuminated by a monochromatic source of light. Now the mirror is rotated about an axis parallel to the length of bench until distinct fringes are observed in a micro meter eyepiece. The plane of the mirror is now exactly parallel to the length of the slit.

The fringe width β is measured by micrometer eyepiece. The distance 2d between the two virtual sources is measured by displacement method using a convex lens. The distance D between screen and slit is measured by meter scale.

The wave length of monochromatic source of light is calculated by using the following formula

$$\beta = \frac{\lambda D}{2d}$$

(or) $$\lambda = \frac{\beta\,(2d)}{D}$$

Distinction between biprism and LIoyd's mirror finger : 1. In biprism arrangement, the complete pattern of interference fingers is obtained on the other hand, in LIoyd's mirror arrangement ordinarily a few fringe itself being invisible.

2. Using a monochromatic light, the central fringe of biprism arrangement is white while the central fringe of Lloyd's mirror arrangement is dark.

3. The central fringe in biprism is less sharp than in LIOyd's mirror.

4. Incase of Lloyd's mirror the condition of constructive and destructive interference are reversed than those of biprism experiment due to phase change of π in reflected beam.

5. In biprism experiment, the fringe width is the same for all pairs of coherent sources. In Lloyd's mirror arrangement (2d) is different for different pairs of coherent sources and hence fringe width is different for different pairs of coherent sources.

6. Using white light, biprism produces a number of limited coloured fringes with central white fringe while the Lioyd's mirror produces a number of black and white fringes with central dark fringe.

Q. 5.Explain how Interference in thin films formed by reflected and transmitted light ? Obtain the condition to fulfill the interference condition for maxima and minima.

(Or)

Deduce the Cosine law for both transmitted and reflected light which forms interference in thin films ?

Ans : **Cosine law :** *GH* and *GH'* are the two surfaces of a transparent film of uniform thickness *t*. μ is the refractive index. *AB* is the monochromatic light ray. *BR* is reflected ray and *BC* is refracted ray. DR_1 is the emergent ray.

To find out the effective path difference between the rays *BR* and DR_1 draw a normal *DE* on *BR*.

Path difference $= \Delta = \mu(BC+CD) - BE$ -----(1)

From the figure we have

$$\cos r = \frac{CF}{BC} \text{ or } \frac{t}{BC} = \cos r$$

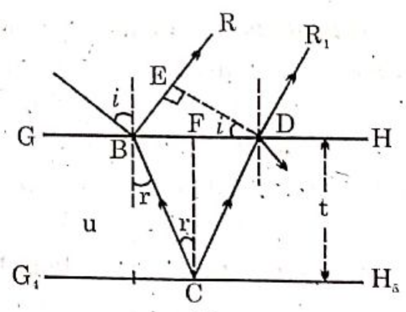


Fig.

$$\therefore BC = CD = \frac{t}{\cos r} \quad ....(2)$$

Also $BD = (BF+FD)$

Consider the Δle BFC,

$$\tan r = \frac{BF}{FC} \text{ (or) } \frac{BF}{t} = \tan r$$

BF = t tan *r*

BD = BF + FD = 2B = 2t tan *r* (∴ BF=FD)

$$\text{Consider the } \Delta le\ BED = \frac{BE}{BD} = \text{Sin } i$$

or, $BE = BD \sin i$

$= 2t \tan r \sin i$

We have, $\frac{\sin i}{\sin r} = \mu$ (or) $\sin i = \mu \sin r$

$\therefore BE = 2t \tan r\ (\mu \sin r)$

$\therefore BE = 2\mu t \tan r \sin r$ ......(3)

From equations (1), (2) and (3) we have

$\Delta = \mu(BC+CD) - BE$

$= \mu\left(\frac{2t}{\cos r}\right) - 2\mu t \tan r \sin r$

$= \frac{2\mu t}{\cos r} - 2\mu t\frac{\sin^2 r}{\cos r} = \frac{2\mu t}{\cos r}\left[1-\sin^2 r\right]$

$\Delta = \frac{2\mu t}{\cos r}\cos^2 r$

$\Delta = 2\mu t \cos r$ ----(4)

This is known as "Cosine law".

Interference pattern in the reflected light : The ray BR is reflected from denser medium. So, it suffers an abrupt phase change of π or path difference $\lambda/2$.

$\therefore$ The effective path difference between BR and DR_1 rays is

$\Delta = 2\mu t \cos r \pm \lambda/2$

For bright band,

$\Delta = 2\mu t \cos r \pm \lambda/2 = n\lambda$

or $2\mu t \cos r = (2n \pm 1)\lambda/2$ ----(5)

Similarly for dark band,

$2\mu t \cos r = n\lambda$ ----(6)

Thus in the reflected light alternate bright and dark bands will be formed.

Interference in the transmitted light : Due to simultanious reflection and refraction, two transmitted rays CT and ET_1 will be obtained.

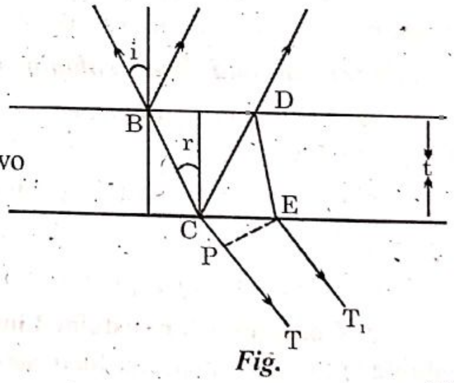


Fig.

From the geometry of figure, the path difference between two transmitted rays will be

$\Delta = \mu(CD + DE) - C_P$

$= 2\mu t \cos r$

If $2\mu t \cos r = n\lambda$ -----(7)

Bright band will be formed.

or $2\mu t \cos r = (2x \pm 1)\frac{\lambda}{2}$ -----(8)

Dark band will be formed. From equations (5), (6), (7), (8) of a bright band is formed at the point of incident of light ray in reflected light, dark band will be formed in the transmitted light. Thus the interference pattern in reflected light is complementary to that formed in transmitted light.

SHORT ANSWER QUESTIONS

Q. 1. What is meant by Coherence ? Explain about spatial and temporal Coherence ?

Ans : **Coherence :** The two sources which maintain zero or any constant phase relation between themselves are known as coherent sources. This phenomenon is known as coherence.

Coherence is the basic need for permanent interference pattern. We have also studied the intensity distribution function when two waves from two sources. So purpose at a certain point. The phase conditions at that point are determined by the following two factors.

1. Phase condition of two sources and
2. Phase relation developed in their journey towards the super position point.

These are two factors to produce interference i.e. Spatial Coherence and temporal Coherence.

a) Spatial Coherence : Let S_1 and S_2 be two atomic emitters (sources) and be a point of observation.

The path difference $(S_2P - S_1P) = 2d \ \sin\theta$. If the path difference (say Δ) is equal or less than $C \times 10^{-9}$ i.e.

$S_2P - S_1P = C = 2d \sin\theta \leq c \times 10^{-9}$.

Then the two sources are said to maintain spatial coherence. Here c, is velocity of light.

For spatial Coherence

$\Delta t \leq 10^{-9}$ sec

(or) $S_2P - S_1P \leq c \times 10^{-9}$.

b) Temporal Coherence : Consider the situation in which the path of one beam is extended. This can be done by introducing a transparent shut in one path or taking the point of observation at a large distance. It is observed that if the path difference exceeds the coherence $l_c = C\, t_c$, then the interference finger lose sharpness or contrast now we say that the beam lack in temporal coherence.

To obtain a permanent interference pattern with sufficient contrast, both spatial coherence and temporal coherence are necessary.

Q. 2. Write the conditions to obtain sustained interference pattern of light ?

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

a) Conditions for sustained interference.

b) Conditions for observation of the fingers.

c) Conditions for good contrast between maxima and minima.

a) Conditions for sustained interference : 1. 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.

2. The two sources must emit continuous waves of the same wave length and time period.

b) Conditions for observation :

1. The separation between the two sources (2d) should be small.
2. The distance Δ between the two sources and screen should be large.
3. The back ground should be dark.

c) Conditions for good contrast :

1. The amplitude of the interfering waves should be equal or nearly equal.
2. The sources must be narrow i.e. they must be extremely small.
3. The sources should be mono chromatic.

Q. 3. What is Interference ? Explain types of Interference.

Ans : **Definition :** When two light waves superimpose, then the resultant amplitude in the region of super position is different than the amplitude of individual waves. This modification in the distribution of intensity in the region of super position is called "Interference".

Types of Interference : The phenomenon of interference is divided into two classes namely1. Division of wavefront and 2. Division of amplitude.

1. Division of wavefront : The incident wavefront is divided into two parts by utilising the phenomena of reflection, refraction or diffraction. These two parts of the same wavefront travel unequal distances and reunited at some angle to produce interference bands. The Fresnel Bisprism, Lloyyd's mirror etc., are the examples of this class.

2. Division of amplitude : The amplitude of the incoming beam is divided into two parts either by parallel reflection or refraction. These divided pars reunits after traversing different paths and produce interference. In this case, it is not essential to employ a point or a narro line source but a broad light source may be employed to produce brighter hands. Newton's rings, Michelson's interferometer etc., come under this class.

Q. 4.Discuss the phase, change on reflection of light from the surface of a Denser Medium? (Stoke's theorem)

Ans : According to the principle of reversibility of light, a reflected ray or a refracted ray will retrace its original path if its direction is reversed, of course in the absence of any absorption.

Consider a light ray incident on an interface of two media of refractive indices m_1 and m_2.

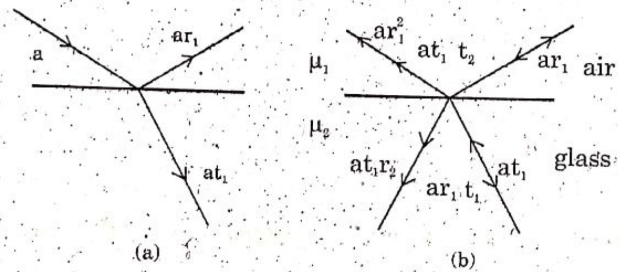


Fig.

When the light ray is incident from (1) on (2) let the amplitude reflection and transmission coefficients be r_1 and t_1 respectively. Thus, if the amplitude of the incident ray is a, then the amplitude of the reflected beam is ar_1 and the amplitude of the refracted beam is at_1.

Now, let us reverse the reflected and the refracted rays. First let the reflected ray of amplitude ar_1 be reversed. This is now travelling from medium (1) to (2). Hence the coefficient of the amplitude of the reflected ray would be ar_1^2 and the coefficient of the refracted ray would be ar_1t_1.

Next reverse the refracted ray of amplitude at_1. Let r_2 and t_2 be the coefficient of reflection and transmission when the light ray falls from(2) to (1). Hence for this ray, the amplitude of the reflected ray would be at_1r_2 and the amplitude of the refracted ray would be at_1t_2.

According to the principle of optical reversibility the rays of amplitudes ar_1^2 and at_1t_2 must combine to give the incident ray of amplitude a.

Thus, $ar_1^2 + at_1t_2 = a$

or $t_1t_2 = 1 - r_1^2$ -----(1)

and the two rays of amplitudes ar_1t_1 and at_1r_2 must cancel each other.

$\therefore\ at_1r_2 + ar_1t_1 = 0$

or $r_2 = -r_1$ ------(2)

eqn.(2) implies that the two reflection coefficients must be negative. Lioyd's mirror proved that the reflection coefficient when the ray travels from rarer to denser medium is negative. Equations(1) and (2) are known *Stoke's* relations.

According to eqn. (2), when a light ray is reflected from denser medium, phase reversal takes place.

Q. 5. Explain the formation of colours in thin film ?

Ans : When a thin film is exposed to a white light, beautiful colours are observed. The incident light get reflected from upper and lower surface of the film. These rays interfere forming colours. At a particular point of the film, for a particular position of the eye, a particular wavelength of light satisfy the condition for bright band. That colour will be seen

Condition for bright band,

$$2\mu t \cos r = n\lambda$$

for a phase difference, $\delta = \frac{2\pi}{\lambda}(2\mu t \cos r)$.

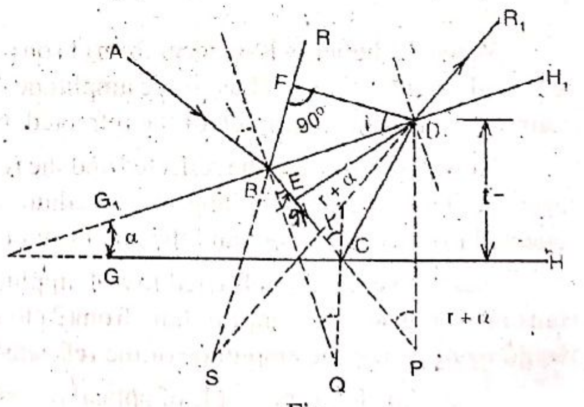
The observed colour will depend on thickness, angle , r and position of eye. In thin films colours will be observed due to formation of Haidinger or isocline fringes, fringes of equal chromatic order or Fizean of fringes of equal thickness.

When a monochromatic light is incident on a wedge shaped film, equally spaced dark and bright fringes formed. The fringe width depends upon the wedge angle wavelength of light and the refractive index of the film. Instead of monochromatic light if we use polychromatic light we will observe coloured fringes. Further, if instead of a wedge we have a film of an arbitrary varying thickness we will again observe fringes, each fringe representing the locus of constant film thickness. This is indeed what we see when sun light falls on a soap bubble.

If the optical path difference between the waves reflected from the two surfaces of the film exceeds a few wavelengths, the interference pattern will be washed out due to the overlapping of interference patterns of many colours. Thus in order to see the fringes with white light, the film should not be more than few wavelengths thick.

Q. 6. Describe how interference formed by wedge -shaped films and obtain the condition for nature of Interference.

Ans : Consider two plane surfaces GH & G_1H_1 inclined at an angle α and enclosing a wedge shaped air film. The thickness of air film increasing from G to H as shown in fig.



Fig

Let μ be the reflactive index of the material of this film. This film is illuminated by sodium light, then the interference between two systems of says, are reflected from the front surface and the other obtained by internal reflection at the back surface and consequent transmission at the first surface takes place from fig the interfering waves B R and DR_1 are not parallel but appear to diverge from a point S.

The path difference between these two waves given by

$$\Delta = \mu(BC + CD) - BF \qquad (\because BF = \mu BE)$$

$$= \mu(BE + EC + CD) - \mu BE$$

$$= \mu(EC + CD) - \mu EP$$

$$= 2\mu t \cos(r + \alpha) \qquad \text{.......(1)}$$

Due to reflection an additional phase difference is introduced i.e. $\lambda/2$

$\therefore \Delta = 2\mu t \cos(r+\alpha) \pm \lambda/2$ ....(2)

For constructive interference $\Delta = n\lambda$

$2\mu t \, Cos\,(r+\alpha) \pm \lambda/2 = n\lambda$

$\therefore 2\mu t \, Cos\,(r+\alpha) = (2n \pm 1)\, \lambda/2$ ....(3)

For destructive interference

$\Delta = (2n \pm 1)\, \lambda/2$

$2\mu t \cos(r+\alpha) \pm \lambda/2 = (2n \pm 1)\, \lambda/2$

$2\mu t \cos(r+\alpha) = n\lambda$ ....(4)

Where n = 0,1,2,3...

Nature of interference pattern : When light is illuminating the film is parallel then i is constant everywhere and so is r, the angle of reflaction. If the light is monochromatic, the path change will occur only due to 't'. In the case of a wedge shaped film, t remains constant only in direction parallel to the thin edge of wedge hence the straight fringes parallel to the edge of the wedge are obtained.

Thus bright or dark fringes are obtained here as the condition of the thickness t is satisfied according to equations (3) and (4) respectively.

Spacing between two consecutive bright bands :

For n^{th} maxima, we have

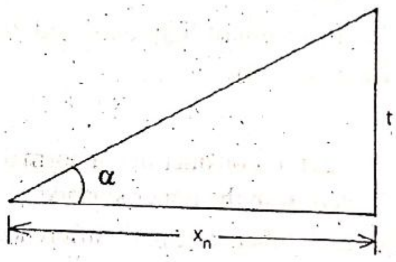
$2\mu t \cos(r+\alpha) = (2n+1)\, \lambda/2$

For normal incidence and air film

$r = 0$ and $\mu = 1$

$2t \cos \alpha = (2n+1)\, \lambda/2$ ....(5)

Let this band be obtained at a distance X_n from the thin edge as shown in fig.



Fig

From fig

$t = X_n \tan \alpha$ ....(6)

From eqn's 5 & 6

$2x_n \tan \alpha \; Cos\, \alpha = (2n+1)\, \lambda/2$

$2x_n \, Sin\, \alpha = (2n+1)\, \lambda/2$ ....(7)

If the (n+1)th maximum is obtained at a distance x_{n+1} from the thin edge

$2x_{n+1} \, Sin\, \alpha = [2(n+1)+1]\, \lambda/2$

$= [2n+3]\, \lambda/2$ ....(8)

Subtracting equations 8 from 7 we get

$2(x_{n+1} - x_n)\, Sin\, \alpha = \lambda$

Spacing $\beta = x_{n+1} - x_n$

$$\therefore \beta = \frac{\lambda}{2\, Sin\alpha} = \frac{\lambda}{2\alpha}$$

Where α is small and measure in radians. As the fringe width is independent of n all bright fringes are equally spaced.

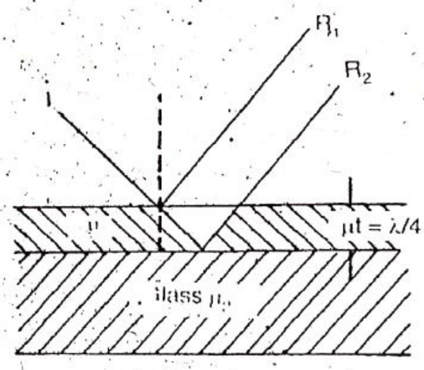
Q. 7.Explain Non reflecting films using neat sketch.

Ans : Let us consider a ray of light travelling in a medium of refractive index ((say air) is incident normally on a substance of refractive index ((say glass). Let I be the intensity of incident light and I_r the intensity of reflected light. Then according to Fresnel's equations.

$$I_r = \left(\frac{\mu_2 - \mu_1}{\mu_2 + \mu_1}\right)^2 I \quad or \quad \frac{I_r}{I}\left(\frac{\mu_2 - \mu_1}{\mu_2 + \mu_1}\right)^2 \qquad \text{.......(1)}$$

For air-glass surface ($\mu_1 = 1$ and $\mu_2 = 1.5$), $I_r / I = 4\%$. This gives that only 96% of the incident light is transmitted. In optical instruments such as compound microscope, telescope, camera lenses etc., a combination of lenses is employed. When the light enters the optical instrument at the glass air interface, light is lost by reflection. At a single reflection about 4% of the incident light is lost. In the achromatic objective of the telescope is made of four lenses (light surfaces), about 30% of the incident light is reflected and only about 70% is transmitted. These reflection losses are undersirable especially under low intensity conditions.

In order to reduce the reflection loss from the surface, a transparent film of proper thickness, is deposited on the surface. This film is known as non reflecting film. This discovery was made by German Physicist Alexander Smakula. The best coated material known is magnesium fluoride MgF_2 because its refractive index (1.38) lies between those of air and glass. In general the thickness of the coating material should be $\lambda / 4\mu$ where λ is the wavelength of light used and μ is the refractive index of the coated material.



Fig

Let us consider that a normal ray of light is incident on the film of MgF_2 coated on glass. This ray is reflected from the upper surface as well as from the lower surface of MgF_2. These reflected rays interfere with each other. The path difference is $2\mu t$ where r is the thickness of the film. It should be remembered that at these two reflections phase reversal takes place so, if path difference is equal to $(2n + 1)\frac{\lambda}{2}$, where n = 0, 1, 2, 3.... destructive interference will take place and for n = 0 we have

$$2\mu t = \frac{\lambda}{2} \quad \therefore t = \frac{\lambda}{4\mu}$$

So the thickness of the film must be $\lambda / 4\mu$.

SOLVED PROBLEMS

Q. 1. Two narrow and parallel slits 1 mm a part are illuminated by monochromatic light. Fringes formed on the screen held at a distance of 100 cm from the slits are 0.5 mm a part. Calculate the wavelength of the light.

Solution : Given that $D = 100\ cm$ $2d = 1mm = 0.1\ cm$ $\beta = 0.05\ cm$

Wavelength, $\lambda = \frac{\beta \times 2d}{D}$

$\therefore \lambda = \frac{0.05 \times 0.1}{100} = 5 \times 10^{-5}\ cm = 5000\ AU.$

Q. 2. Light passes through narrow slits with a separation of 0.4 mm. On a screen 1.6 m away. The distance between two second order maxima is 2.5 mm. Calculate the wavelength of light used.

Solution : Given that $\beta = 0.25\ cm$ $2d = 0.04\ cm$ $D = 1.6\ cm$

$\therefore$ Wavelength, $\lambda = \frac{\beta \times 2d}{D}$

$= \frac{0.25 \times 0.04}{1.6} = 6.25 \times 10^{-5}\ cm = 6250\ AU.$

Q. 3. In bi–prism experiment interference fringes of width 0.0149cm are observed at a distance of 50 cm from the slits. The separation between the two images obtained for the two positions of the convex lens are 10.33 mm and 0.43 mm respectively. Calculate the wavelength.

Solution : Given that $d_1 = 1.033\ cm$; $d_2 = 0.043\ cm$

$D = 50\ cm$; $\beta = 0.0149\ cm$

$\therefore$ The distance between two coherent slits,

$$2d = \sqrt{d_1 d_2} = \sqrt{1.033 \times 0.043} = 0.21\ cm$$

Wavelength, $\lambda = \frac{\beta \times 2d}{D} = \frac{0.21 \times 0.0149}{50} = 6.258 \times 10^{-5}\ cm = 6258\ AU.$

Q. 4. Fresnel Bi–prism angle is 1^0 and refractive index, 1.5 forms interference fringes on the screen at a distance of 80 cm from the prism. The distance between the prism and the slit is 30 cms. The wavelength of light is 5000AU. Find the fringe width.

Solution : Given that $A = 1^0$ $ad = 30$ cm

$D = 30 + 80 = 110$ cm

$a = 30$ cm

Distance between two coherent sources, $2d = \frac{2a(\mu - 1)A \times \pi}{180}$

$$\therefore 2d = \frac{2 \times 30(0.5)3.14}{180} = 0.523cm$$

$\therefore$ Band width, $\beta = \frac{\lambda D}{2d} = \frac{5 \times 10^{-5} \times 110}{0.523} = 0.0105\ cm$

Q. 5. 20 fringes are displaced when a thin glass plate of refractive index 1.5 is introduced in one of the interfering beam. Find its thickness. (wavelength of light used 6000 AU)

Solution : Given that, $n = 20$ $\lambda = 6 \times 10^{-5}\ cm$.

$(\mu - 1)t = n\lambda$

$\therefore$ Thickness, $t = \frac{n\lambda}{(\mu - 1)} = \frac{20 \times 6 \times 10^{-5}}{(1.5 - 1)} = 24 \times 10^{-4}\ cm$

Q. 6. Magnesium fluoride has refractive index of 1.38 and is used to coat lens. How thick this coating should be for maximum transmittance at a wavelength of 530 nm?

Solution : Given that $\mu = 1.38$; $\lambda = 5.30\ nm = 5300 \times 10^{-8} cm$

Required thickness, $t = \frac{\lambda}{4\mu}$

$\therefore t = \frac{5300 \times 10^{-8}}{4 \times 1.38} = 0.9601 \times 10^{-5}\ cm$.

Q. 7. White light falls normally on a film of soapy water of refractive index 1.33 and thickness 5×10^{-7} m. which wavelength in the visible region will be reflected most strongly.

Solution : Given that, $t = 5 \times 10^{-7}$ m.

For normal incidence, $\cos r = 1$

Visible region is from 4000 to 7800 AU.

condition for maxima in the reflected light

$$2\mu t \cos r = (2x+1)\frac{\lambda}{2} \qquad \lambda = \frac{4\mu t}{2x+1} = \frac{4 \times 1.33 \times 5 \times 10^{-7}}{(2x+1)}$$

For n = 0,1,2,3,-----, a series of reflecting wavelengths will be obtained.

$\therefore$ for n = 0, $\lambda_1 = 26.6 \times 10^{-7}$ m

for n = 1, $\lambda_2 = 8.86 \times 10^{-7}$ m

n = 2, $\lambda_3 = 5.32 \times 10^{-7}$ m

n = 3 $\lambda_4 = 3.8 \times 10^{-7}$ m and so on

From the above series, 5.32×10^{-7} m. Only wavelength which lies in the visible region.

Q. 8. A parallel beam of sodium light of wavelength 5890 A' strikes a thin oil film floating on water. When viewed at an angle of 30° from normal, 8th dark band is observed. Find the thickness of the film (μ of oil is 1.46)

Solution : Given that $i = 30^0$; $\mu = 1.46$,

$n = 8$; $\lambda = 5890 \times 10^{-10}$ m

$$\therefore 2\mu t \cos r = n\lambda \qquad t = \frac{n\lambda}{2\mu \cos(r)}$$

$$\text{But } \cos r = \sqrt{1 - \sin^2 r} \text{ and } \mu = \frac{\sin i}{\sin r}$$

$$\therefore \cos r = \sqrt{1 - \frac{\sin^2 i}{\mu^2}} = \left[\frac{\mu^2 - \sin^2 i}{\mu^2}\right]^{1/2}$$

$$\therefore t = \frac{8 \times 5890 \times 10^{-10}}{2\left[(1.46)^2 - (1/2)^2\right]^{1/2}} = 17.18 \times 10^{-7} m$$

Q. 9. A light of wavelength 6000 AU incident normally on a wedge film of refractive index 1.4. Then interference bands of width 1.5 mm are formed in the reflected light. Calculate the angle of the wedge.

Solution : Given that $\beta = 0.15$ cm, $\mu = 1.4$ $\lambda = 6000 \times 10^{-8}$ cm

We know that $\beta = \frac{\lambda}{2\mu\alpha}$ or $\alpha = \frac{\lambda}{2\mu\beta}$

$$= \frac{6000 \times 10^{-8}}{2 \times 1.4 \times 0.15} = 1.428 \times 10^{-4} rad.$$

= 29.46 seconds of an arc.

Q. 10. In Newton ring's experiment, the diameters for 5th and 25th ring's are 0.3 cm and 0.8 cm respectively. The radius of curvature of convex lens is 100 cm. Find the wavelength of light used.

Solution : Given that $D_{25} = 0.8$ cm ; $D_5 = 0.3$ cm ; R = 100 cm

We know that $\lambda = \frac{D_m^2 - D_n^2}{4(m-n)R}$

$$\therefore \lambda = \frac{D_{25}^2 - D_5^2}{4(25-5)100}$$

$$\lambda = \frac{(0.8)^2 - (0.3)^2}{4(25-5)100} = 4.87 \times 10^{-5}\ cm$$

Q. 11. The diameter of 9th dark ring in Newton ring's experiment is 0.28 cms. Calculate the diameter of 16th dark ring.

Solution : Given that $D_9 = 0.28\ cm$, $D_{16} = ?$

We know that $\frac{D_m^2}{D_n^2} = \frac{m}{n}$

$$\therefore D_n^2 = D_m^2 \cdot \frac{n}{m}$$

$$D_{16}^2 = D_9^2 \cdot \frac{16}{9} = (0.28)^2 \cdot \frac{16}{9}$$

$$\therefore D_{16} = 0.28\left(\frac{4}{3}\right) = 0.3733\ cm.$$

Q. 12. The diameter of with bright ring in Newton ring's experiment changes from 1.4 to 1.27 cm as a liquid is introduced between the lens and the glass plate. Find the refractive index of the liquid.

Solution : The diameter of nth bright ring is given by

$$\mu D_n^2 = 4R(2n-1)\frac{\lambda}{2}$$

For air film, $1 \times (1.4)^2 = 4R(2n-1)\frac{\lambda}{2}$ ——(1)

For liquid film, $\mu(1.27)^2 = 4R(2n-1)\frac{\lambda}{2}$ ——(2)

From (1) and (2) $\frac{\mu(1.27)^2}{1(1.4)^2} = 1$

$$\therefore \mu = \left(\frac{1.4}{1.27}\right)^2 = 1.215$$

Q. 13. Newton rings are formed by sodium light and viewed normally. What will be the order of the dark ring with will have double the diameter that of 40th ring?

Solution : We know that $D_m^2 = 4m\lambda R$

$$\therefore D_{40}^2 = 4 \times 40 \times \lambda R$$ ——(1)

Let n be the order of the ring for which $D_n = 2D_{40}$

$$\therefore D_n^2 = 4 \times n \times \lambda R$$

$$\therefore (2D_{40})^2 = 4 \times n \times \lambda R$$ ——(2)

From (1) and (2) $\frac{D_n^2}{D_{40}^2} = \frac{n}{40}$ $\left(\frac{2D_{40}}{D_{40}}\right)^2 = \frac{n}{40}$

$$4 = \frac{n}{40}$$

$$\therefore n = 4 \times 40 = 160$$

Q. 14. In Newton's rings experiment, the diameters of 4th and 12th dark rings are 0.4 cm and 0.7 cm respectively. Find the diameter of 20th ring.

Solution : We know that

$$D_m^2 - D_n^2 = 4(m-n)\lambda R \quad \text{---(1)}$$

$$\therefore \; D_{12}^2 - D_4^2 = 4(12-4)\lambda R \quad \text{---(2)}$$

$$D_{20}^2 - D_4^2 = 4(20-4)\lambda R$$

From (1) and (2),

$$\frac{D_{20}^2 - D_4^2}{D_{12}^2 - D_4^2} = \frac{4\times16\times\lambda R}{4\times8\times\lambda R} = 2$$

$$\therefore \; D_{20}^2 - D_4^2 = \left[(0.7)^2 - (0.4)^2\right] 2$$

$$D_{20}^2 - 0.16 = 0.66 \qquad D_{20}^2 = 0.16 + 0.66 = 0.82 \qquad D_{20} = \sqrt{0.82} = 0.906\ cm$$

Q. 15. ***Newton rings are formed with a source emitting two wavelengths $\lambda_1 = 6000\ A^0$ and $\lambda_2 = 4500\ A^0$ and is found that n^{th} dark ring due to λ_1 is in coincidence with $(n+1)^{th}$ dark ring due to λ_2. Find the order of the ring due to λ_1. Which is coinciding with other ring.***

Solution : The diameter of n^{th} dark ring due to λ_1 is $D_n^2 = 4n\lambda_1 R$

And the diameter of $(n+1)^{th}$ dark ring due to λ_2 is $D_{n+1}^2 = 4(n+1)\lambda_2 R$

From the give condition, $D_n^2 = \left(D_{n+1}^2\right)$ due to λ_2

$\therefore\ 4n\lambda_1 R = 4(n+1)\lambda_2 R. \qquad n\lambda_1 = (n+1)\lambda_2$

$$\therefore \; n = \frac{\lambda_2}{\lambda_1 - \lambda_2} = \frac{4500}{6000-4500} = 3.$$

Q. 16. ***In Michelson interferometer, 200 fringes cross the field of view when the movable mirror is displaced through 0.0589 mm. Calculate the wavelength of light used.***

Solution : Here, $x_2 - x_1 = 0.0589\ \text{mm} = 0.00589\ \text{cm}$

$N = 200$

$$\therefore \; \lambda = \frac{2(x_2 - x_1)}{N} = \frac{2\times0.00589}{200} = 5890\times10^{-8} = 5890\ A^0$$

Q. 17. ***Circular fringes are observed in Michelson interferometer illuminated with a light of wavelength 5896 A^0. When the path difference between the mirrors M_1 and M_2 is 0.3 cm, the central fringe is bright. Calculate the angular diameter of 7^{th} fringe.***

Solution : For circular fringes, $2d\cos r = n\lambda$ At centre, $r = 0$

$\therefore\ 2d = n\lambda$ ---(1)

Here n is the order of central fringe. The outer 7^{th} fringe order is $(n-6)$.

Let 'θ' be the angular radius of $(n-6)^{th}$ fringe,

Then, $2d\cos\theta = (n-6)\lambda \qquad 2d\cos\theta = n\lambda - 6\lambda = 2d - 6\lambda.$

$2d(1-\cos\theta) = 6\lambda$

$$\cos\theta = 1 - \frac{6\lambda}{2d} \qquad \cos\theta = 1 - \frac{6\times5896\times10^{-8}}{2\times0.3} = 0.9994$$

$\theta = \cos^{-1}(0.9994) = 2^0$

$\therefore$ Angular diameter of 7^{th} ring is 4^0.

18. Calculate the distance between two successive positions of movable mirror in Michelson interferometer for which we get coincidence of fringes due to sodium light ($\lambda_1 = 5896\ A^0$, $\lambda_2 = 5890\ A^0$)

Solution : If 'd' be the distance between two positions of the mirror for which we get coincidence of fringes,

$$d = \frac{\lambda_1\lambda_2}{2(\lambda_1 \sim \lambda_2)} = \frac{5896\times10^{-8}\times5890\times10^{-8}}{2\left(6\times10^{-8}\right)} = 0.29\ cm.$$

— O —

UNIT - II

DIFFRACTION OF LIGHT

LONG ANSWER QUESTIONS

Q. 1.Explain with necessory theory Fraunhofer diffraction at single slit?

Ans : Fig represents a section AB of a Narrowslit of width e Perpendicular to the plane of the paper. Let a plane wave front ww1 of monochromatc light of wavelength λ propagating normally to the slit be incident on it. Let the diffracted light be focussed by means of a convex lens on a screen placed in the focal plane of the lens. Here every slit on the plane is acts as a secondary source. These sources spread out the spherical wavelets in all directions. The secondary wavelets travelling at an angle θ with the normal are focussed at a point P_1 on the screen. The point P_1 is of the minimum in intensity or maximum intensity depending upon the path difference between the secondary waves originating from the corresponding points of the wav- f---t

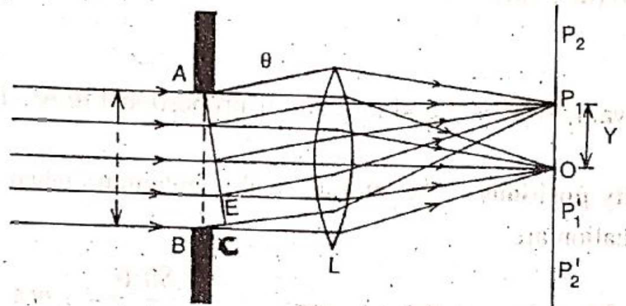


Fig.

General mathematical theory : To find the Intensity at P_1 draw a perpendicular AC on BR_1 the path difference between secondary wavelets from A and B in direction θ.

$= BC \quad = AB \, Sin\,\theta = e \, Sin\,\theta$ and corresponding phase difference

$$= \left(\frac{2\pi}{\lambda}\right) e \, Sin\,\theta$$

Let us consider that the width of the slit is divided into n equal parts and the amplitude of the wave from each part is a. The phase difference between any two consecutive waves from these parts would be

$$\frac{1}{n} \text{(total phase)} = \frac{1}{n}\left(\frac{2\pi}{\lambda} e \, Sin\theta\right)$$

d (say)

The resultant amplitude R is given by

$$R = \frac{a \, Sin\left(n \, d/2\right)}{Sin\left(d/2\right)} = \frac{a \, Sin\left(\pi \, e \, Sin \, \theta/\lambda\right)}{Sin\left(\pi \, e \, Sin \, \theta/\lambda n\right)}$$

$$= \frac{a \, Sin\,\alpha}{Sin \, \alpha/n} \qquad \text{Where } \alpha = \pi \, e \, Sin \, \theta/\lambda$$

$$= \frac{a \, Sin\alpha}{\alpha/n} \qquad (\because \alpha/n \text{ is very Small})$$

$$= n\,a\,\frac{Sin\alpha}{\alpha} = \frac{A\,Sin\alpha}{\alpha}$$

When $n \to \alpha, a \to 0$ then n a = A

The intensity is given by

$$I = R^2 = A^2\left(\frac{Sin\,\alpha}{\alpha}\right)^2 \quad \text{(or)} \quad I = I_0\left(\frac{Sin\,\alpha}{\alpha}\right)^2$$

Intensity distribution : The resultant amplitude can be written in ascending powers of α as

$$R = \frac{A}{\alpha}\left(\alpha - \frac{\alpha^3}{3!} + \frac{\alpha^5}{5!} + \frac{\alpha^7}{7!} + \ldots\right) = A\left(1 - \frac{\alpha^2}{3!} + \frac{\alpha^4}{5!} + \frac{\alpha^6}{7!} + \ldots\right)$$

The value of R will be maximum i.e. $\alpha = 0$

$$\alpha = \frac{\pi\,e\,Sin\,\theta}{\lambda} = 0\ (or)\ Sin\theta = 0$$

$$\therefore \theta = 0$$

So the maximum value of R is A and intensity is proportional to A^2. The maximum is known as principal maximum.

Minimum intensity positions : The intensity will be minimum when Sin $\alpha = 0$. The values of α which satisfy this equation are

$$\alpha = \pm\pi, \pm 2\pi, \pm 3\pi, \pm 4\pi \ldots \pm m\pi \quad \text{(or)} \quad \frac{\pi\,e\,Sin\theta}{\lambda} = \pm m\pi \quad \text{(or)} \quad e\,Sin\theta = \pm m\lambda$$

Where m = 1, 2, 3....etc

In this way we obtain the points of minimum intensity on either side of the principal maximum.

Secondary maxima : In addition to principal maximum at $\alpha = 0$ there are weak secondary maxima between equal spaced minima.

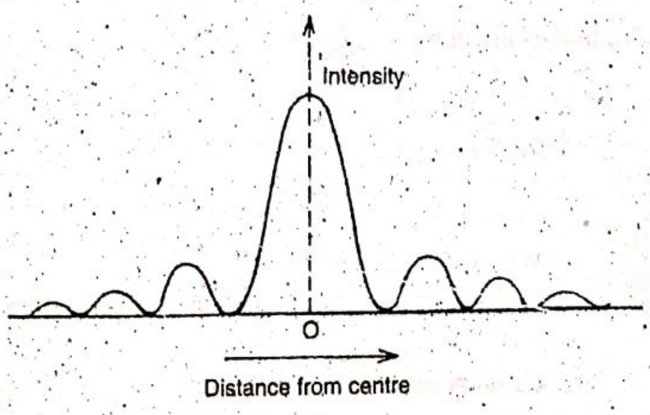
Differentiating I value w.r. to α and equating to 0, wehave

$$\frac{dI}{d\alpha} = \frac{d}{d\alpha}\left[A^2\left(\frac{Sin}{\alpha}\right)^2\right] = 0 \quad \text{(or)} \quad A^2\,\frac{2\,Sin\alpha}{\alpha}\left(\frac{\alpha\,Cos\alpha - Sin\alpha}{\alpha^2}\right) = 0$$

either Sin $\alpha = 0$ (or) $\alpha\,Cos\alpha - Sin\alpha = 0 \quad \alpha\,Cos\alpha = Sin\alpha$

$$\alpha = \frac{Sin\alpha}{Cos\alpha} = \tan\alpha$$

A graph showing the variation of intensity with α is shown in fig.



Fig

Q. 2. Discuss the fraunhafer diffraction pattern due to N-slit grating and obtain intensity distribution for it ?

Ans :

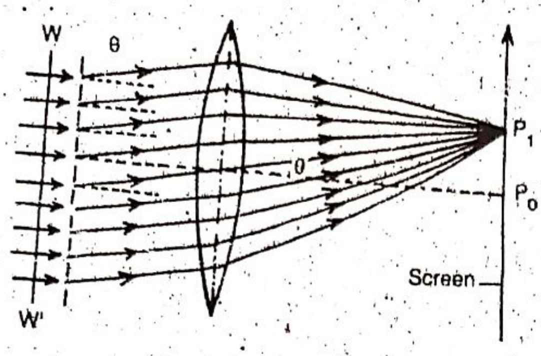


Fig.

Fig represents the section of a plane transmission grating placed perpendicular to the plane of the paper. Let e be the width of each slit and d the width of each opaque part. Then (e+d) is known as grating element. XY is the screen placed perpendicular to the plane of a paper. Suppose a light will come to focus at a point P_0 on the screen. The point P_0 will be a central maximum. If the secondary wavelets travelling at an angle θ to the incident direction reach at P_1 on the screen. As a result dark and bright bands on both sides of central maxima are obtained.

For a single slit the wave amplitude is $\frac{A\,Sin\alpha}{\alpha}$ at $\theta = 0$ where $\alpha = \frac{\pi\, e\, Sin\theta}{\lambda}$

If there are N-slits. So the path difference between two slits is (e+d) $Sin\theta$. The corresponding phase difference is $\left(\frac{2\theta}{\lambda}\right)$. The resultant amplitude for N vibrations each of amplitude $\frac{A\,Sin\alpha}{\alpha}$ and having a common phase difference $\frac{2\pi}{\lambda}(e+d)\,Sin\theta = 2\beta$

Resultant amplitude in the direction of θ will be

$$\therefore R = \frac{A\,Sin\alpha}{\alpha}\,\frac{Sin\,N\,\beta}{Sin\,\beta}$$

$$\therefore I = R^2 = \left(\frac{A\,Sin\alpha}{\alpha}\right)^2\left(\frac{Sin\,N\,\beta}{Sin\,\beta}\right)^2 = I_0\left(\frac{Sin\alpha}{\alpha}\right)^2\left(\frac{Sin^2\,\beta}{Sin\,\beta}\right)$$

Intensity distribution in grating :

1. Principal maximum would be when $Sin\,\beta = 0$ (or) $\beta = \pm n\,\pi$ Where n = 0, 1, 2, 3...

So $\frac{Sin\,N\beta}{Sin\,\beta}$ becomes indeterminant

So we apply the hospitals rule $\underset{\beta \to \pm n\pi}{Lin}\left(\frac{Sin\,N\beta}{Sin\,\beta}\right)^2 = N^2$

The resultant intensity is $\left(\frac{A\,Sin\alpha}{\alpha}\right)N^2$. The maxima are most intense and are called as principal maxima

Then $(e+d\ Sin\theta)=\pm n\lambda$

n = 0, 1, 2, 3...

Minima : A series of minima occur when

$$Sin\ N\beta = 0 \qquad N\beta = \pm m\pi$$

$$N \tfrac{\pi}{\lambda}(e+d)\ Sin\theta = \pm m\pi$$

N (e + d) $Sin\theta = \pm m\lambda$

Where m has all integral values except 0, N, 2N .... n N.

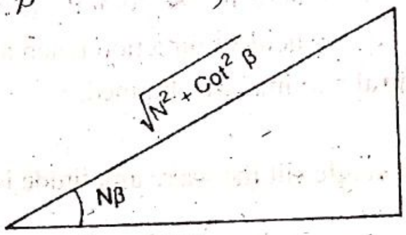
2. Secondary maxima : The secondary maxima have (N-1) minima between two adjacent principal maxima these must be (N-2) other maxima between two principal maxima, to find the position of secondary maxima consider

$$\frac{dI}{d\beta} = \left(\frac{A\ Sin\alpha}{\alpha}\right)^2 2\left(\frac{Sin\ N\ \beta}{\beta}\right)\left(\frac{N\ Cos\ N\beta\ Sin\beta - Sin\ N\beta\ Cos\beta}{Sin^2\beta}\right) = 0$$

(or) N Cos N β Sin β - Sin N β Cos β = 0

N tan β = tan N β

Consider a triangle as shown in fig.



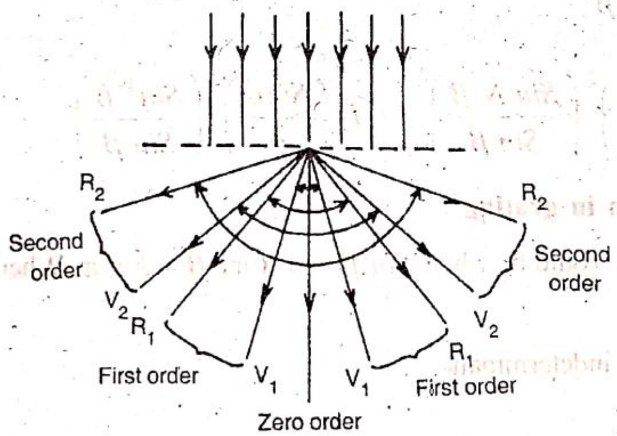
Fig

From fig $Sin\ N\beta = \dfrac{N}{\sqrt{N^2 + Cot^2\beta}}$

$$\therefore \frac{Sin^2\ N\beta}{Sin^2\ \beta} = \frac{N^2}{(N^2 + Cot^2\beta)\times Sin^2\beta} = \frac{N^2}{N^2 Sin^2\beta + Cos^2\beta}$$

$$= \frac{N^2}{1+(N^2-1)Sin^2\beta} = \frac{1}{1+(N^2-1)Sin^2\beta}$$

The intensity of secondary maxima is relative to principal maxima. The resultant is shown in fig.



Fig

Q. 3. Derive the formula for resolving power of a plane transmission grating.

Ans : The resolving power of a grating is its power of distinguishing two near by spectral lines and is defined by the equation.

$$R = \frac{\lambda}{\Delta\lambda}$$

Where λ and $\lambda + \Delta\lambda$ are two wavelengths which the grating can resolve. It is clear that the smaller the value of $\Delta\lambda$, the larger the resolving power.

According to Rayleigh's criterion if the principle maximum of wavelength $\lambda + \Delta\lambda$ falls on the first minimum of the wavelength λ, then the two colour are said to be just resolved if

$$d\sin\theta = m(\lambda + \Delta\lambda) \; and \; \sin\theta = m\lambda + \frac{\lambda}{N}$$

are simultaneously satisfied where θ is the common angle of diffraction for the lines.

For the equation we have $R = \frac{\lambda}{\Delta\lambda} = mN$

Which implies that the resolving power depending on the number of slits in the grating.

The principal maxima of λ in a direction θ is

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

The equation for minima is $N(e+d)\sin\theta = m\lambda$ -----(1)

where m = 3N, 5N.........

Similarly first minima in the direction $(\theta_n + d\theta_n)$ is

$N(e+d)\sin(\theta_n + d\theta_n) = (nN+1)\lambda$ ----(2)

The principal maxima for $(\lambda + d\lambda)$ in $(\theta_n + d\theta_n)$ is

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

or $N(e+d)\sin(\theta_n + d\theta_n) = nN(\lambda + d\lambda)$ ----(3)

From (2) and (4) ----(4)

$(nN+1)\lambda = nN(\lambda + d\lambda)$

$$or\ \lambda = nNd\lambda\ or\ \frac{\lambda}{d\lambda} = nN$$

Thus the resolving power is directly proportional to order and number of lines.

Q. 4. Describe the construction and working principle of zone plate.

Ans : Zone plate : Definition : The correctness of Fresnels method of dividing a plane wavefront into half period zones, which forms the bases of the proof of the rectilinear propagation of light, can be verified by means of an optical device known as **"Zone plate".**

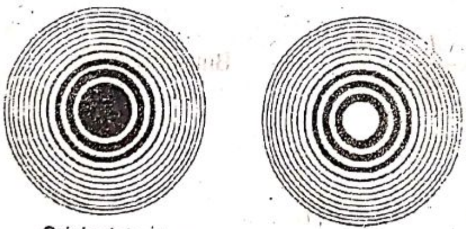


Fig.

Construction of a zone plate : To construct a zone plate concentric circles are drawn on white paper with their radii proportional to the square root of their natural numbers. The odd numbered zones are blackened and is photographed. In the negative the odd numbered zones will be transparent and the even numbered zones will be blackened. This negative itself acts as a zone plate.

Theory of zone plate : Consider a plane wavefront incident normally on a zone plate, then an image of the distant object is formed at a distance b from the zone plate, such that $b = \frac{r_1^2}{\lambda}$, where r_1 is the radius of the first circle. It can be shown that the zone plate acts as convex lens not only for a plane wave front but also for a spherical wavefront.

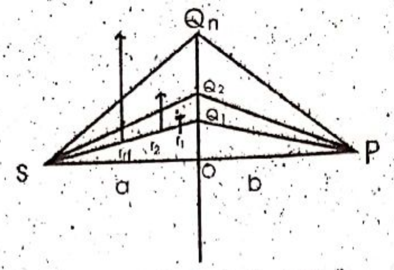


Fig.

Let S be a point source and let $SO=a$ and $OP=b$, let SOP be the axis of the zone plate. Let Q_n be a point on the n[th] circle so that

$$OQ_n = r_n = \sqrt{n}.r_1 \qquad \text{-----(1)}$$

Take a point P on the axis such that

$$SQ_n + Q_nP = SO + OP + \frac{n\lambda}{2} \qquad \text{------(2)}$$

Now $SQ_n^2 = SO^2 + OQ_n^2 = SO^2\left[1+\frac{OQ^2}{SO^2}\right]$

$$SQ_n = SO\left[1+\frac{OQ_n^2}{2.SO^2}\right]\left[\because OQ_n << SO\right] = SO\left[1+\frac{r_n^2}{2SO^2}\right] = SO + \frac{r_n^2}{2SO} \qquad \text{-----(3)}$$

$$\text{Similarly } Q_nP = OP + \frac{r_n^2}{2OP} \qquad \text{----(4)}$$

$$\therefore SQ_n + Q_nP = SO + OP + \frac{r_n^2}{2}\left[\frac{1}{SO}+\frac{1}{OP}\right] \qquad \text{----(5)}$$

From (2) and (5) we get, $\frac{r_n^2}{2}\left[\frac{1}{SO}+\frac{1}{OP}\right] = \frac{n\lambda}{2}$ But $r_n^2 = n.r_1^2$

$$\therefore \frac{r_n^2}{2}\left[\frac{1}{SO}+\frac{1}{OP}\right] = \frac{n\lambda}{2}$$

$$\therefore \frac{1}{SO}+\frac{1}{OP} = \frac{\lambda.n}{r_n^2} \qquad \text{------(6)}$$

$$\frac{1}{a}+\frac{1}{b}=\frac{1}{f}, \text{ where } f_n = \frac{r_n^2}{n\lambda} \qquad \text{-----(7)}$$

Where f represents the focal length. Equation (7) resembles the lens law. So zone plate acts like a convex lens.

SHORT ANSWER QUESTIONS

Q. 1. What is diffraction and explain its types ?

Ans : Water waves escaping through a small hole spread out in all directions as if. They have originated at the hole. Similarly sound waves found to pass round obstacles. The amount of bending, however, depends upon the size of the obstacle and the wavelength. It was found that light waves also bend round obstacles. When the size of the obstacle or aperture is comparable with the wavelength of the light, bending is more predominant. This phenomenon is known as diffraction. Thus bending of light waves round the corners or sharp edges of the obstacles and enters the geometrical shadow is called diffraction.

According to Fresnel, the diffraction phenomenon is due to mutual interference of secondary wavelets which are not obstructed by the obstacle.

For example, consider a plane wavefront falling normally on a narrow opening. Around the opening secondary wavelets spread move widely than the size of the opening.

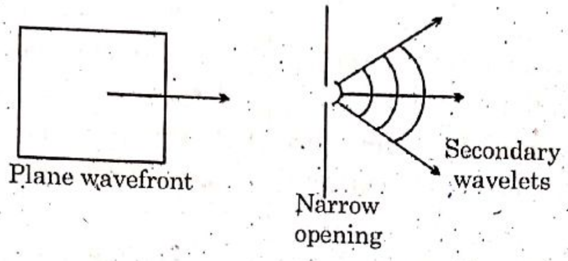


Fig.

Thus light spreads in the geometrical shadow region also due to diffraction phenomenon. This is of two types

(i) Fraunhofer diffraction : In this class plane wavefront undergoes diffraction. Source of light, and the screen are effectively at infinity.

ii) Fresnel diffraction : In this class, spherical or cylindrical wavefronts bend at the sharp edges. Source of light and screen are nearly at finite distance.

Q. 2. Difference between Fraunhofer and Fresnel diffraction.

Ans :

Fraunhofer diffraction	Fresnel diffraction
1. The distance of the source and the screen from the diffracting elements are effectively infinite.	1. The source or the screen or both are the finite distance from the diffracting elements.
2. The wave front incident on the aperture is plane which is realised by using a collimating lens.	2. The wave fronts are divergent either spherical or cylindrical
3. The angular inclinations are important in this type of diffraction.	3. Distances are important in this type of diffraction.
4. Diffracted light is collected by a lens as in a telescope.	4. No mirrors or lenses are used for observation
5. There is a large number of parallel rays falling on the lens corresponding to each point on the screen.	5. The rays proceed directly to the axial points.
6. The effects of several diffracted elements can be added together.	6. No such additions of effects is possible.
7. The observed pattern is an image of the source modified by the diffraction at the diffracting device.	7. The observed pattern is a projection of the diffracting device modified by diffracting effects and the geometry of the source.
8. In case of points off the axis, the incident rays on the lens have the same obliquity and hence the amplitude contribution due to each zone is the same.	8. For points off the axis, the obliquity is different for different rays and therefore the amplitude contribution due to different zones is different.
9. The centre of the diffraction pattern is always bright for all paths parallel to the axis of the lens.	9. The centre of the diffraction pattern may be bright or dark depending upon the number of Fresnel zones.
10. Mathematical investigations are regorous and easy.	10. Mathematical investigations are complicated and only approximate.

Q. 3. What are the difference between interference and diffraction?

Ans : Interference	Diffraction
1. Interference phenomenon is the result of interactions between the secondary wavelets from two different wave fronts.	1. Diffraction phenomenon is due to mutual interference of the disturbances propagated from the various elements of a single wavefront.
2. In interference phenomenon, the fringes are generally of the same width.	2. In Diffraction phenomenon, the fringes are always of unequal width. The fringe width goes on decreasing continuously.
3. In interrerence phenomenon, all the bright fringes are of the same intensity.	3. In Diffraction phenomenon, the intensity of bright fringes gradually changes.
4. In interrerence phenomenon, the minimas are usually of zero intensity, i.e. they are perfectly dark.	4. In Diffraction phenomenon, the minimas are not perfectly dark.
5. In interrerence one can observe easily a large number of fringes.	5. In Diffraction only a few fringes can be observed.

Q. 4. Describe how wavelength of light determined using diffraction grating.

Ans : Theory : Diffraction grating is used in the laboratory for measuring wavelength of light.

In the diffraction grating principal maxima are obtained in directions.

$(e+d)\sin\theta = n\lambda$ where (e+d) is grating element

$\frac{1}{(e+d)} = N$ number of ruled lines per cm

$\therefore \sin\theta = nN\lambda$

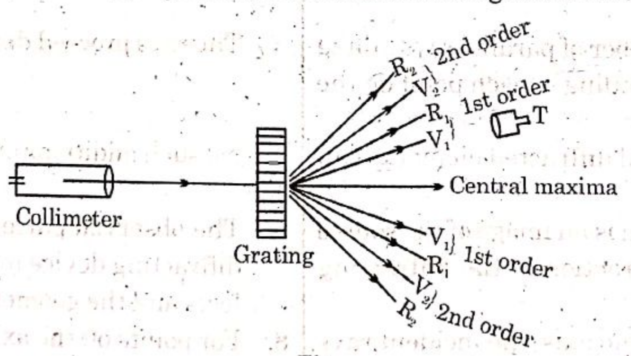
n– is the order of spectrum and 'θ' is the angle of diffraction of given wavelength of light, λ. In the laboratory spectrum of given source of light is obtained by using spectrometer.

Spectrometer adjustments : The following adjustments are done.

(i) Collimater in the spectrometer adjusted for parallel rays.

(ii) The grating is adjusted for normal incidence of light.

Measurement of 'θ' : The slit of the collimeter is illuminated by given source of light. The beam gets dispersed by the grating. In each order of spectrum, constituent wavelengths are observed.



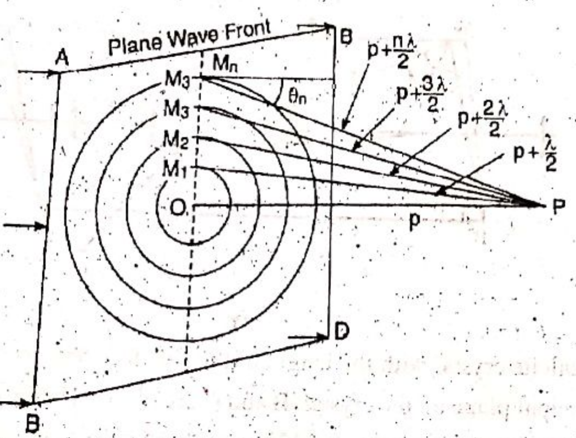
Fig

the spectrum as the wavelength increases, angle of diffraction also increases. The telescope, T is turned and the cross-wire is adjusted on the line for which wavelength is to be measured. The telescope position reading of the two verniers are noted. The telescope is then turned to the other side and adjusted on the same line. The position of telescope verniers are again noted. The difference between readings of the same vernier gives twice the angle of diffraction for that line in the 1st order. By substituting the value of 'θ' in the above equation. The wavelength of that line can be calculated.

By following same procedure the wavelength of different lines can be calculated with the help of grating.

Q. 5. What are Fresnel's half period zones?

Ans : Fresnel's half period zones ; Let a plane wavefront, ABCD of wavelength, λ is proceeding in the direction. P is a point where the resultant intensity is to be calculated. Fresnel divided the wavefront into a number of components known as half period zones. Let OP is the normal say $OP=P$. With P as centre and radii equal to P+ $\lambda/2$, P+ $2\lambda/2$....., P+$n\lambda/2$ sphere are drawn. The wavefront, ABCD cuts these spheres in concentric circles of radii OM_1, OM_2,.........The first innermost circle is the 1st half period zone. Similarly the area enclosed between first and second circle is second half period zone. The path difference between successive half period zones is $\lambda/2$ or phase of π radial that is why they are called half period zones.



Fig

Q. 6. Compare Zone plate and Convex lens.

Ans :

Zone Plate	Convex lens
1. Zone plate acts as convex and concave lenses symulta -niously.	1. It can not
2. Image is formed by diffraction.	2. Image is formed by refraction.
3. It pocesses number of focal points.	3. It contains only one focal point.
4. It can work with x-rays.	4. It works only in the range of visible lihgt.
5. Image is formed by any two alternate zones.	5. All the rays coming from the lens form the image.

—O—

UNIT - III

POLARISATION OF LIGHT

LONGANSWER QUESTIONS

Q. 1. Describe the construction and working of a Nicolprism. Explain how it can be used as polarizer and analyzer.

Ans : This prism was designed by Nicol and the name Nicol prism. The construction is shown in the figure.

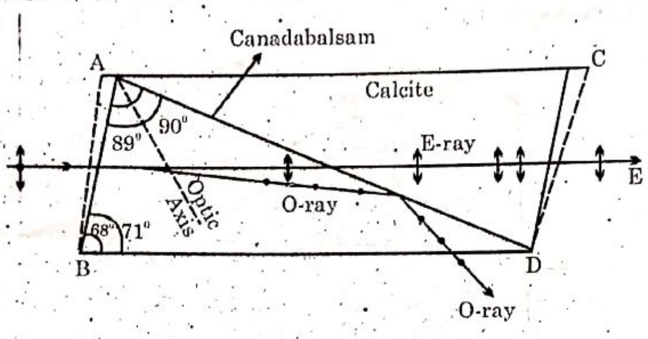


Fig.

A Rhomb shaped calcite crystal with the length of the side face three times the length of end face is taken. ABCD represents the principal plane of the crystal. B and C are of 71°. The faces of the crystal are grounded such that B and C becomes 68°. The crystal is cut into two halves perpendicular to the principal plane and to the side faces. The cut faces are joined by Canada Balsam.

The refractive index of canadabalsam lies between the refractive indices for the ordinary and extraordinary rays for calcite.

Refractive index of calcite with reference to ordinary ray,

$\mu_o = 1.658$

Refractive index of calcite with reference to extra-ordinary ray $\mu_e = 1.486$

Refractive index of canada balsam $\mu_B = 1.55$

Critical angle for canada balsam is 69°.

Working : When an unpolarized light coming parallel to BD is incident on the crystal it splits up into ordinary ray and extra ordinary ray. These two rays travel with different velocities in the crystal. Thus, the two rays have different values of refractive indices. In between these two value lies the refractive index of Canada Balsam. Thus, Canada Balsam acts as a rarer medium for one ray (0–ray) and denser medium for another ray (E–ray). The crystal was cut in such a way that the O–rays falls on the layer of Canada Balsam at an angle greater than the critical angle. Hence the O–ray suffers from total internal reflection. The E–ray gets transmitted directly and is plane polarized.

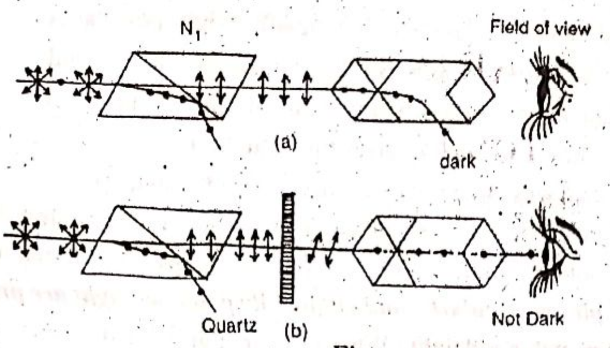
The plane of vibration lies in the plane of paper. The reflected 0–ray will be absorbed at the blackened surface.

Uses : (i) Nicol is used to produce plane polarised light.

(ii) It acts as polariser and analyser.

Nicolprism can be used both as polariser and an analyser : When two Nicols are arranged co-axially as shown in fig. The first nicol which prodûces plane polarised light is known as polariser while the second which analyses the polarised light is known as analyser.

The extra-ordinary say transmitted by one is freely transmitted by the other. If the second prism is gradually rotated then the intensity of extra-ordinary say gradually decreases and when the two Nicols are at right angle to each other i.e. they are in a crossed position, no light comes from second prism. This is due to the fact that when the polarised extra-ordinary says enters the second Nicol prism, it acts as ordinary say and is totally internally reflected. Therefore the first Nicols prism N_1 produces plane polarised light and the second Nicol's prism N_2 detects it.

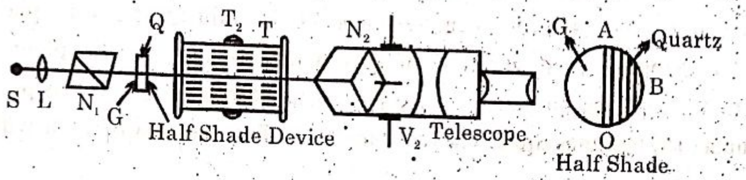


Fig

Q. 2. ***Describe the construction and working of Laurent's half-shade polarimeter. Explain how you would use it to determine the specific rotation of sugar solution.***

Ans : Experiment : Laurent half shade polarimeter is used to measure specific rotation of sugar solution.

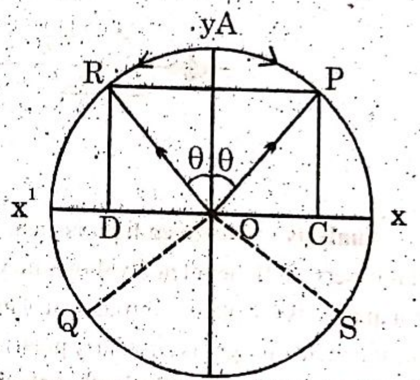
The parts of a Laurent half shade polarimeter are shown in the fig. *S* is a monochromatic source of light. N_1 and N_2 are two Nicol prisms. N_2 is capable of rotating on a circular scale and acts as analyser.



Fig

Light after passing through polariser N_p the light becomes plane polarised. This light now passes through half shade device and then through a tube containing active solution. The emergent light on passing through N_2 is viewed through telescope.

Half shade device consists of a semi circular half-wave plate ABC of quartz and a semicircular glass plate. The two plates are cemented along AC.



Fig

Let the plane of vibration of polarised light incident normally on half shade plate along PQ. The vibrations emerge from the glass plate as such i.e., along PQ. The quartz plate introduces a phase of r - rad between ordinary and extraordinary components of light. Due to this the direction of ordinary component is reversed to the initial position. Now the resultant of these components. OR making a angle 'θ' with y - axis. Thus the vibration of the beam emerging out of the quartz will be along RS. If the principal plane of the analyser N_2 is along PQ, then the light from glass portion will pass unobstructed while light from quartz portion will partly obstructed. If however, the principal plane of N_2 is along 'AC' it is equally inclined to both the portions and both parts appear equally bright.

Fig.

Dermination of specific rotation :

Specific rotation, $S = \dfrac{\theta}{l \times C}$

where l- is length of tube in decimeters, C– is concentration of the solution and θ is the angle of rotation. First of all, the experiments tube is filled with water and placed in its position.

The telescope is focussed and analyser is rotated till equally bright position is obtained. The readings are noted. Now the tube is filled with sugar solution and again analyser is rotated till equally bright position is obtained. This reading also noted. The difference between these two reading gives the rotation θ.

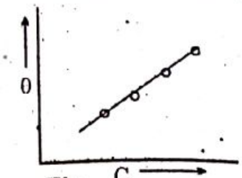


Fig.

The experiment is repeated with different concentrations of the solution.

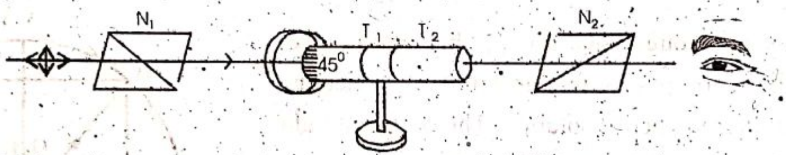
A graph is plotted between concentration and angle of rotation. It gives a straight line. From the graph (θ/C) is calculated and substituted in the formula to calculate specific rotation of sugar solution.

Q. 3. Explain in detail how plane, circularly and elliptically polarised light are produced and detected.

Ans : (i) Production of plane polarised light : When ordinary light is made to incident on Nicol, plane polarised light is produced.

Detection : When the second Nicol or analyser is rotated about the incident light, the intensity of light varies between maximum and zero. Then the incident light is plane polarised.

(ii) Production of circularly Polarised light : A beam of monochromatic light is allowed to fall on a Nicol Prism N_1. The emergent light from Nicol Prism N_1 is plane polarised light. Another Nicol prism N_2 is placed at a certain distance in a crossed position i.e., no light transmits from it. Now a quarter wave plate Q mounted on a tube T_1 is introduced between the two nicols and hold normal to the incident beam. The tube T_1 can rotate about a horizontal axis through any desired angle. Now some light emerged from N_2. Now the Quarter wave plate is rotated till the field of view is again dark. This happens when vibrations of light incident on quarter wave plate are along the optic axis and so perpendicular to N_2. Now the quarter wave plate is rotated through 45^0. At this position the amplitude of ordinary and extra-ordinary ray becomes equal. The resultant beam after quarter wave plate will be circularly polarised light.



Fig

Analysis : The given light is passed through a Nicol and by rotating this Nicol, the intensity of emergent light is observed. If the intensity shows no variation the incident light is either unpolarised (or) circularly polarised. Now a quarter wave plate is introduced. Thus the rotating Nicol shows variation in intensity with minimum as zero. Hence the incident light is circularly polarised light.

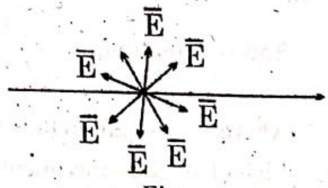
iii) Production of elliptically polarised light : To produce elliptically polarised light, the two waves vibrating at right angles to each other and having unequal amplitudes should have a phase difference π/2 or a path difference of λ/4. A parallel beam of monochromatic light is allowed to fall on the nicol prism N_1. The prism N_1 & N_2 are crossed and the field of view is dark. A quarter wave plate is introduced between N_1 and N_2. The plane polarised light from the nicol N_1 falls normally on the quarter wave plate. The field of view is illuminated and light coming out of the quarter wave plate is elliptically polarised.

Detection : The beam is allowed to fall on a nicol prism. If the beam is elliptically polarised, the intensity varies from a maximum to minimum value when the nicol prism is rotated.

To distinguish between unpolarized and polarised light, the original beam is allowed to fall on a quarter wave plate and on a nicol prism. If the beam is elliptically polarised, the ordinary and the extraordinary rays will undergo a further path difference of λ/4.

SHORT ANSWER QUESTIONS

Q. 1. What is polarisation of Light? Explain plane of vibration and plane of polarisation.



Fig

Ans : According to Maxwell electromagnetic theory light waves are transverse waves containing electric and magnetic fields perpendicular to each other and perpendicular to the direction of propagation. Eye sight is produced by electric field. In a source of light different atoms produce different wave trans containing electric vectors in all possible directions perpendicular to the direction of propagation. There is, thus perfect symmetry around. The direction of propagation.

If such symmetry is lacking i.e any beam of light, the beam is said to be polarised.

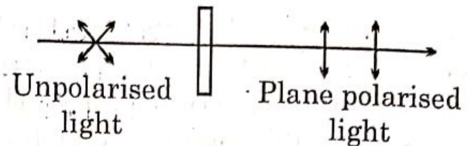


Fig.

For example, in case of plane polarised light, all the electric vectors lie in one plane containing the direction of propagation.

Plane of vibration : The plane containing the direction of vibration and also the direction of propagation is called the "Plane of vibration".

Plane of Polarisation : The plane passing through the direction of propagation but containing no vibrations is called the "Plane of polarisation".

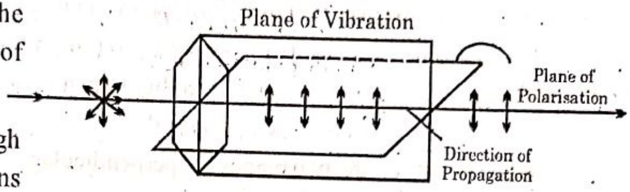


Fig.

The plane of polarisation, must be perpendicular to the plane of vibration.

Q. 2. State and prove Brewster's Law.

Ans : Brewster's law : Brewster proved that the tangent of the angle of polarisation (p) is numerically equal to the refractive index(μ) of the medium.

i.e., $\mu = \tan p$.

This is known as Brewster's law. He also proved that the reflected and refracted rays are perpendicular to each other. Angle between reflacted and refracted rays. Suppose a beam of unpolarised light is incident on glass surface at polarising angle p as shown in fig. The polarising angle for air-glass is 57^0. A part of the incident light is reflected while a part is refracted. Let r be the angle of refraction. From Brewster's law.

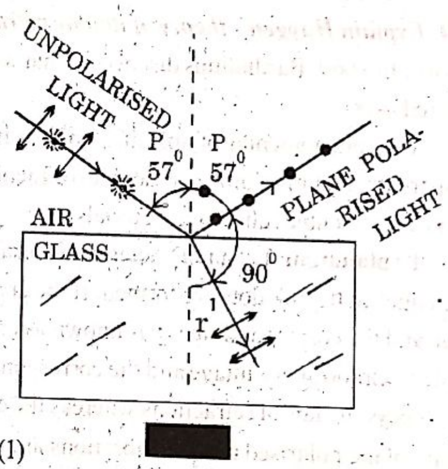


Fig.

$$\mu = \tan p \quad \text{----(1)}$$

From Snell's law

$$\mu = \frac{\sin p}{\sin r} \quad \text{----(2)}$$

Comparing equations (1) and (2)

$$\tan p = \frac{\sin p}{\sin r} \quad \text{or} \quad \frac{\sin p}{\cos p} = \frac{\sin p}{\sin r}$$

$\therefore$ $\sin r = \cos p = \sin(90^0 - p)$ or $r = 90 - p$ or $r + p = 90^0$

Thus reflected and refracted rays will be perpendicular to each other.

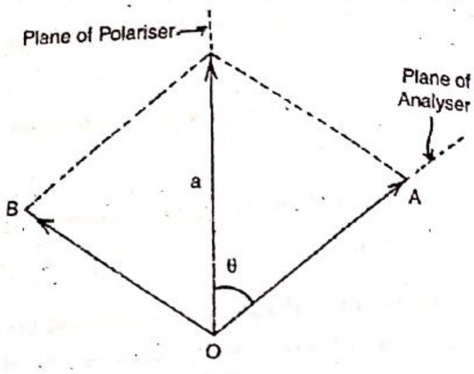
Therefore the reflected and refracted rays are at right angles to each other.

Here it should be noted that the refractive index of a substance varies with wavelengths of incident light hence the polarising angle will be different for different wavelengths. Therefore for complete polarisation the light should be monochromatic.

Q. 3. Law of Malus.

Ans : Malus discovered a law regarding the intensity of light transmitted by the analyser. According to Malus when a completely plane polarised light beam is incident on an analyser, the intensity of the polarised light transmitted through the analyser varies as the square of the cosine of the angle between the plane of transmission of the Analyser and the plane of polariser. This law holds good for a combination of reflecting surfaces, polarising and analysing tourmaline crystals, Nicol prisms etc., but fails when the light is not completely plane polarised etc., but fails when the light is not completely plane polarised.

To prove this let OP = a (Fig) be the amplitude of the incident plane polarised light from a polariser and θ, the angle between the planes of polariser and analyser. The amplitude of incident plane polarised light can be resolved in two components, one parallel to the plane of transmission of analyser (a cos θ) and the other perpendicular to it (a sin θ). The component a cos θ is transmitted through the analyser.



Fig

∴ Intensity of the transmitted light through the analyser.

$I_0 = (a\cos\theta)^2 = a^2\cos^2\theta$. (∵ Intensity α (amplitude)^2)

If I be the internsity of incident polarised light, then $I = a^2$

$\therefore I_0 = I\cos^2\theta$ or $I_0\, \alpha \cos^2\theta$.

When $\theta = 0$ *i.e.,* the two planes are perpendicular,

$I_0 = I$ *as* $\cos\theta = 1$

When $\theta = \dfrac{\pi}{2}$ i.e., two planes are perpendicular, $I_0 = 0$.

The above results are experimentally observed in case of two tourmaline crystals.

Q. 4. Explain Huygen's theory of double refraction.

Ans : In 1669, Barthalinus discovered that when a light ray is refracted by a certain crystals, they give rise to two refracted rays.

This phenomenon of splitting up of a light ray into two rays when it is passed through a homogeneous transparent medium is known as double–refraction. Double refraction is exhibited by quartz, mica, calcite etc. These are known as double refracting materials.

Explanation: Let an ink dot is made on a sheet of white paper and it is reflected through calcite crystal. Then two images of the ink dots are formed. If the crystal is rotated, one of the image will be stationary called stationary image and the corresponding ray is known as ordinary ray (O–ray). The other image which rotates around the first is called extraordinary image and the corresponding light ray is known as extraordinary ray (E –ray). The ordinary image obeys the law of refractions whereas the extraordinary image does not obey the laws of refraction. Both these rays are plane polarised and the vibrations are orthogonal.

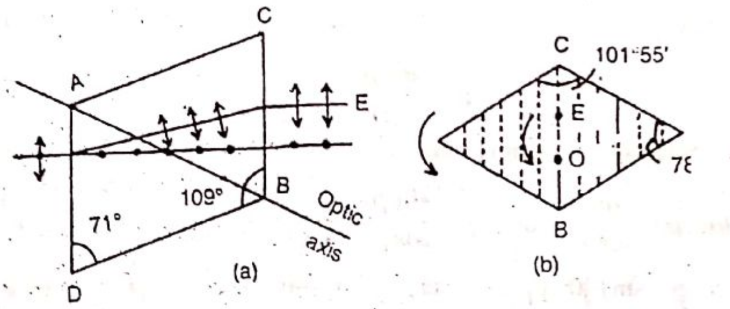


Fig.

When light is allowed to pass through a birefrigerent crystal along the optic axis, both O –ray and E –ray travel with same speed. Hence the refractive index of the crystal for ordinary ray is constant.

$$\mu_0 = \frac{velocity\ of\ light\ in\ vacuum}{velocity\ of\ O-ray\ in\ the\ crystal}$$

But the refractive index for E–ray is not constant and it depends on direction of traverse for a positive crystal.

$$\mu_e = \frac{velocity\ of\ light\ in\ vacuum}{minimum\ velocity\ of\ E-wave}$$

Huygen explained the phenomenon of double refraction in uniaxial crystals by using the principle of secondary wavelengths. The assumptions of this theory are as follows.

1) When a wavefront incident on a double refracting crystal, every point on it gives out two secondary wavefront, one for O–ray and the other for E– ray.

2) The O–ray travels with same velocity in all directions and the wavefront is spherical.

3) The E– ray travels with different velocities in different directions and hence the wavefront is ellipsoid.

4) The velocities of O –ray and E–ray are same along the optic axis.

For a positive crystal like quartz

1) The ellipsoid of revolution corresponding to the extra–ordinary ray is totally contained in the sphere corresponding to the O–ray.

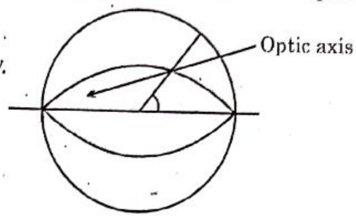


Fig.

2) The velocity of the extraordinary ray is smaller than that of the O–ray.

$V_e < V_0$

3) The refractive index for E–ray is greater than that of O–ray

($\mu_0 = 1.544$ and $\mu_e = 1.553$)

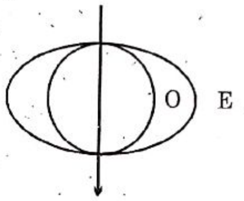
(i.e) $\mu_e > \mu_0$

4) The value of $\Delta\mu = \mu_e - \mu_0$ is a positive quantity and hence the crystal is called a positive crystal like quartz, the ellipse lies inside the sphere.

5. For negative crystals like calcite, the ellipse lies outside the sphere.

The velocity of E–ray is more than O–ray. The refractive index for O–ray is more than E–ray

$\mu_0 > \mu_e$



Optic axis
(Negative crystal)
Fig.

Q. 5.Explain Quarter wave and half wave plates ?

Ans : **Quarter wave plate :** Consider the case of a calcite plate cut with optic axis parallel to the surface as in fig.

It has been shown that when a plane polarised light falls normally on a thin plate uniaxial crystal cut parallel to its optic axis, the light splits up into ordinary and extra ordinary plane polarised lights. They travel along the same path but with different velocities.

The velocity of extra-ordinary say is greater than the velocity of ordinary say.

If the thickness of the crystal plate is such that it introduces a phase difference of $\pi/2$ radian or a path difference of $\lambda/4$ then it is called a quarter wave plate.

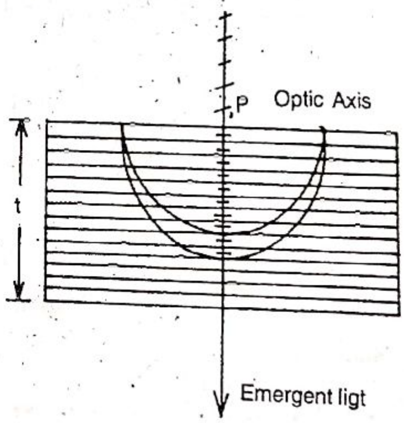


Fig.

$$\therefore t = \frac{\lambda}{4(\mu_0 - \mu_e)}$$

Half wave plate : If the thickness of a calcite crystal plate, cut with its faces parallel to optic axis, is such that it introduces a phase difference of π or a path difference of between ordinary and extra-ordinary waves, then it is called a half-wave plate. For a half wave plate.

$$(\mu_0 - \mu_e)\,t = \lambda/2$$

$$\therefore t = \frac{\lambda}{2(\mu_0 - \mu_e)}$$

— O —

SOLVED PROBLEMS

Q. 1. Calculate the Brewster's angle for Ethyle alcohol for which refractive index is 1.361

Solution : From Brewster's law $\mu = \tan p$

Angle of polarisation, $p = \tan^{-1}\mu = \tan^{-1}(1.361) = 53^0 42^1$

Q. 2. For Flint glass, the angle of polarisation is $62^0 24^1$. Calculate the refractive index of it.

Solution : Given that $p = 62^0 24^1$

From Brewster's law,

$\mu = \tan p = \tan(62^0 24^1) = 1.9128$

Q. 3. Refractive index of glass is 1.6. Find its angle of polarisation.

Solution : If P is the angle of polarisation

$P = \tan^{-1}\mu = \tan^{-1}(1.6) = 58^0$

Q. 4. Two polarised sheets are parallel to each other through what angle either sheet must be turned so that

(i) The intensity of transmitted light become half.

(ii) The intensity of transmitted light becomes half the intensity of un polarised light.

Solution : (i) From Malus law, $I = I_0 \cos^2\theta$

Given that $I = I_0/2$

$$\therefore \frac{I_0}{2} = I_0 \cos^2\theta \qquad \cos^{-1} = \pm\frac{1}{\sqrt{2}} \qquad \theta = \cos^{-1}\left(\pm\frac{1}{\sqrt{2}}\right) = 45^0 \text{ or } 135^0$$

(ii) When light is plane polarised, its intensity becomes half

From Malus law $I = I_0 \cos^2\theta$

Given that, $I_0 = I_0^1/2$ and $\frac{I}{I_0^1} = \frac{1}{2}$

where I_0^1 is the intensity of un-polarised light. $\frac{I}{I_0^1} = \frac{1}{2}$

$$\therefore \frac{2I}{I_0^1} = \cos^2\theta \qquad \cos\theta = \pm 1 \qquad \theta = 0 \text{ to } 360^0$$

Q. 5. ***A ray of light is incident on the surface of Benzene of refractive index 1.5. If the reflected light is linearly polarised. Calculate the angle of refraction.***

Solution : If 'P' is the angle or polarisation.

Then $\mu = \tan p$

$\therefore P = \tan^{-1}(\mu) = \tan^{-1}(1.5) = 56^0 18^1$

If 'S' is the angle of refraction, then $s + p = 90^0$

$\therefore s = 90 - p = 90 - 56^0 18^1 = 33^0 42^1$

Q. 6. ***Two Nicols are in crossed position. Now one of them is rotated through 60^0. What percentage of incident unpolarised light will pass through the system?***

Solution : If I_0^1 is the intensity of unpolarised light, it becomes $I_0^1/2$ when it is polarised.

$$\therefore I_0 = I_0^1/2$$

When one of the Nicols are rotated through 60^0, the angle between two nicols becomes $90 - 60 = 30^0$

$$\therefore I = I_0 \cos^2\theta \qquad \frac{I}{I_0} = \cos^2\theta = (\cos 30)^2 = \frac{3}{4}$$

But $I_0 = I_0^1/2$

$$\therefore \frac{2I}{I_0^1} = \frac{3}{4} \qquad \frac{I}{I_0^1} = \frac{3}{8} = 37.5\%$$

Q. 7. ***Plane polarised light is incident on a piece of quartz unit parallel to the axis. Find the least thickness for which the ordinary and extraordinary rays combine to form plane polarised light given that $\mu_o = 1.5442$, $\mu_e = 1.5533$ and $\lambda = 5 \times 10^{-5}$cms.***

Solution : Half wave plate can produce plane polarised light.

$$\therefore t = \frac{\lambda}{2(\mu_0 - \mu_e)} = \frac{5 \times 10^{-5}}{2(1.5533 - 1.5442)} = 2.75 \times 10^{-3} \text{ cm}$$

Q. 8. ***Calculate the thickness of a mica sheet required for making a quarter wave plate for $\lambda = 5460\ A^0$. The refractive indices for ordinary and extraordinary rays in mica are 1.586 and 1.592 respectively.***

Solution : Thickness of quarter wave plate, $t = \frac{\lambda}{\mu(\mu_e - \mu_o)}$

$$\therefore t = \frac{5460 \times 10^{-8}}{4(1.592 - 1.586)} = 2.275 \times 10^{-3} \text{ cms.}$$

Q. 9. ***Determine the thickness of calcite crystal plate which can produce circular polarised light for calcite $\mu_e = 1.486$, $\mu_o = 1.658$, $\lambda = 5893 \times 10^{-8}$ cm.***

Solution : A quarter wave plate produces circular polarised light.

$\therefore$ Thickness of quarter wave plate,

$$t = \frac{\lambda}{4(\mu_e - \mu_0)} = \frac{5893 \times 10^{-8}}{4(1.658 - 1.486)} = 8.56 \times 10^{-5} \text{ m}$$

Q.10. ***A half wave length plate is constructed for a wavelength of 6000 A^0. For what wave length does it work as a quarter wave plate?***

Solution : For quarter wave plate, $t = \frac{\lambda_1}{4(\mu_0 - \mu_e)}$

For half wave plate, $t = \frac{\lambda_2}{2(\mu_0 - \mu_e)}$

$$\therefore \frac{\lambda_1}{4(\mu_0 - \mu_e)} = \frac{\lambda_2}{2(\mu_0 - \mu_e)}$$

$$\lambda_1 = \frac{\lambda_2}{2} \times 4 = 6000 \times 2 = 12000\ A^0$$

Q.11. ***For quartz, the refractive indeces for left handed and right handed vibrations are 1.55821 and 1.55810 respectively for $\lambda = 4000\ A^0$. Find the amount of optical rotation produced by a quartz plate of thickness 2 mm with its optic axis perpendicular to the force.***

Solution : Angle of rotation of the plane of polarisation

$$\theta = \frac{\pi d}{\lambda}(\mu_L - \mu_R) = \frac{\pi \times 0.2}{4 \times 10^{-5}}(1.55821 - 1.55810) \text{ radians}$$

$$= \frac{\pi \times 0.2}{4 \times 10^{-5}}(1.55821 - 1.55810) \times \frac{180}{11} = 98^0$$

Q.12. ***A sugar solution of specific rotation 52^0 per decimeter per gm/cc causes a rotation of 12^0 in a column of 10 cm long. Calculate the concentration of the solution.***

Solution : Given that $S = 52^0$, $l = 10$ cm, $\theta = 12^0$

$$S = \frac{10.\theta}{lc} \quad \text{or} \quad C = \frac{10.\theta}{l.s} = \frac{10 \times 12}{10 \times 52} = 0.23 \text{ gm / cc}$$

Q.13. ***Calculate the specific rotation if the plane of polarisation is turned through 26.4°, travelling 20 cms length of 20% sugar solution.***

Solution : Hence $C = 20\,\% = \frac{20}{100} = 0.2 gm / cc$

$l = 20$ cm

$\theta = 26.4^0$

$\therefore$ Specific rotation, $S = \frac{10.\theta}{l.c} = \frac{10 \times 26.4}{20 \times 0.2} = 66^0$

Q.14. ***80 gm of impure sugar when dissolved in a litre of water gives an optical rotation of 9.9° when placed in a tube of length 20 cm. If the specific rotation of sugar is 66°. Find the percentage purity of the sugar sample.***

Solution : Here $\theta = 9.9^0$, $l = 20$ cm; $s = 66^0$,

$\therefore$ Concentration, $C = \frac{10.\theta}{l.s} = \frac{10 \times 9.9}{20 \times 66} = 0.075 gm / cc = 75$ gm/lit

But 80 gm of sugar is dissolved in water.

$\therefore$ Purity is $\frac{75}{80} \times 100 = 93.75\%$

Q.15. ***A tube of sugar solution 20 cm long is placed between crossed Nicols and illuminated with light of wave length 0.6×10^{-5} cms. If the optical rotation produced by the solution is 13° and specific rotation is 65°, determine the sugar present in one litre solution.***

Solution : Here, $s = 65^0$; $l = 20$ cm ; $\theta = 13^0$

$\therefore$ Concentration $C = \frac{10.\theta}{l.s} = \frac{10 \times 13}{20 \times 65} = 0.1 gm / cc$

$\therefore$ Sugar present in 1 litre solution,

$m = C \times 1000$

$= 0.1 \times 1000 = 100$ gm.

Q.16. ***The values of μ_0 and μ_e for calcite are 1.652 and 1.488 respectively. Calculate the phase retardation for $\lambda = 6000\,A^0$ where the plate thickness is 0.04 mm.***

Solution : Here $t = 0.004$ cm ; $\mu_0 = 1.652$; $\mu_e = 1.488$; $\lambda = 6000\,A^0$.

The path difference between O–ray and E–ray after emergence $= (\mu_0 - \mu_e)t$

$$= (1.652 - 1.488)\,0.004 = 6.56 \times 10^{-4} \text{ cms.}$$

$\therefore$ Phase retardation, $\delta = \frac{2\pi}{\lambda} \times (path\ difference)$

$$\delta = \frac{2\pi}{6 \times 10^{-5}} \times 6.56 \times 10^{-4} = 68.7 \text{ radians.}$$

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UNIT - IV

ABBERATIONS AND FIBRE OPTICS

LONG ANSWER QUESTIONS

Q. 1. What is meant by spherical aberration ? Explain how we minimized the spherical aberration ?

Ans : **Spherical aberration : Statement**

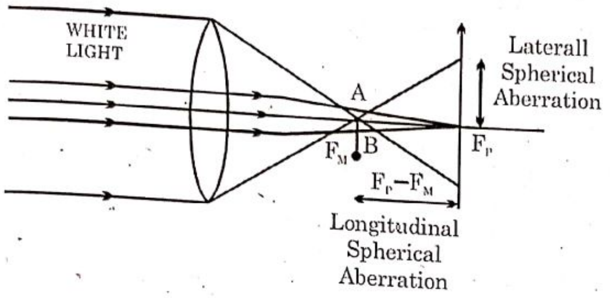


Fig.

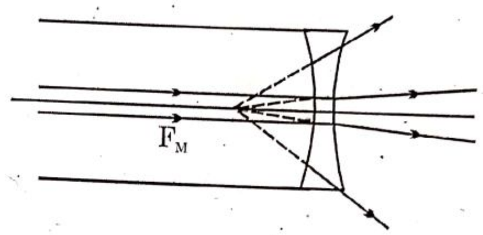


Fig.

When a beam of light parallel to the axis is incident on a lens then the marginal rays focus at a point F_M near the lens and the paraxial rays focus at a point F_p far from the lens. Thus a point image is spreading over a space along the axis. This defect is called spherical aberration.

F_M is called the marginal focus and F_p is called paraxial focus. f_M is the marginal focal length and f_p is the paraxial focal length.

$(f_p - f_M)$ is called the 'longitudinal spherical aberration'. The distance between the paraxial focus and the point at which the marginal ray strikes the paraxial focal plane is called 'lateral spherical aberration'.

If we move from F_M to F_p then at a position AB a bright circle is formed. This is called the 'circle of least confusion'. In general we consider this as the image.

Minimising Methods :

1. We can cut off the marginal rays with the help of a 'stop'. But the intensity is reduced.

2. By using of a crossed lens having a refractive index 1.5 and ratio of radii of curvature $-\frac{1}{6}$ we can minimise the spherical aberration.

3. With the help of two coaxial lenses separated by a distance.

Conditions for two lenses on the same axis separated by a distance to minimise spherical aberration.

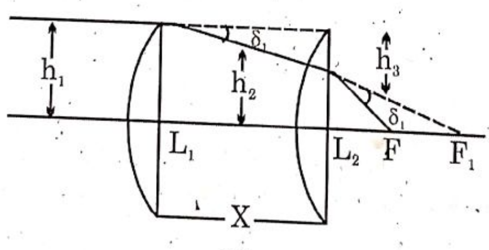


Fig.

Two lenses L_1 and L_2 of focal lengths f_1 and f_2 are placed at a distance X on the same axis.

A light ray parallel to the axis is touching the first lens at a height of h_1 and deviating through an angle δ_1.

$$\therefore \delta_1 = \frac{h_1}{f_1} \quad \text{-----(1)}$$

This emergent ray is touching the second lens at a height h_2 and gets deviated through an angle δ_2.

$$\therefore \delta_2 = \frac{h_2}{f_2}$$ -----(2)

But $h_2 = h_1 - h_3$

$$\therefore \delta_2 = \frac{h_1 - h_3}{h_2}$$ -----(3)

As δ_1 is small

from fig. $\delta_1 = \tan \delta_1 = \frac{h_3}{X}$ $h_3 = \delta_1 X$

From (1), $h_3 = \frac{h_1 X}{f_1}$ Substituting in (3) $\delta_2 = \frac{h_1}{f_2} - \frac{h_3}{f_2} = \frac{h_1}{f_2} - \frac{hX}{f_1 f_2}$ -----(4)

If the spherical aberration is to be reduced then the deviation of the marginal rays be reduced. If the deviations produced by the two lenses are equal then the total deviation is minimised.

So,

$$\delta_1 = \delta_2$$

From (1) and (4) $\frac{h_1}{f_1} = \frac{h_1}{f_2} - \frac{h_1 X}{f_1 f_2}$ $\frac{1}{f_1} = \frac{1}{f_2} - \frac{X}{f_1 f_2}$ $\frac{X}{f_1 f_2} = \frac{1}{f_2} - \frac{1}{f_1}$

$\therefore X = f_1 - f_2$

Thus, by placing the two lenses at a distance equal to the difference of their focal lengths the spherical aberration can be reduced.

Q. 2. State and explain chromatic aberration and derive equation for longitudinal chromatic aberration.

Ans : The image of a white object formed by a lens is coloured and blurred. This defect of image is known as chromatic aberration. This is due to the inability of lens to focus all the colours at one point. The refractive index of the material of the lens is different for different colours. or appear to be converged. Thus different colours will be converged or appear to be converged at different points on the axis of the lens.

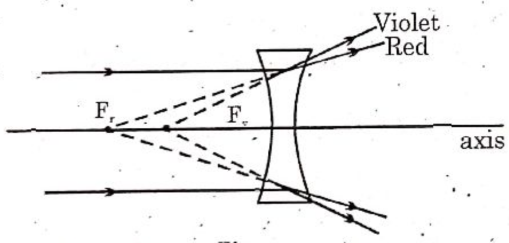


Fig.

Explonation :

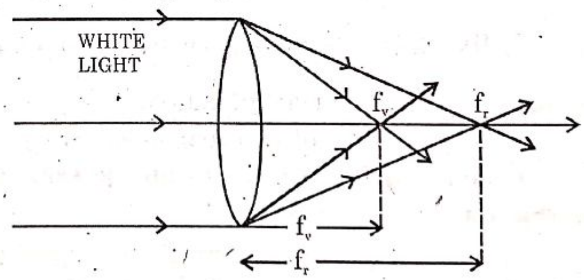


Fig.

For a thin lens,

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Different colours have different values for μ. So different colours have different focal lengths.

If μ_v is the refractive index for violet, μ_r is the refractive index for red, we know $\mu_v > \mu_r$.

$\therefore f_v < f_r$

Hence the violet rays meet the axis at a point F_V near the lens and the red rays at a point F_r far from the lens.

The distance between F_r and F_V is $(f_r - f_v)$ is called the longitudinal chromatic aberration.

When an object is situated at infinity, the focal length of a lens is given by

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

If f_V, f_R and f_y be the focal lengths of lens for Violet, Red and Yellow colours and μ_V, μ_R and μ_y be the refractive indices then

$$\frac{1}{f_v}=(\mu_V-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \text{--------(1)}$$

$$\frac{1}{f_R}=(\mu_R-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \text{--------(2)}$$

$$\frac{1}{f_Y}=(\mu_y-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \text{--------(3)}$$

Subtracting eq.(2) from eq. (1)

$$\frac{1}{f_V}-\frac{1}{f_R}=(\mu_V-\mu_R)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$\frac{f_R-f_V}{f_Vf_R}=\frac{\mu_V-\mu_R}{\mu_Y-1}(\mu_Y-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

But $f_Vf_R=f_Y^2$

$$\frac{f_R-f_V}{f_Y^2}=\frac{\mu_V-\mu_R}{\mu_Y-1}\cdot\frac{1}{f_Y} \text{ (from eq.3)}$$

$$\frac{f_R-f_V}{f_y}=\omega\left[\because \omega=\frac{\mu_V-\mu_R}{\mu_Y-1}\right]$$

$f_R-f_V=\omega f_Y$

Where f_R-f_V= Longitudinal chromatic aberration.

Q. 3. Explain the defect "Coma" in a lens. How is it reduced?

Ans : Coma: When a lens is corrected for spherical aberration, it forms a point image of a point object situated on the axis. But when two point object is situated. Slightly off the axis, the image of the point object formed by the lens is found to have an egg-like (or comet like) shape. This defect in the image is called "Coma" after its shape.

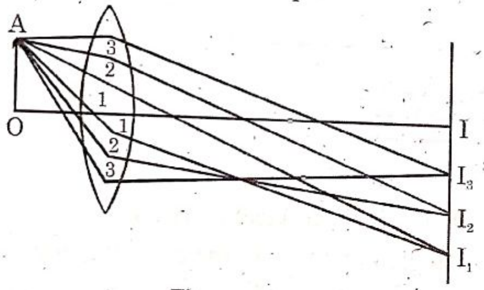


Fig.

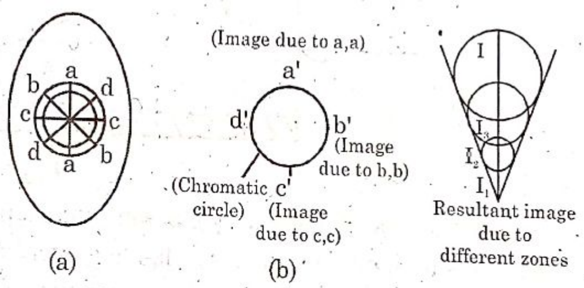


Fig.

Explanation : Let us consider an of axis point in the object. Rays leaving the off axis point A in the object and passing the optic centre of the lens meet at B. The rays leaving A and passing through the different zones of the lens such as (1,1) ; (2,2) ; (3,3) etc are brought to focus at different points B_1 , B_2 -----etc, gradually nearer to the lens. On the screen placed at B perpendicular to the axis these form circles of increasing diameters from B. This defect is known as "Coma". It arises due to the following reasons.

1) Different zone of the lens produce different lateral magnifications.

2) Each zone, forms the image of a point in the form of a circle.

Elimination of coma : (1) Coma may be reduced to a certain extent by using a proper stop, of suitable diameter and arranged at a suitable distance from the lens. This restricts the outer zones and allows only the central zones to refract the rays.

(2) It may be reduced by designing lenses of suitable shapes and materials. For example, a lens with μ = 1.5 and $\left(\frac{R_1}{R_2}\right)=-\left(\frac{1}{9}\right)$ forms an image of an object, at finite distance, sufficiently free from coma. Both spherical aberration and coma are completely eliminated for "aplanatic points".

(3) Above showed that lenses are completely free from spherical aberration and coma, if the following sine condition is satisfied.

$\mu_1 y_1 \sin\theta_1 = \mu_2 y_2 \sin\theta_2$

Where μ_1 and μ_2 are the refractive indices of the object and image regions respectively. y_1 and y_2 are the heights of the object and image and θ_1 and θ_2 are the angles which the incident and conjugant emergent rays make with the axis.

Q. 4. What is an Optical fibre ? Describe construction and working principle of Optical Fibre.

Ans : An Optical fibre is hain-thin transparent medium which guides information carrying light waves from one end to the other.

An optical fibre consisting of "core" of high quality glass of diameter about 100 μm, surrounded by a "cladding" glass of slightly lower refractive index. Total diameter of fibre is of the order of 120 μm to 140 μm. This fibre is coated with polymer to protect the fibre against chemical, mechanical attacks especially the humidity. And finally for strengthening it another coating is applied.

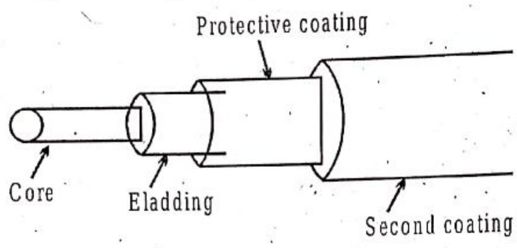


Fig.

Working Principle :

The Optical fibre works on the principle of "Total internal reflection".

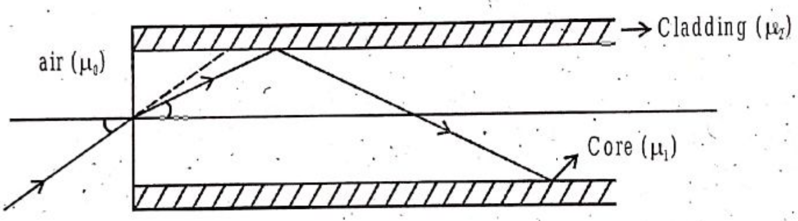


Fig.

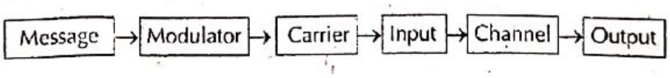
Fibre optics was developed by Hopkins and Kapany of U.K. and Van Heel of Holland.

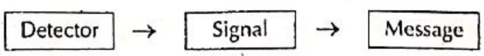
Light rays inpigning on the core cladding interface at an angle greater than the critical angle, rays under go "Total internal reflection" and are trapped inside the core of the fibre. If μ_1 is the retractive index of core material and μ_2 that of cladding material, then the critical angle at the core cladding interface is $\sin^{-1}\left(\frac{\mu_2}{\mu_1}\right)$. Under this condition the ray will bounce from side to side along the fibre until it emerges out at the far end. The light signal is thus trapped in the fibre core; which acts as an optical wave guide.

How ever not all reflection angles are possible for a ray to be guided along the length of the fibre due to interference of parallel light waves. The result is that a discrete reflection angle is allowed following the condition that for two parallel rays striking the boundary at opposite ends of a diameter the difference in phase is "whole number times π - radians". For each of these allowable angles stable and self- reproducing interference pattern is formed as propagating modes in the fibre.

Q. 5. Explain the system for fibre optics communication ?

Ans : The basic optical fibre communication system parts is shown in fig.





The functions of different parts are discussed below.

1. Message origin : It converts a non electrical message into an electrical message. For ex, microphone is used for convesting sound waves into current and video (TV) camera for converting images into currents.

2. Modulator : It performs two main functions. Firstly it converts the electrical message into proper format and secondly it impresses this signal on to the wave generated by the carrier source.

3. Carrier source : The function of carrier source is to generate the wave on which the information is transmitted. The wave is known as carrier wave.

4. Channel Coupler (input) : The function of channel coupler is to feed power into the information channel. For ex, the channel coupler in radio or T.V broad casting system is an antenna.

5. Information channel : It provides a path between transmitter and receiver. Information channels are two types : unguided and guided channels.

6. Channel coupler (output) : In radio communication system, an antenna is a channel coupler which collects the signal from information channel and routes it to the receiver. In fibre system the output coupler directs the light emerging from the fibre on to the light detector.

7. Detector : The function of detector is to separate the information from the carrier wave. In fibre system, the optic wave is converted in an electronic current by photo detector.

8. Signal processor : Signal processing includes amplification and filtering of undesired frequencies in analog transmission.

9. Message output : Here the message is presented to a person. The person may either hear or view the information.

SHORT ANSWER QUESTIONS

Q. 1. Write a note on "Astigmatism".

Ans : Astigmatism : Definition : When a point object is situated far off the axis of a lens the image formed by the lens is not in a perfect focus. The image consists of two mutually perpendicular lines separated by a finite distance. Moreover, the two lines lie in perpendicular planes. This defect of the image is called as "astigmatism".

Explanation : Consider an off axis point *P*. The plane containing this point of observation and the axis is called Meridian plane of the lens. i.e., a plane containing P and the principal axis of the lens. A plane perpendicular to this plane is called Sagittal plane of the lens.

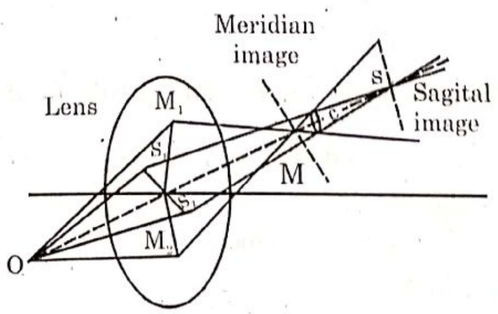


Fig.

The light rays in the meridian plane are focussed along a straight line at *T* called "tangential focus". The light rays in sagittal plane are focussed along a straight line called "sagittal focus". The distance *ST* is a measure of astigmatism. This is called "astigmatic difference".

When the screen is moved between S and T, the patch of the light reduces to a circle. This is known as the "circle of least confusion". This is the nearest approach to a point image.

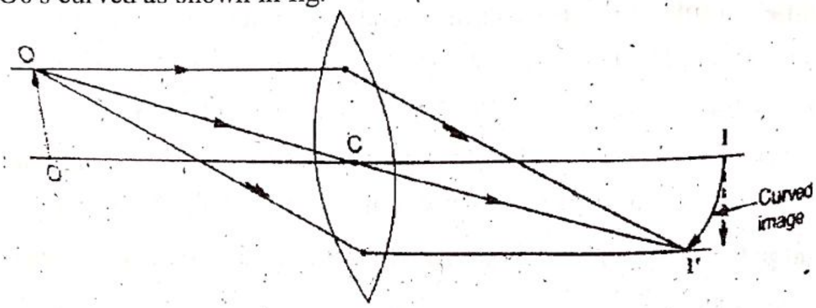
Removal of astigmatism : (1) The astigmatism is due to large inclination of the rays with the axis of the lens. So, if the rays making large angles with the axis are cut off by placing stop in the suitable position the lens may be corrected for astigmatism.

(2) For a system of several lenses, the astigmatism may be eliminated by adjusting their positions. Such systems are widely used as photographic objectives on which narrow pencils of rays are incident at large angles.

(3) In case a of concave lens, the astigmatic difference is negative. So, a suitable convex and concave lenses, separated at a suitable distance may be used to reduce the astigmatism. Such a combination of lenses is called "astigmatic combination'.

Q. 2. Explain about curvature ? (or) Write a short note on Curvature ?

Ans : When the lens is free from spherical aberration (Coma and astigmatism) the image of an extended plane object O0's curved as shown in fig.



Showing the defect of curvature.

Fig

If a screen is placed at I perpendicular to the axis of lens, then the image I'Will not be in focus but this is curved. This defeet is called Curvature. This arises due to the fact that points away from the axis, such as 0' are at a greater distance from the centre 'c' of the lens than the axial point O. There fore, the image I' formed smaller distance than I.

Elimination of curvature : The curvature may be removed by the following methods.

1. For a single lens, the curvature may be reduced by placing an aperture in a suitable position in front of the lens.

2. For a combination of lenses, the condition for absence of curvature is $\Sigma \frac{1}{\mu f} = 0$

In case of two lenses

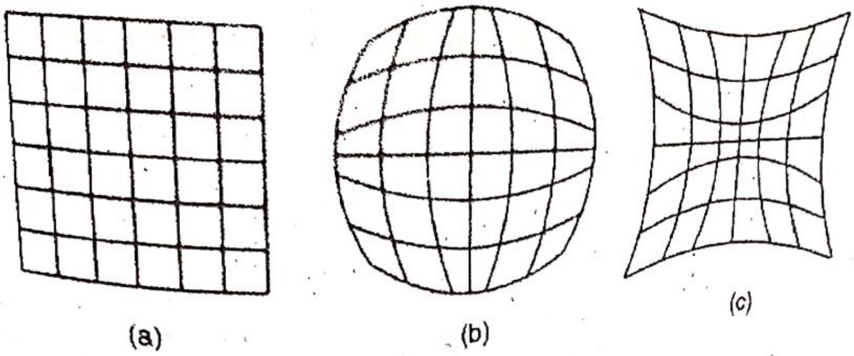
$$\mu_1 f_1 + \mu_2 f_2 = 0$$

Where μ_1 *and* μ_2 are refractive indices and f_1 and f_2 are the focal lengths of the lenses.

Here μ_1 *and* μ_2 are both positive so that f_1 and f_2 must necessarily be of opposite sign. If one of lens is convex then the other lens should be concave. The above condition holds good whether the lenses are in contact or they are separated at a certain distance.

Q. 3. Write a short note on distortion ?

Ans : The image of a plane aqelare like object placed perpendicular to the axis of the lens is not of the same shape i.e, it is distorted. This defect is known as distortion. This defect arises due to the fact the same lens produces different magnification for different axial distances. There fore different parts of the object suffer from different magnifications.



Fig

The distortion is of the two types :

a) Barial shaped distortion : When the real image of a rectangular piece of wire guage (in fig b) formed on the screen by convex lens appears like a barrial shaped. So it is known as barrel shaped. distortion.

b) Pin-Cushion distortion : When the image of a rectangular object formed by a convex lens is like shown in fig (c). The defeet is known as pin-cushion distortion. In this case, the magnification increases with increasing axial distance fears the centre.

c) Removal of distortion : The distortion can be removed by using a combination two similar meniscus convex lenses, with their concave surfaces facing each other and placing an aperturee stop in the middle as shown in fig. Such a combination is called as an or thoscopic doublet or a rapid rectilinear lens.

Q. 4. How is the chromatic aberration minimised in achromatic doublet?

Ans : The combination of two lenses made up of materials with different dispersion powers, kept in contact to avoid chromatic aberration is called an 'achromatic doublet'.

Let two lenses of focal lengths f_1, f_2 and dispersive powers w_1, w_2 are placed in contact. Let F be their combined focal length.

Then,

$$\therefore \frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \quad \text{-----(1)}$$

For a thin lens,

$$\therefore \frac{1}{F} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \text{----(2)}$$

differentiating $$-\frac{\delta f}{f^2} = \delta\mu\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

From (2) we have $$-\frac{\delta f}{f^2} = \delta\mu \frac{1}{f(\mu-1)}$$

$$\therefore -\frac{\delta f}{f} = \frac{\delta\mu}{\mu - 1}$$

But $\frac{\delta\mu}{\mu - 1} = \omega$ (dispersive power)

$$\therefore -\frac{\delta f}{f} = w = \frac{d\mu}{(\mu - 1)} \quad \text{-----(3)}$$

By differentiating equ.(1) $$-\frac{\delta F}{F^2} = -\frac{\delta f_1}{f_1^2} - \frac{\delta f_2}{f_2^2}$$

For achromatism all the colours must focus at same point i.e., F, constant for all colours.

$\therefore \delta F = 0$

$$\therefore -\frac{\delta f_1}{f_1^2} - \frac{\delta f_2}{f_2^2} = 0 \quad \therefore \frac{w_1}{f_1} + \frac{w_2}{f_2} = 0$$

$$\therefore \frac{w_2}{f_2} = -\frac{w_1}{f_1}$$

$$\therefore \frac{f_1}{f_2} = \frac{w_1}{w_2} \quad \text{------(4)}$$

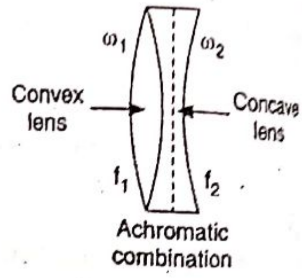


Fig.

negative sign indicates if one of the lenses is converging, then the other must be diverging. Hence for an achromatic doublet the ratio of the focal lengths of the two lenses must be equal to the ratio of their dispersive powers.

In an achromatic doublet convex lens is made up of crown glass and of low focal length.

Concave lens of greater focal length is made up of denser Flint glass.

Q. 5. Derive the condition for minimum chromatic aberration when two lenses made up of same material are co-axially separated by a distanced.

Ans : Two lenses with focal lengths f_1 and f_2 and dispersive powers ω_1 and ω_2 are placed at a distance t on the same axis. If F is the combined focal length of the system then

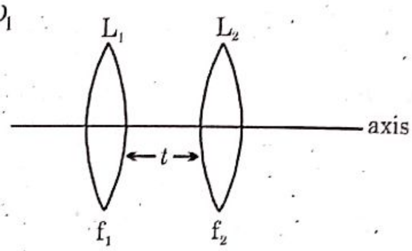


Fig.

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{1}{f_1 f_2} \quad \text{----(1)}$$

Differentiating

$$-\frac{\delta F}{F^2} = -\frac{\delta f_1}{f_1^2} - \frac{\delta f_2}{f_2^2} - t\left[\frac{1}{f_1}\left(-\frac{\delta f_2}{f_2^2}\right) + \frac{1}{f_2}\left(-\frac{\delta f_1}{f_1^2}\right)\right]$$

$$= -\frac{\delta f_1}{f_1^2} - \frac{\delta f_2}{f_2^2} - \frac{t}{f_1 f_2}\left[\left(-\frac{\delta f_2}{f_2}\right) + \left(-\frac{\delta f_1}{f_1}\right)\right] \quad \text{----(2)}$$

For achromatism $\delta F = 0$

and $\omega_1 = -\frac{\delta f_1}{f_1}$, $\omega_2 = -\frac{\delta f_2}{f_2}$,

$$\therefore D = \frac{\omega_1}{f_1} + \frac{\omega_1}{f_2} - \frac{t}{f_1 f_2}(\omega_1 + \omega_2) \quad \text{-----(3)}$$

If the two lenses are made up of the same material then

$\omega_1 = \omega_2 = \omega$ (say)

$$\therefore \frac{\omega}{f_1} + \frac{\omega}{f_2} - \frac{t}{f_1 f_2}(2\omega) = 0$$

$$\therefore \frac{1}{f_1} + \frac{1}{f_2} - \frac{2t}{f_1 f_2} = 0 \qquad \frac{f_1 + f_2}{f_1 f_2} = \frac{2t}{f_1 f_2}$$

$$\therefore t = \frac{f_1 + f_2}{2} \quad \text{---(4)}$$

Hence the two lenses made of same material separated by a distance equal to the average of their focal lengths, minimise the chromatic aberration.

Q. 6. Explain the types of optical fibres ?

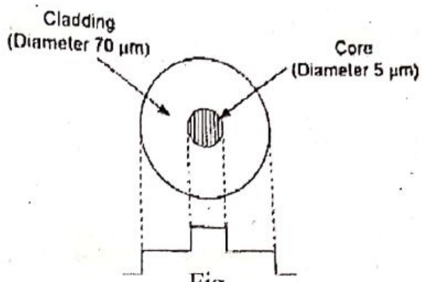
Ans : The optical fibres are classified into two categories based on :

1. The number of modes and 2. The refractive index.

1. Classification of fibre based on number of modes : on the basis of number of modes of propagation, the optical fibres are classified into two types.

a) Single mode fibre, b) Multi mode fibre.

a) Single mode fibre : It is shown in fig. It has smaller core diameter (5 μ m) and high adding diameter (70 μ m). The difference between the refractive indices of the core and the cladding is very small. In single mode fibre only one mode can propogate through the fibre. There is no dispersion. this fibres are more suitable for long distance communications such as telephone lines. The light is passed into single-mode fibre through laser diodes. The fabrication such fibers is very difficult and so they are costly.



Fig

b) Multi mode fibre : The multi mode fibre is shown in fig. It has larger core diameter than single mode fibre. The core diameter is (40 μ m) and that of cladding is (70 μ m). The relative refractive index difference is also larger than single mode fibre. Multimode fibre allows a large number of modes for the light says travelling through it. There is signal degradation due to multimode dispersion. They are not suitable for long distence communication due to large dispersion and attention of the signal. The fabrication of multi-mode fibre is less difficult and so the fibre is not costly.

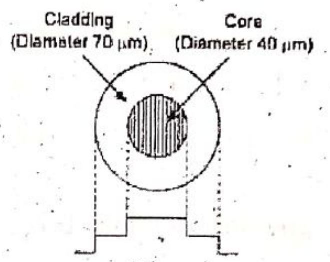
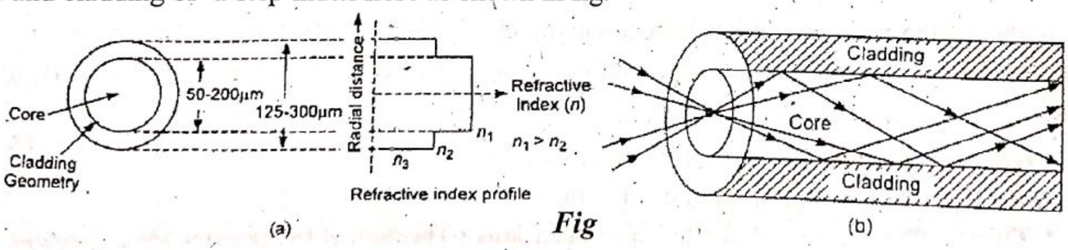


Fig.

2. Classification of fibre based on refractive index : There are two types of optical fibres viz.

1. Step-index optical fibre
2. Graded-index optical fibre.

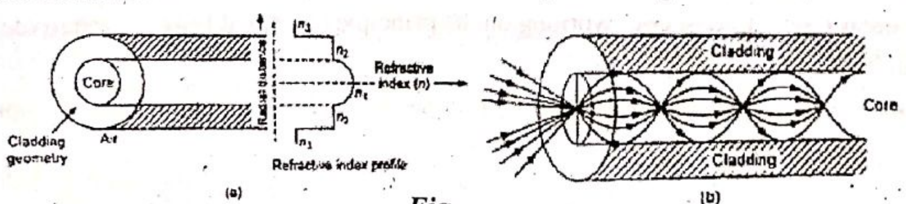
1. Step-index optical fibre : In this the core has a uniform refractive index (say n_1) and the cladding has also a uniform refractive index (Say n_2) of $n_1 > n_2$. Let 'a' and 'b' the radi of core and cladding respectively. The refractive index profile and radices of core and the reflactive index profile and radices of core and cladding of a step index fibre as shown in fig.



Fig

As the diameter of the core is high, there fore, more number of modes of propagation of light can be possible. So the fibre also called as multi-mode step index fibre.

2. Graded-index optical fibre : If the core has a non-uniform refractive index that gradually decreases from the centre towards the core-cladding interface, the fibre is called graded-index fibre. The cladding has a uniform reflactive index. The reflactive index profile of graded index fibre is shown in fig.

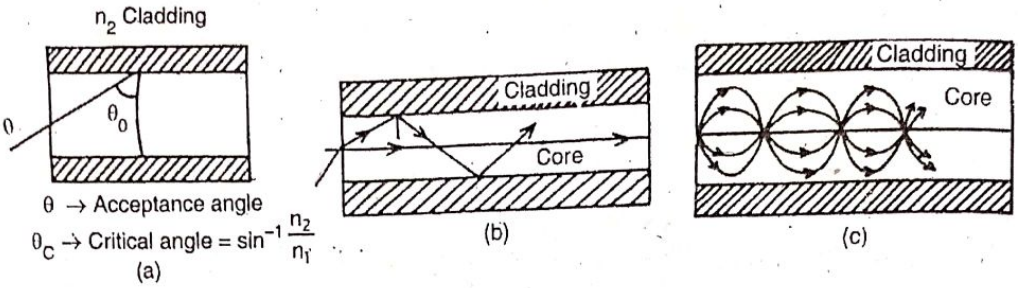


Fig

The core and cladding diameters are about 50 μ m and 70 μ m respectively in case of multi mode fibre.

Q. 7. Explain Ray and optic representation of optical fibre ?

Ans : The optical fibres are based on the principle of total internal reflection. The optical fibres are made either glass or plastic. This is shown in fig.



Fig

When light is incident on one end of the fibre at small angle, it passes through the fibre as explained below. Let 'i' be the angle of incidence of the light say with the axis and r be the angle of refraction. If θ be the angle at which the ray is incident on the fibre boundary. then $\theta = (90 - r)$. Suppose n_1 be the refractive index of fibre. If $\theta \geq \theta_c$ critical angle where $\theta_c = Sin^{-1}\left(\frac{1}{n_1}\right)$ then the ray is totally internally reflected. In this way the ray undergoes repeated total internal reflections until it emerges out of the other end of the fibre.

In the step-index fibre the light rays propagate through it are in the form of meridional rays which cross the fibre axis during every reflection at the core-cladding boundary. Fig shows paths of says in step-index fibre. Wehave shown two rays entering at different angles of incidence with the axis. The two says travels different paths. It is obvious from the figure that an input pulse gets widened as it travels along the fibre.

In graded index fibre light rays propogates through it in the form of skew rays or helical rays. They do not cross the fibre axis at any path and are propagating around the fibre axis in helical or spiral manner. The paths of the rays in multimode graded index fibre are shown in fig.

In the fig, the say is continuously bent and travels a periodic path along the axis. The rays entering at different angles follow different paths with the same period, both in space and time. Thus, there is a periodic self focusing of the rays.

Q. 8. What are the applications of Fibre optics.

Ans : Optical fibres are used in diverse fields.

1. Optical fibres are used in telecommunications : The optical frequencies are extremely large (~ 10^{15}Hz). So, it is capable of carrying more information than a radio wave. It is reported that 140 M bits/sec information can be send through single fibre. Which is equivalent to 450,000 voice channel-k.m. More over optical fibres are cost effective more reliable and disturbance free.

2. Optical fibres are used in sensing systems : A fibre optic sensing system can gather information about an environmental parameter like pressure, voltage current etc.

3. Medical Use : "Endoscope" working on the principle of optical fibre is used to see the inner parts of the human body.

4. Fibre Optic technologies are used in Opto-electronics, heterodyning systems, optical switching etc.

— O —

UNIT - V

LASERS AND HOLOGRAPHY

LONG ANSWER QUESTIONS

Q. 1. Derive the relation between Einstein coefficients.

Ans : Einstein coefficients explain. The probable occurance of absorption and spontanious and stimulated emission of radiation.

The probable rate of absorption transition from lower state 1 to higher state 2 depends on the energy density of incident radiation u(v).

i.e $P_{12} \propto u(\nu)$

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

The probability of spontanious emission depends only on the nature of states 1 and 2.

i.e., $P_{21} = A_{21}$

But stimulated emission depends on $u(\nu)$

$\therefore P_{21} = A_{21} + B_{21}\, u(\nu)$ ------(2)

Here A_{21}, B_{12} and B_{21} are known as Einstein coefficients.

Let N_1 and N_2 be the number of atoms in state 1 and 2 respectively.

The number of atom instate 1 that absorb a photon and rise to state 2 is given by

$N_1 P_{12} = N_1 B_{12}\, u(\nu)$ -----(3)

The number of atoms that cause emmission is given by

$N_2 P_{21} = N_2 [A_{21} + B_{21}\, u(\nu)]$ -----(4)

In the equilibrium state absorption and emission must be equal.

i.e $N_1 P_{12} = N_2 P_{21}$

$$N_1 B_{12}\, u(\nu) = N_2 [A_{21} + B_{21}\, u(\nu)]$$

$$= N_2 A_{21} + N_2 B_{21}\, u(\nu)$$

$$u(\nu)\, [N_1 B_{12} - N_2 B_{21}] = N_2 A_{21} \qquad u(\nu) = \frac{N_2 A_{21}}{(N_1 B_{12} - N_2 B_{21})}$$

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

According to Boltzman distribution law the number of atoms N_1 and N_2 in energy states E_1 and E_2 in equilibrium is given by

$$N_1 = No\, e^{-E_1/KT}\ ;\ N_2 = No\, e^{-E_2/KT}$$

$$\therefore \frac{N_2}{N_1} = \frac{e^{-E_2/KT}}{e^{-E_1/KT}} = e^{-(E_2 - E_1)/KT} = e^{-h\nu/KT} \qquad \text{where } E_2 - E_1 = h\nu$$

$$\frac{N_2}{N_1} = e^{-h\nu/KT} \qquad \text{------(6)}$$

$$\therefore u(\nu) = \frac{A_{21}}{B_{21}} \frac{1}{\left[e^{h\nu/KT}\left(\frac{B_{12}}{B_{21}}\right) - 1\right]} \qquad \text{-----(7)}$$

According to Plank's law,

$$u(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{\left(e^{h\nu/KT} - 1\right)} \quad \text{------(8)}$$

Comparing (7) and (8)

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3} \quad \text{and} \quad \frac{B_{12}}{B_{21}} = 1 \text{ or } B_{12} = B_{21}$$

From above equalities,

As $B_{12} = B_{21}$, The probability of stimulated emission is same as induced absorption.

$\frac{A_{21}}{B_{21}} \propto \nu^3$ i.e. This shows that the probability of spontaneous emission increases rapidly with energy difference between two states.

Q. 2. Describe the construction and working of Ruby Laser ?

Ans : Ruby Laser is a solid laser. Main parts of the LASER.

i) Active working material : It consists of Al_2O_3 rod 5mm diameter and 30 to 50 cm long cylindrical rod in which some Al_2O_3 molecules are replaced by cromium atoms (Cr_2O_3) at about, it is called as ruby rod. The active material is Cr^{+3} ions.

ii) Resonant Cavity : The end faces of the rod are made strictly parallel and polished to a high degree. Then the end faces are silvered in such a way that one face is fully reflecting and the other end face is partially reflecting. The space between two mirrored faces is known as resonance cavity. The distance between the two end mirrors, L must be as per the equation,

$$\nu = \frac{mc}{2L} - \frac{\alpha C}{2\pi L}$$

where ν – Laser frequency, m – Integral multiple, α – Phase change in reflection, L – Length of the rod.

If the mirrors are non parallel or the above equation is not satisfied, no laser beam will be produced. Such lasers are dead lasers.

(iii) Pumping system : A helical xenon flash tube is arranged round the ruby rod. This tube gives light in green region. This green light is absorbed by Cr^{+3} ions and yield to lasing action producing monochromatic laser beam.

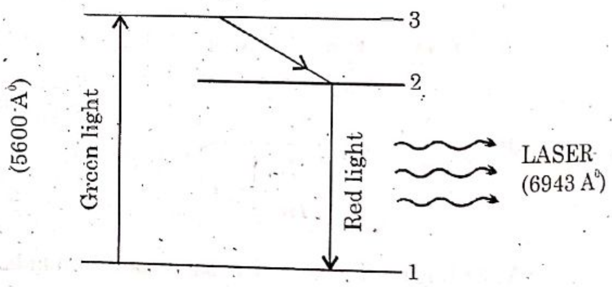


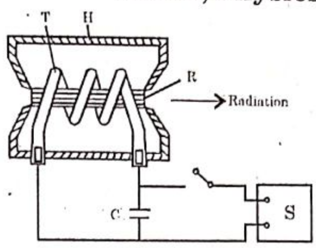
Fig.

Ruby crystal consists of aluminium oxide Al_2O_3 with chromium as impurity. The energy levels due to chromium are used in ruby laser. They are shown as 1 and 2 in figure. When the ruby crystal is illuminated by very intense green light, more than half of the chromium, atoms contained in the crystal, can be transferred to level 2, i.e., to obtain an 'unnatural' ratio between the population of the levels required for the working of lasers.

The design of a Ruby laser is shown in the figure.

A pumping flash of green light appears when capacitor C is discharged through a gas discharge tube T contained in a reflecting house H. The tube T forms a spiral around ruby rod R having accurately polished plane parallel faces to which mirror coats are applied. As soon as the pumping flash accumulates a sufficient surplus of atoms is level 2 (first figure) as compared with level 1, the lasers action begins. The photon get reflected between the two parallel surfaces of the ruby crystal for a number of times. As the distance between the two faces is kept equal to the integral multiple of the wavelength of the light formed by the photons, the light corresponding to this wavelength increases and the light having a different wavelength is diminished by the destructive interference. When the emission of photons overtaken the absorption in the ruby crystal a light beam with tremendous intensity is created and it comes out through one of the plane surfaces of the ruby crystal which is partially silvered.

In ruby lasers, a very great surge of energy is put into the flash lamp, which in turn gives off a '*burst*' of very intense light and the ruby crystal laser. This process is then repeated and the crystal laser with each burst. The ruby lasers are therefore, known as pulsed lasers.



Q. 3. Describe the construction and working of He-Ne laser ?

Ans : In general, atoms in the excited state emit quanta of light and tries to come to the ground state. Thus there will be more number of atoms in the ground state or lower energy level than those in the excited state or lower energy level.

If more atoms can be kept in the proper excited state than those in the ground state that is known as population inversion.

The gaseous lasers such as *He–Ne* lasers can be pumped into excited states continuously and are called continuous wave (*CW*) lasers.

In solids, the energy levels formed by different phenomena are very close to each other. But energy levels in gases are formed by electrons only and are far from each other. That is why, the spectral lines in the spectra formed by gases are very sharp. More over in gases the transitions from the excited states are very much delayed. Thus gases are perfect media for the production of a monochromatic laser beams. This gas is contained in a glass tube and placed between appropriate mirrors.

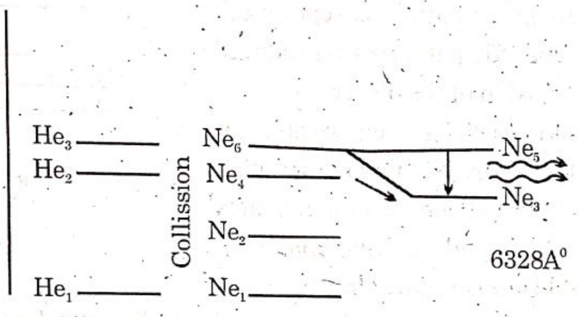


Fig.

The most common of this type is the helium–neon laser that was ten parts helium and one part neon. The neon atom provide the energy states for the transitions while the helium provides a mechanism for efficiently exciting these neon atoms to upper metastable states. The figure shows the energy level diagram for the important states in the helium and neon.

When an electric field is applied across the laser, electrons collide with helium atoms and drive them into the upper states labelled He_2 and He_3. These are metastable states. Thus the atoms remain in these excited states long enough to interact with neon atoms in the ground state. This interaction exites the neon atoms to their metastable states., labelled Ne_4 and Ne_6, where they stay until laser transitions take place from these states to the states labelled Ne_3 and Ne_5, respectively. The lasing transitions that take place and are reinforced to produce the laser beam depend on the construction of the glass envelop and mirrors. This is controlled by choosing a mirror with maximum reflectivity at the wavelength desired. These lasers are continuous because the collision process maintains the energy states Ne_6 and Ne_4 at large population invesion gives continuous lasing action.

The figure 64 shows the *He–Ne* gas laser which produces stimulated emission and hence a valence of photons. This gas laser uses mirrors that reflect as much as 95% of the radiation back into the tube. The 'Brewster windows' shown are not necessary for lasing, but they are frequently used since they make more efficient use of the radiation available, and they cause the lasing radiation to be photons are produced so that more

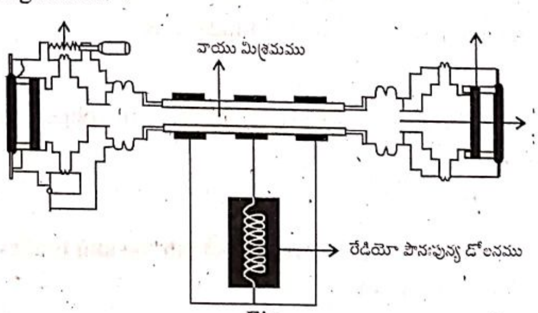


Fig.

Photons are produced than polarised. Thus, photons of the proper frequency are sent back into the tube to produce a cascade of similar photons. When enough absorbed, lasing begins. The output mirror is generally a dielectrically coated mirror that reflects most of the radiation back into the tube but also allows part of it to leave the lasers.

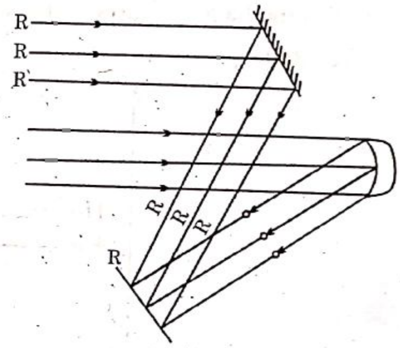
Q. 4. Write an essay on Holography ?

Ans : The word "Holography" originates from the greek "holes" meaning "The Whole" by this word it gives the meaning of whole information about the wave both about its amplitude and its phase " Denis Gabor in 1948 invented this type of recording. In 1963 E.Heith and J.Upatneiks prepared laser holograms for the first time.

Holography is a process by which the image of an object can be recorded by wavefront reconstruction. It does not record the image of the object being photographed but records the light waves themselves. The record of light waves thus produced is called a hologram.

Principle : When an object is illuminated by light from a coherent source, each point on the object becomes a source of secondary waves. These secondary waves (0,0,0) spread out it in the surrounding medium, with amplitudes characteristic of the different points in the object. The reflected waves are also coherent and the path differences depend on the counters of the body. These interfere and the interference pattern is produced. This pattern is characteristic of the object alone.

The amplitude pattern recorded in a suitable way in a hologram. When this record is illuminated with a coherent source again, the original amplitude pattern is reproduced giving rise to the original amplitude pattern is reproduced giving rise to the original impression of the object.

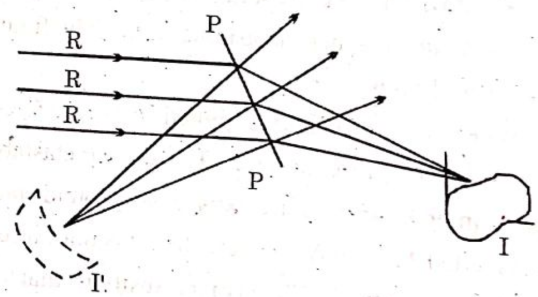


Recording : The laser beam is divided into two different beams. The first beam (R,R,R) is reflected into photographic plate P by means of a mirror. The second beam illuminates the object. Now the film is exposed simultaneously to reference beam and reflected beam from the object.

Since both the beams belong to the same laser wavefront, they interfere in the photographic plate.

Thus we obtain a characteristic interference pattern on the film. This film is called a hologram.

Reconstruction of the image : Remove the object and put the hologram in the place where it was when formed. Now look through the hologram, one will see the object at its previous position. When reference laser beam is directed at the hologram, part of the light is diffracted through the hologram forming 3-dimensional image. It form virtual image also. The real image can be photographed without the aid of lenses.



Theory : (i) Recording of Hologram : Let us consider small object , O illuminated by a source of light. The photographic place receives direct light and light diffracted from the object. The direct wave can be represent by a plane wave from of amplitude E_r as

$$E_r = A_r e^{i(kz-\omega t)} \qquad \text{------(1)}$$

The reflected wave fronts from the objects are spherical and so can be represented.

$$E_e = \frac{A_0}{r} e^{i(Kr-\omega t)} \qquad \text{------(2)}$$

The photograph receives both the amplitudes

i.e $E = E_r + E_s$

$$I = |E_r + E_s|^2$$

$$= |A_r|^2 + \left|\frac{A_o}{r^2}\right|^2 + \frac{A_o A_r}{r} e^{iK(r-z)} + \frac{A_o A_r}{r} e^{iK(z-r)}$$

The above equation can be simplified by choosing constants K and θ.

$$\therefore I = |A_r|^2 + \frac{(A_o)^2}{r^2} + K\frac{\cos[K(r-z)+\phi]}{r}$$

First two terms gives the amplitudes distribution on the film. The third term gives the interference pattern of the plane wave E_o with spherical wavefront E_s. Thus produces a set of circular interference fringes on the film.

(ii) Reconstruction : The power of transmission of holographic plate is given by

$T^2 = 1 - Ia$

where a is a constant

$$T \sim 1 - \frac{1}{2} I\alpha$$

When the hologram is illuminated by light, the transmitted light is given by

$E_r = T E_r$

$$= \left(1 - \frac{1}{2} I\alpha\right) A_r e^{i(Kz-\omega t)}$$

Substituting I value in above eqn

$$= \left[1 - \frac{\alpha}{2}|A_r|^2 - \frac{\alpha}{2}\frac{|A_r|^2}{r^2}\right] A_r e^{i(Kz-\omega t)} - \frac{\alpha}{2}\frac{A_o A_r}{r} e^{iK(r-z)} A_r e^{i(Kz-\omega t)} - \frac{\alpha}{2}\frac{A_o A_r}{r} e^{iK(z-r)} A_r e^{i(Kz-\omega t)}$$

In the above equation, first term represents alternated incident wave.

The second term represents the virtual image and the third term represents real image.

Properties of hologram : (i) The hologram acts like a diffraction grating. It produces two first order diffracted beams. One beam forms real image and the other virtual image.

ii) Each section of hologram is capable of producing image of entire object.

iii) The viewer always sees a positive image whether a positive or negative hologram is used.

iv) The information about a point object is recorded over the whole area of the hologram.

v) A single hologram can be used to record waves from several objects or several states of the same object and reconstruct several constructively recorded images.

Applications of holography :

Holography has wide range of application in science and technology.

i) It can be used to study the image formed by sound.

ii) The distribution of strain suffered by a body can be studied.

iii) In cinematography and television three dimensional images can be produced.

iv) It is used in microscopic study.

v) It is used in spatial filteration and character recognition.

SHORT ANSWER QUESTIONS

Q.1. State and explain spontaneous and stimulated emission of radiation.

Ans : Spontaneous emission : Light is absorbed or emitted by particles during their transitions from one energy state to another. The atom absorbs a photon and goes to higher energy state. The excited atom after short interval of time 10^{-8} sec, it falls to its lower energy state by emitting a photon.

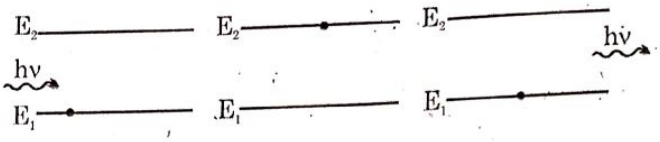


Fig.

The excited atom jumps back to its ground state on its own accord. "Thus the emission of radiation with out external influence is known as spontaneous emission." This emission depends on the type of the atom and type of transition. The spontaneous emission is random. So, the radiation contains different wavelengths and is in coherent. It has broad spectrum.

Stimulated emission : Suppose and atom is already in excited state E_2 at this moment a photon of energy $h\nu = E_2 - E_1$ is incident on the atom. The incident atom stimulates the emission of similar photon. Now the atom returns to the ground state in time much sooner than 10^{-8} sec.

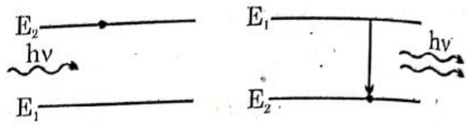


Fig.

"This the process of speeding up the atomic transition from the excited state to ground state is called stimulated emission". The stimulated emission is proportional to the intensity of incident radiation.

The emitted radiation is coherent with incident photon. It has the same frequency and phase as the incident photon. These photons in turn stimulate two more atoms. Thus they form the source of intense and coherent monochromatic LASER beam.

Q. 2. Distinguish between spontaneous and stimulated emission.

Ans : The distinction between spontaneous and stimulated emission is as follows.

Spontaneous emission	Stimulated emission
1. Transition occurs from a higher energy level to a lower energy level.	1. Transition also occurs from higher energy level to lower energy level.
2. No incident photon is required.	2. Photon whose energy is equal to the difference of two energy levels is required.
3. Single photon is emitted.	3. Two photons with same energy are emitted.
4. The energy of emitted photon is equal to the energy difference of two levels.	4. The energy of the emitted photons is double the energy of stimulated photons.
5. This was postulated by Bohr.	5. This was postulated by Einestein.
6. It is instantanious process.	6. It is induced process.

Q. 3. Give a brief note on Population inversion.

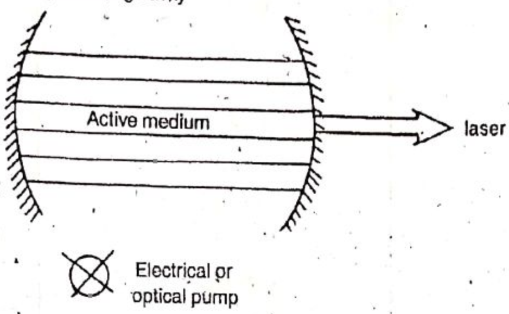
Ans : In the process of Laser operation, an incident photon of right frequency can produce atomic transitions either upward or downward. Both Processes can occur with equal probability. In the upward transition the incident photons are absorbed by the atoms. It decreases the intensity of the radiation. In the downward transition, photons coherent with the incident photons are emitted. It increases the intensity. The total change in the intensity depends upon the process which predominates. In a normal condition there are number of atoms in the ground state than in the excited high energy states. Hence the probability of the absorption of photons is more than the stimulated emission. If by some means a large number of atoms are made available in the excited state than in lower state, stimulated emission is increased. The condition where the number of atoms in the excited state exceeds that in the lower state is called "Population Inversion".

Q. 4. Explain the principle of Laser ?

Ans : Each and every system consists of an active medium having ions or molecules or atoms possessing at least one meta stable state. The active medium is placed in resonating cavity having reflectors at its ends and an electrical or optical pump to excite the atoms of the medium.

The basic principle of all lasers is to first bring about population inversion, i.e., to have more atoms in the metastable state than that in the ground state. This is done by supplying suitable energy to the atoms of the active medium with help of a pump. This process of bringing about population inversion is known as fluroscent or phosphorescent photon.

As this photon happens to pass near by other atom, in similar metastable states, stimulates them to de-excite to emit similar photons which in turn make other atoms to de exite. Before these photons escape from the active medium, they are made to move to and fro in the medium several times a second by reflections so as to build up an intense beam of photons by de-exciting more and more atoms of the medium. All photons emitted in this way are found to possess same frequency, direction and speed as that of primary photon or stimulating photon. This constitutes a leaser beam. To obtain continuous supply, the pumping is continued.



Fig

Q. 5. What are the applications of Laser?

Ans : The laser beam has two special features not available in light from ordinary sources.

i) Narrow band width : This results in high monochromaticity or high temporal coherence of a laser beam.

ii) Narrow angular spread : In usual sources of light each emission occurs in random direction, so that a directional beam is obtained by using a limited aperture and a collimator. In contrast in laser the emission from different atoms are coherent in phase and direction so that the radiations come out as a parallel beam. That is why the energy flux in a laser beam is very high. Thus narrow angular spread results in high directionality and hence high intensity or large spatial coherence.

Due to high monochromacity, high directionality and coherence a laser beam may be conveniently used for interference experiments.

The narrow band width of a laser beam gives rise uses of lasers typically in communication systems and computers.

Lasers are used in Raman spectroscopy : Using Laser beam Raman spectrum can be obtained from much smaller samples and faster too. High directionality of laser beam enables laser Raman spectra to show finer details of energy level separation of molecules, while high intensity leads to additional information.

Narrow angular spread of laser beam makes it a very useful tool for communication with earth satellites and rockets to moon and other planets. The earth moon distance has been measured accurately with the use of lasers.

The narrow angular spread of a laser beam results in focussing of laser beams on very small areas of the order of $10^{-10}m^2$. As a result with a laser of only ~0.1 watt power, an image of intensity ~ 10^9 watt/m^2 may be obtained. These considerations lead to the use of lasers in industry and medicine. In industry a laser beam can bore a narrow hole through thick sheets of metal; because it melts the metal where it falls without affecting neighbouring parts. In medicine micro-surgery has been possible since laser beam can destroy any harmful component without seriously damaging the neighbouring regions.

A List of some useful LASERS

Active Medium LASER	Wavelength (mM)	Nature
He–Ne	0.6328	Continuous
	1.1523	Continuous
	3.3912	Continuous
CO_2	10.6	Continuous
Ruby		

$(Al_2O_3 + 0.05\% Cr)$	0.6943	Pulsed
Nd–Y_{AG}	1.06	Pulsed
Nd–Ca WO_4	1.63	Pulsed
Ar–Ion	0.4579	Continuous
	0.5017	Continuous
	0.4727	Continuous
	0.4658	Continuous
	0.4965	Continuous
	0.4765	Continuous
He – Ccl	0.4416	Continuous
	0.3250	Continuous
Kr–Ion	0.4762	Continuous
	0.4825	Continuous
	0.5208	Continuous
	0.5309	Continuous
	0.5682	Continuous
	0.6471	Continuous

* For both English and Telugu media.

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PHYSICS PRACTICALS

1. NEWTON'S RINGS - COMBINATION METHOD

Aim : To determine the radius of curvature of the given concave lens by forming Newton's rings with the combination of convex and concave lenses.

Apparatus : Convex and concave lenses combinations, glass plate, black paper, travelling microscope, a glass plate fixed to a stand and sodium vapour lamp.

Procedure : Formation of newton's rings with the convex lens.

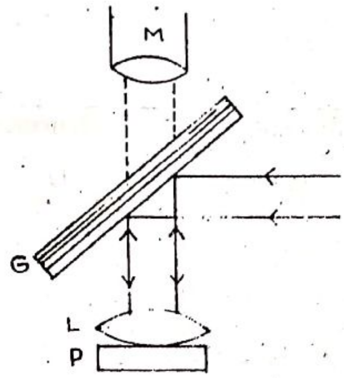
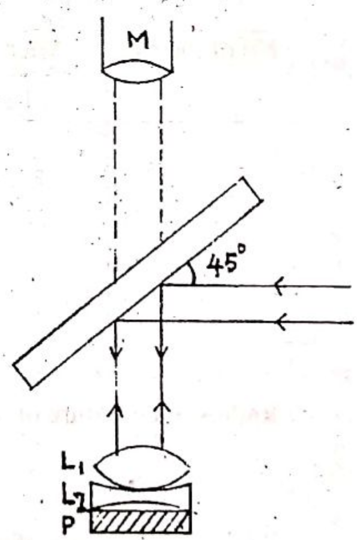


Fig.

The glass plates and the lens are cleaned well. The glass plate p is placed over a black paper under the microscope and is focussed. The glass plate G is fixed to a stand and is placed at 45⁰ to the horizontal so that

the light form the sodium vapour lamp falls normally on the lens as shown in the figure. By adjusting the lens and the angle of the glass plate G. Newton's rings are formed and are observed through the microscope M placed above it. The microscope is taken to one side through a definite number of rings. Then the cross wire is placed tangential to 20th ring and reading of the vernier is noted on the horizontal scale. Then by moving to different rings till 5th ring, the vernier readings are noted. Then on the other side also for the same rings the readings are noted and tabulated. From these readings, the diameters of different rings are obtained. A graph is drawn between the ring nos and the square of the corresponding diameters. The radius of curvature R_1 of the convex lens is calculated by using the formula



Fig

$$R_1 = \left[\frac{\left(D_m^2 - D_n^2\right)}{4\lambda(m-n)}\right]$$

where λ is the wavelength of the light used.

The experiment is repeated with the combination of convex lens L_1 and the concave lens L_2. The convex lens L_1 is placed above the concave lens L_2 as then R is calculated using the above eqn

$$R = \left[\frac{\left(D_m^2 - D_n^2\right)}{4\lambda(m-n)}\right]$$

If R_2 is the radius of curvature of the concave lens

$$\frac{1}{R_2} = \frac{1}{R} - \frac{1}{R_1}$$

$$= \frac{R_1 - R}{R\,R_1}$$

$$\therefore\ R_2 = \left[\frac{R\ R_1}{R_1 - R}\right]$$

Observations

When the convex lens is used :

No.of the ring	Microscope Reading		Diameter D	D^2
	Left	Right		
20				
19				
18				
5				

Radius of curvature of convex lens = $R_1 = \frac{D_m^2 - D_n^2}{4\lambda\,(m-n)}$ = ...cms.

when the combination of lenses is used

No.of the ring	Microscope Reading		Diameter D	D^2
	Left	Right		

Radius of curvature of combination R = $\frac{D_m^2 - D_n^2}{4\lambda\,(m-n)}$ = ...cms

Radius of curvature of concave lens = $R_2 = \frac{R\ R_1}{R_1 - R}$

Precautions :

1. In order that there is less error in $D_n^2 - D_m^2$, the convex lens should be of larger focal length and should be also thin.
2. When viewed through the travelling microscope, the point of contact between the convex lens L_2 and the plane glass plate P should appear as a black spot (dark ring). Otherwise, the lens and the

plate are not clean. Once again, they should be perfectly cleansed with benzene or spirit.

3. The reflecting glass plate G shouled be carefully tilted such that the light beam falls on the lens L_2 normally.

4. Care should be taken to see that there is no back-lash error while taking readings with the travelling microscope. For this, the screw should be *rotated in a single direction..* This is why we move from R.H.S. of 20th dark ring to R.H.S. of 18^{th}, 16^{th} .... etc., dark rings and then L.H.S. of 2^{nd}, 4^{th}, 6^{th} .... etc., dark rings from right to left only.

5. We should ensure in the beginning, itself that all the 20 dark rings in full appear completely in the field of view.

VIVA-VOCE QUESTIONS AND ANSWERS

1. What is the cause of Newton's rings formation ?

Ans : Newton's rings are formed due to the interference of light.

2. Are the Newton's rings formation is in accordance with the 'Corpuscular theory' proposed by Newton or not ?

Ans : Newton's rings are formed due to interference of light and Newton's corpuscular theory could not account for interference. It is only Huygens' wave theory that can explain interference.

3. To which class of nterference Newton's rings belong to ?

Ans : Newton's rings are due to interference by division of amplitude.

4. Is the central ring of the system of Newton's rings a dark ring or a bright ring? Why ?

Ans : The central spot (ring) is a dark ring. Even though the path difference is zero here, it is not a bright ringk. This is because, in the reflection at the glass plate (a denser medium) there will be an additional phase difference of π or an additional path difference of $\frac{\lambda}{2}$.

5. As the number (or order) of the ring increases, the distance between the consecutive rings gets decreased (and they come clósure and closure). Why ?

Ans : In the case of dark rings.

$r_n \; \alpha \; \sqrt{n}$ (n = number of dark ring).

$\therefore \quad r_n - r_m = \sqrt{n} - \sqrt{m}$. For consecutive rings $m = n - 1$ and hence.

$r_n - r_{(n-1)} = \sqrt{n} - \sqrt{n-1}$. Clearly, as n increases, this value gets decreasede and hence the distance between consecutive dark rings gets decreased.

Same is the case with bright rings also where $r_n \; \alpha \; \sqrt{2n-1}$

6. In this experiment how do you get the required coherent beams for interference ?

Ans : Part of the incident light (on the lens L_2 and glass plate P system) gets reflected from the upper surface of the air film and part of the light gets passed through the air film and gets reflected at the plane glass plate P. These two are derived from the same source and hense form coherent beams of light. The extra distance passed through the air film (twice) provides the path difference.

7. What are the conditions required for sustained interference ?

Ans : For a sustained interference we should have

1. The interfering beams should be coherent. That is, they should be having the same frequency (or wave length) and should have a constant phase relationship.
2. The amplitudes of the two waves should be equal so that there will be maximum contast between the bright and dark fringes (rings).

8. What are "Coherent" sources ?

Ans : Coherent sources of light are those which produce light waves having a constant phase difference between them. This constant phase difference may be zero also in which case the two waves will be in the same phase.

9. What is interference ?

Ans : The changes in the intenwsity of the resultant of two different waves duje to super position of one over the other is called interference.

10. Here, where are the interference rings formed ?

Ans : When viewed through the microscope the rings appear to be formed inside the air film between the lens and the plate. (Actually the interference takes place only when the two beams come out of the lens vertically up. There is only one beam of light travelling inside the air film).

11. Why are the interference fringes formed here are in the shape of circles ?

Ans : The condition for dark fringes in interference is

$2\mu t \cos r = n\lambda$ – destructive interference (1)

t = Thickness of air film.

For normal incidence $r = 0$ and $\cos r = 1$ and for air $\mu = 1$

Condition for destructive interference is, $2t = n\lambda$. (2)

Similarly, condition for constructive inerference is, $2t = (2n - 1)\dfrac{\lambda}{2}$ (3)

12. Why is a sodium vapour lamp used in this experiment ?

Ans : For sustained interference we should have the two light beams of same frequency (or wave length). Hence we have to use a monochromatic source of light.

13. What happens if we replace sodium light by mercury light (or white light) ?

Ans : In that cae we get rings of different colours. The rings will be violet in colour at the centre and red in colour at the outer most region. However, when the number of rings exceeds seven (n > 7) different colours get overlapped and we see only white colour. As this is of uniform internsity, there will be no separate dark and bright rings.

14. What is the use of Newton's rings ?

Ans : Forming Newton's rings we can

a) determine the wavelength of a monochromatic beam of light.

b) determine the radius of curvature of a convex lens.

c) determine the refractive index of a liquid.

d) determine the coefficients of expansion of a crystal.

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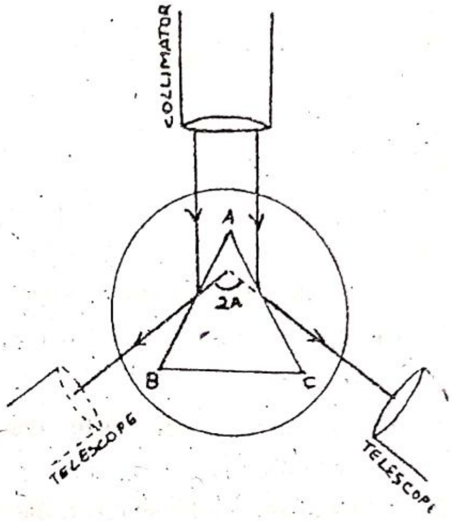
2. RESOLVING POWER OF GRATING

Aim : To determine the resolving power of a grating with a spectromer.

Apparatus : Spectrometer, plane diffraction grating, sodium vapour lamp, a rectangular slit of adjustable width, travelling microscope.

Procedure : The preliminary adjustments of the spectrometer are done. The primary adjustments of spectrometer are to be done as explained. Then hollow prism is filled with expermental liquid. Then the hollow prism is placed at the centre of prism table such that both refracting edges of the prism is placed at the centre of prism table such that both refracting edges of the prism are facing the collimator symetrically as shown in fig. Then the prism is fixed. The telescope is released and rotated to observe reflected image of the slit from one face say AB. The tangent screw of the telescope is worked until the reflected image coincides with vertical cross wire. The readings of the two verniers are noted. The telescope is rotated such that the reflected image of the slit from second face AC is focussed. Then readings of both verniers are noted. Then difference between the respective readings of the vernier gives the value of 2A, from which the refracting angle can be determined.



Fig

The slit of the spectrometer is illuminated with sodium light.

The grating is mounted on the prism table such that the rullings are parallel to the slit and perpendicular to the prism table. The grating is adjusted for normal incidence. An adjustable slit is arranged in front of the objective of the telescope.

The telescope is turned to observe the two yellow lines (D_1 and D_2) of the first order spectrum on right side. The slit is narrowed down until the yellow lines just merge. The reading of the spectrometer is noted. The slit is removed from the telescope and its width a_1 is determined using a microscope. The experiment is repeated for the first order on the left side and the width of the slit a_2 is determined. The average "a" of a_1, a_2 is noted. The expect is repeated for second order spectrum and the readings are tabulated. If "a" is the critical width of the slit as measured with the travelling microscope, then light enters only through a portion $\frac{a}{\cos\theta}$ of the grating where θ is the average angle of diffraction for D_1 and D_2 lines.

The resolving power of the portion of the grating is equal to $\frac{\lambda}{d\lambda}$ where λ is the mean wave length of the D_1 and D_2 lines and d λ is the difference in wavelengths. The resolving power of the total length of the grating =

$$\frac{\lambda}{d\lambda} \times \frac{l\cos\theta}{a}$$

Where l is the length of the grating. The resolving power of the grating is also equal to Nn where N is the total number of lines on the grating and n is the order of the spectrum. The experiment is repeated for the second order.

Observations :

Total number of lines on the grating N =

Length of the grating l =

Order n	Reading of the Spectrometer				2n		Mean 2n
	Vernier I		Vernier II		Vernier I	Vernier II	
	Left	Right	Left	Right	x ~ y	x' ~ y'	
	x	y	x'	y'			

θ	a			$\frac{\lambda}{d\lambda}$ $\frac{l\cos\theta}{a}$	Nn
	a_1	a_2	Mean a		

The result in last two columns will be found to be equal.

Result : The resolving power of the grating =

Precautions :

1. The preliminary adjustments that are to be attended to with a spectrometer should be all carried out meticulously.
2. To avoid any backlash error, the micrometer screw and the travelling micrometer screw should be moved only along one direction.
3. The edges of the slit used for finding critical width should be cleaned perfectly.
4. The grating plane should not be touched with hand. We should handle the grating only at the edges having cover over them.
5. The plane of grating should be normal to the incident light.

VIVA-VOCE QUESTIONS AND ANSWERS

1. What is meant by resolving power ?

Ans : The ability of an optical instrument to separate and show distinctly two spectral lines having very close wavelengths is called the resolving powe4r of the instrument.

2. Which instruments do possess the resolving power ?

Ans : All optical instruments like a grating, a telescope and a human eye will be having the resolving power.

3. What is the cause for the resolving power ?

Ans : It is the phenomenon of diffraction that gives rise to the resolving pwer of an instrument.

4. On what factors does the resolving power of a grating depend on ?

Ans : The resolving power of a grating depends on (1) order of the spectrum (n) (2) Total number of lines (N^1) on the grating.

5. Does the resolving power of a grating depend on the grating element or not ?

Ans : The resolving power of a grating does not depend on the gratng element $(e + d)$ or $(a + b)$.

6. In the case of a grating what is the difference between its resolving power and dispersive power ?

Ans : In the case of a grating

a) The resolving power RP = $\left(\frac{\lambda}{d\lambda}\right) = N^{l}n$. It is its ability two separate and show distinctly the diffraction maximum two wavelengths λ and $\lambda + d\lambda$ that are very close to each other.

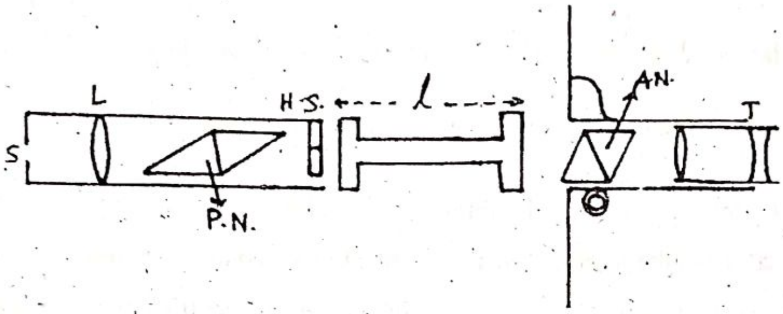
— O —

3. POLARIMETER

Aim : To determine the specific rotation of an optically active substance, say canesugar using Laurent's Saccharimeter.

Apparatus : Laurents's saccharimeter, sodium lamp, cane sugar, distilled water, balance etc.

The essential parts of Laurent's saccharimeter are represented in the fig. Light from a source S is renderd parallel by means of a convex lens L. The emergent parallel beam passes through the polarising nicol P.N. and then illuminates the half shade H.S. The emergent beam is viewed through an analysing nicol A.N and a long tube with glass ends.

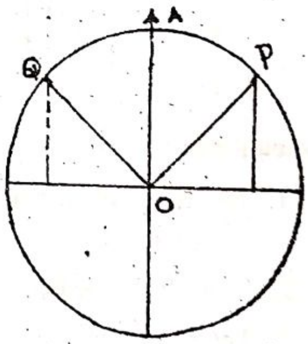


Fig

The analysing nicol and the telescope are fixed in a tube capable of rotating on its axis. The position of the analysing nicol may be observed by means of verniers attached to it moving on a fixed circular scale.

Principle : The half shade consists of two semi circular placed side, by side, plates one of them being a quartz plate cut with its optic axes parallel to the refracting surfaces and the other a glass plate of such thickness as to absorb the same amount of light as absorbed by the quartz plate. The quartz plate is a half wave plate which introduces a phase difference π between the ordinary and extraordinary rays. The

polarising nicol transmits only its extraordinary ray with vibrations parallel to its principal plane. Suppose the plane of vibration of the light incident on the half shade is OP which is also the principal plane of the polarisation nicol. The plane of vibration of the incident light continues to be OP after passing through a glass. But the plane polarised light incident on the quartz plate will be split up into components polarised in two mutually perpendicular directions. They travel in the same direction but with different velocities. After emergence due to the acquired phase difference π, they recombine to give plane polarized light with its plane of vibration OQ so that OP and OQ are equally inclined to the principal plane AB of the quartz plate. The rays transmitted through the right half are



Fig

characterised by their vibrations along OP and the rays transmitted through the left half (i.e. passing the half wave quartz plate) are characterised by their vibrations along OQ, both being equally incident to AB. Of these vibrations the analysing nicol transmits only vibrations parallel to its principal plane. The two halves will be equally bright or equally dim when the principal plane of the analysing nicol is either parallel or perpendicular to AB. In any other position of the analysing nicol one half appears much brighter compared to the other.

Procedure : The tube "l" is filled completely with distilled water leaving no air bubbles inside and is introduced in the polarimeter between the half shade and the analysing nicol. The analysing nicol is rotated till the two halves appear equally dim. The vernier reading is taken. The position of the analysing nicol is disturbed and the point of equal dimness is obtained from the other side. The means vernier reading is calculated. A weighed amount of sugar, say 10 gms. is dissolved in 100 c.c of distilled water and the solution is filtered. The tube is taken out emptied rinsed with sugar solution, and filled with the solution in place of water, leaving no air bubbles inside. The tube is replaced in the polarimeter and the analyser is rotated to get the position of equal dimness. The vernier readings gives the angle of rotation θ of the plane of polarisation produced by the solution. If M gms of the solute is dissolved in V c.c. of the solvent then the concentration c = (M/V) gms/c.c. Specific rotation ρ of the optically active substance is calculated from the formula

$$\rho = \frac{100}{cl}$$

where "l" is the length of the tube in cms. The experiment is repeated for the concentrations $\frac{c}{2}, \frac{c}{4}$ and $\frac{c}{8}$ and the corresponding angles of rotations are obtained in each cash.

A solution of concentrations $\frac{c}{2}$ is obtained by adding equal volumes of distilled water and the solution first prepared. In a like manner other concentrations also are prepared.

A graph is drawn between the angle of rotation and the concentration and it will be a straight line.

Results : Length of the tube = ...cms

Mean reading of the vernier with distilled water = (θ_w) =

Concentration c	Position of the analyser with solution θ_S	Angle of rotation 100 $(\theta_S - \theta_w)$	s = $\frac{100}{cl}$

Precautions :

1. The glass tube G and the metal screw caps of the polarimeter should eb cleansed to have no grease, oil or due.
2. Case should be taken to see that there are no air bubbles along the length of the glass tube G.
3. The screw caps are to be closed after keeping rubber washers in between the glass tube and the glass plates used as air. Otherwise, when the screws are tightened there is a possibility for the glass also to acquire optical activity.
4. For the same reason as above, the caps are to be screwed lightly.
5. it is better to distill the solution so as to remove impurities.
6. Readings should be taken only when the two halves in the H.S. are exactly of equal brightness.

VIVA-VOCE QUESTIONS AND ANSWERS

1. To which class of polarization does the light coming out of P.N. belong to ?

Ans : It is a plane polarised light.

2. Why does the light passing through the Nicol prism get divided into ordinary and extra ordinary lights?

Ans : It is due to double refraction.

3. **How will be the plane of polarization and plane of vibration will be relative to each other ?**

Ans : These two planes are one and the same as per the most recent nomenclature.

4. **What is the use of the protrudings on the glass tube G ?**

Ans : They ensure that there will be no air bubbles along the length of the glass tube. Any (small) air bubble will go into the protruding region.

5. **What is the disadvantage of having any air bubbles inside the sugar solution ?**

Ans : These air bubbles obstruct the transmission of light through the solution and thereby give rise to wrong results.

6. **How do you define in words, the specific rotatory power of a solution ?**

Ans : The specific rotatory power of a solution is defined as the angle of rotation of the plane of polarisation by a solution of 10 cm length and having a concentration of one gm/cm^3.

7. **Why do you get the number 0 in** $S = \frac{10\theta}{lc}$ **?**

Ans : We measure the length of solution l in cm. But in definition, we have to find θ for 10 cm. (or decimeter). Hence $\frac{1}{10}$ in denominator gives rise to $\frac{10}{l}$ in the formula.

8. **In what direction Clock-wise or Anti clock-wise will be the rotation of plane of polarization?**

Ans : The direction of plane of polarization will be clock wise in certain (optically active) substances and will be anti clockwise in certain other (optically active) substances.

Substance like sugar solution, tartaric acid, comphor etc., will rotate the plane of polarization in the the clock wise direction and are called Dextro-Rotaroty substances.

Substances like turpentine, fructose etc., that rotate the plane of polarization in the anti-clock wise direction are called Laevo-Rotatory substances.

9. **What is the name for substances that rotate the plane of vibration of incident light ?**

Ans : They are called optically active substances.

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4. SPECTROMERER - DISPERSIVE POWER OF A PRISM

Aim : The determine the dispersive power of the material of a given prism by the spectrometer.

Apparatus : Spectrometer, the given prism and mercure vapour lamp.

Principle : The dispersive power of the material of the given prism is expressed by the relation.

$$\omega = \frac{\mu_2 - \mu_1}{\mu - 1}$$

where μ_1 and μ_2 are the refractive indicies of two colours and $\mu = \frac{\mu_1 + \mu_2}{2}$.

Usually the colours chosen are blue and red so that $\omega = \frac{\mu_b - \mu_r}{\mu - 1}$

where $\mu = \frac{\mu_b - \mu_r}{2}$

Procedure : The usual adjustments of the spectrometer are made. The preliminary adjustments of the spectrometer are done. The primary adjustments of spectrometer are to be done as explained. Then hollow prism is filled with expermental liquid. Then the hollow prism is placed at the centre of prism table such that both refracting edges of the prism is placed at the centre of prism table such that both refracting edges of the prism are facing the collimator symetrically as shown in fig. Then the prism is fixed. The telescope is released and rotated to observe reflected image of the slit from one face say AB. The tangent screw of the telescope is worked until the reflected image coincides with vertical cross wire. The readings of the two verniers are noted. The telescope is rotated such that the reflected image of the slit from second face AC is focussed. Then readings of both verniers are noted. Then difference between the respective readings of the vernier gives the value of 2A, from which the refracting angle can be determined. The refracting angle A of the prism is found.

Then the prism is mounted on the prism table and the position of the prism is adjusted to observe the spectrum of the mercury vapour. Observing the blue line the spectrum through the telescope, the prisms adjusted for minimum deviation position. Working with the tangent screw of the telescope, the position of the prism is adjusted so that the blue line is just on point of retracing its path after coming to the point of intersection of the cross wires. The readings of the telescope for the minimum deviation of red line are noted. The telescope is brought in line with the collimator and removing the prism, the direct readings on both verniers are noted. The respective differences give the minimum deviations for blue and red colours. Their refractive indices are found by

$$\mu_b = \frac{\sin\left(\frac{A+D_b}{2}\right)}{\sin\left(\frac{A}{2}\right)} \quad \text{and} \quad \mu_r = \frac{\sin\,(A+D_r)}{\sin\left(\frac{A}{2}\right)}$$

The dispersive power of the material of the prism for blue and red colours is found by the relation.

$$\omega = \frac{\mu_b - \mu_r}{\mu - 1}$$

The readings are tabulated as shown.

Observations

Dispersive of own $\omega = \frac{\mu_b - \mu_r}{\mu - 1}$

Precautions : 1. The prism should be adjusted for each colour seperately.

Result : Dispersive power of the material of the prism =

	Vernier I			Vernier II			Average		
Colour	Min Dev. pos	Direct reading	Min Dev. pos	Min Dev. pos	Direct reading	Min Dev.	Min Dev.	Min Dev.	μ
Blue									
Red									

Precautions :

1. There should be no parallax between the vertical cross wire and the image of the slit while taking the readings of the positions of telescope on the circular scale.
2. The readings on the circular scale are to be looked down vertically so as to avoid parallax error. The Reading lens and the torch light should invariably used while noting the readings.
3. The slit should be sufficiently narrow, but at the same time should be of sufficient brightness also.
4. Much care should be taken in adjusting the collimator to render the light beam parallel and the telescope to catch the parallel beam. Once adjusted for this, the lengths of either collimator or the telescope should not be altered further.

VIVA-VOCE QUESTIONS AND ANSWERS

1. Why should we take readings from the two verniers on the circular scale ? Is not one sufficient ?

Ans : The base of the circular scale may have some eccentricity - that is one side up and the other side down. To eleminate the rror due to this eccentricity we read from both the verniers on either side.

2. What do you understand by the dispersive power of a prism ?

Ans : It is the ability of the prism to separate different colours of the incident composite light into their component colours and show them separately.

3. What is the difference between deviation and dispersion ?

Ans : The incident light on a prism gets refracted through and emerges out in a diretion away from the incident direction and bent towards the base. This is called the deviation (D). If the incident light is a composite colour and consists of several colours then the deviations will be different for different colours. This results in the different colours getting separated (dispersed) while coming out. This is called dispersion.

4. When will be the dispersive power of a prism be maximum ?

Ans : The dispersive power of the prism will be maximum when it is in the minimum deviation position.

5. When the prism is in the minimum deviation position, how will be the path of the light ray inside the prism ?

Ans : When the prism is in the minimum deviation prism, the light ray will travel parallel to the base inside the prism. That is the path inside the prism will be parallel to BC.

6. What is the need for adjusting the collimator to render light rays parallel and telescope to catch the parallel light rays ?

Ans : This is all necessary to get a pure spectrum - no overlap of different colours after dispersion.

7. What is a pure spectrum ?

Ans : If the different colours in the resulting spectrum (due to dispersion) do not overlap one over the other, it is called a pure spectrum.

If the different colours get overlapped one over the other, it is called an impure spectrum.

The spectrometer is a convenient device used in the laboratory to get a pure spectrum.

— O —

5. DIFFRACTION GRATING - MINIMUM DEVIATION

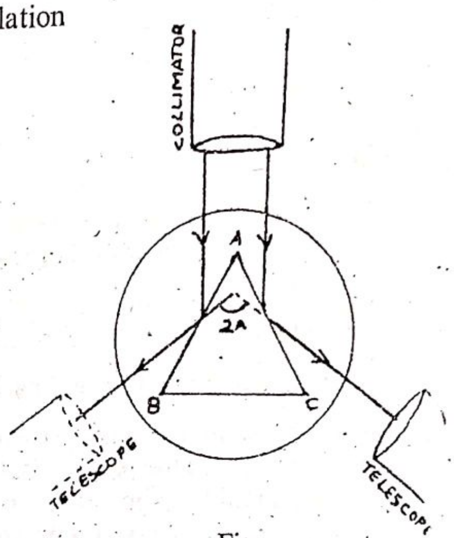
Aim : To determine the wavelength of light using a plane diffraction grating by measuring the angle of minimum deviation.

Apparatus : Plane diffraction grating, spectrometer, reading lens, sodium vapour lamp.

Principle : If a parallel beam of monochromatic light is incident on a grating such that the angle of deviation is minimum, the wave length of light is given by the relation

$$\lambda = \frac{2\sin\left(\frac{D}{2}\right)}{Nn}$$

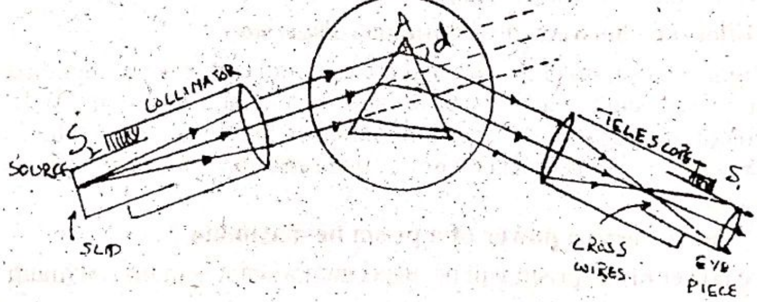
where D is the angle of minimum deviation, n is the order of the spectrum and N is the number of lines per cm.



Fig

Procedure : The preliminary adjustments of the spectrometer are done.

Determination of Angle of minimum deviation (D) : The vernier table is clamped and the prism table is released. The prism is clamped centrally on the prism table such that the surface of the ground glass is almost parallel to the axis of the collimator and the light from collimator incident on the polished surface of the prism emerges out from the other polished surface as shown in the fig.



fig

The telescope is turned to observe the refracted image of the slit. Looking at the image the prism table is slowly turned such that the image moves towards the direct position. The telescope is also moved so as to keep the image of the slit in the field of view. At certain stage it will be found that the image changes its direction of motion even though the prism is continued to move in the same direction.

The refracting angle A of the prism is found. The slit is illuminated with sodium light. The grating is clamped to the prism table. The plane of the grating is adjusted to be vertical and perpendicular to the axis of the collimator.

The direct image of the slit is observed through telescope and by working the tangent screw of the telescope, the point of intersection of the cross wires is set on the image of the slit. The readings of the two verniers are noted.

The telescope is moved to the left to observe the diffracted image of the first order. The prism table is released and it is rotated to the left. Then the first order image moves to the right, reaches a limiting position and then tries to retrace its path. The telescope is fixed in this limiting position such that the point of intersection of the cross-wires is on the D_1 line. The readings on both the verniers are noted. The respective difference on the verniers give the minimum deviation for the D_1 line. Similarly the experiment is repeated on the right hand side for the first order D_1 line. The experiments is repeated for D_2 line.

The experiment is also repeated for the second order spectrum on both sides.

The observations are tabulated as shown below.

Precautions : After noting the readings on each side, the direct reading is again checked to make sure that it has not alterd

Observations :

No.of lines per cm on the grating (N) =

Direct reading ver I =

of the slit Ver II =

Spectral Line	Spectrometer Reading Minimum deviation position				Minimum deviation				D (Average)	$\lambda = \frac{2\sin\frac{D}{2}}{Nn}$
	Left		Right		Left		Right			
	Ver I	Ver II	Ver I	VerII	Ver I	Ver II	Ver I	Ver II		
D_1										
D_2										

Precautions :

1. The preliminary adjustments with the spectrometer are to be carefully attended to.
2. The grating should be vertical, with its lines parallel to the slit and in Normal - incidence position for incident light. These arrangements should be carefully attended to.
3. The vertical cross wire is to be coincided with the image of the slit without any parallax.
4. The readings are to be viewed in normal position on the circular scale to avoid parallax error.
5. To avoid the error due to the eccentricity of the base of circular scale we should take readings from both the verniers V_1 and V_2.
6. Grating should not be touched with hand. It should be handed only at the edges (with cover).

VIVA-VOCE QUESTIONS AND ANSWERS

1. What are the units in which the wavelength of light is expressed ?

Ans : The wavelength of light is expressed in SI in metre (m) and in C.G.S. system in centimetre (cm). But, it is conventional and customary to express the wavelength in Angstrom units or in nanometre (nm) units.

$1\,\overset{0}{A} = 10^{-10}\,m = 10^{-8}\,cm$ and

$1nm = 10^{-9}\,m = 10^{-7}\,cm$

2. What is diffraction of light ? What is the importance of this phenomenon ?

Ans : The light bends at obstacles that are very small (and are of comparable size as of its wavelength) and enters into the geometric shadow of the obstacle. This phenomenon is called diffraction of light.

The phenomenon of diffraction of light clearly establishes the wave nature of light.

3. In order for the light to get diffracted, how should be the obstacles or apertures (in size) ?

Ans : The obstacles or apertures (slits) should be of very small size - comparable to the wave length of light (of the order of λ).

4. How many kinds of diffraction are there ? What is the difference between them ?

Ans : There are two kinds of diffraction

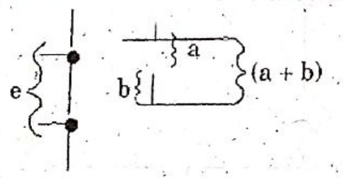
1. Fresnel's class of diffraction and
2. Fraunhofer's class of diffraction.

5. What is a diffraction grating ?

Ans : The arrangement a large number slits of equal widths, parallel to each other and at equal distances is called a grating. The separation between the consecutive slits acts as an opaque obstacle to light.

6. What is meant by grating element ?

Ans : The distance between the mid points of any two consecutive slits is called the grating element or grating constant. If the width of the slit is 'a' and the opaque distance between the two consecutive slits is 'b' then the grating element is c = a + b as shown in figure.



7. How many number of line will be there on the grating we use in our laboratory ?

Ans : Usually there will be 15,000 lines per inch.

8. What is a transmission grating ?

Ans : If the lines engraved on a grating act as opaque obstacles to light and the space between the lines act as transparent slit it is called a transmission grating. We observe the diffraction pattern of the transmitted light.

9. What is the difference between interference and diffraction ?

Ans : Super position taking place between the two separate wave fronts that originate from two different but coherent sources is called interference.

Super position taking place between the secondary wavelets originating from different points of the same wave front is called diffraction.

10. What is meant by order of the spectrum ? Do we have different orders of spectra in a prism also?

Ans : The two spectra formed very close to the central maximum on either side is called the first order spectra. The next spectra formed on either side away from the first order spectra and close to the spectra is called second order spectrum. So on and so forth.

In a prism only a single spectrum is formed (that is why the intensity will be more in a prism spectrum).

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6. DIFFRACTION GRATING - NORMAL INCIDENCE

Aim : To determine the wavelength of a given source of light by using the diffraction grating in the normal incidence position.

Apparatus : Plane diffraction grating, spectrometer, spirit level, reading lens, sodium vapour lamp.

Description : A plane diffraction grating consists of a parallel sided glass plate with equidistant fine parallel lines drawn very closely upon it by means of a diamond point. The number of lines drawn is about 15,000 per inch. (The gratings used in the laboratory are exact replicas of the original grating on celluloid film).

Theory : When light of wavelength λ is incident normally on a diffraction grating having N lines per cm and if θ is the angle of diffraction in the n the order spectrum, then

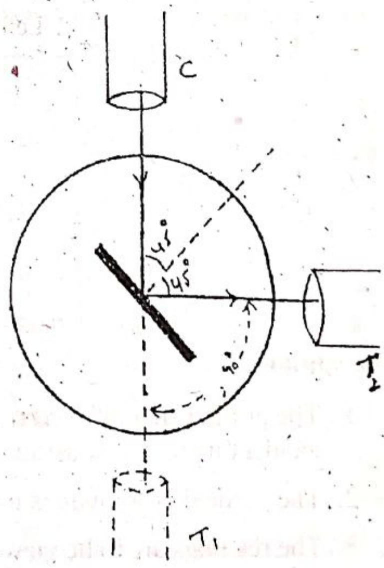
$$nN\lambda = \sin\theta$$

$$\text{or, } \lambda = \frac{\sin\theta}{Nn}$$

from which λ can be determined.

Procedure : The usual initial adjustments of the spectrometer are done. The primary adjustments of spectrometer are to be done as explained. Then hollow prism is filled with expermental liquid. Then the hollow prism is placed at the centre of prism table such that both refracting edges of the prism is placed at the centre of prism table such that both refracting edges of the prism are facing the collimator symetrically as shown in fig. Then the prism is fixed. The telescope is released and rotated to observe reflected image of the slit from one face say AB. The tangent screw of the telescope is worked until the reflected image coincides with vertical cross wire. The readings of the two verniers are noted. The telescope is rotated such that the reflected image of the slit from second face AC is focussed. Then readings of both verniers are noted. Then difference between the respective readings of the vernier gives the value of 2A, from which the refracting angle can be determined. The least count of the vernier of the spectrometer is found.

1. Normal Incidence : The slit of the spectrometer is illuminated with sodium vapour lamp. The telescope is placed in line with the axis of the collimator and the direct image of the slit is observed. The slit is narrowed and the vertical cross-wire is made to coincide with the centre of the image of the slit (T_1 in fig). The reading of one of the verniers is noted. The prism table is clamped firmly and the telescope turned through exactly 92^0 and fixed in position (T_2 in fig).



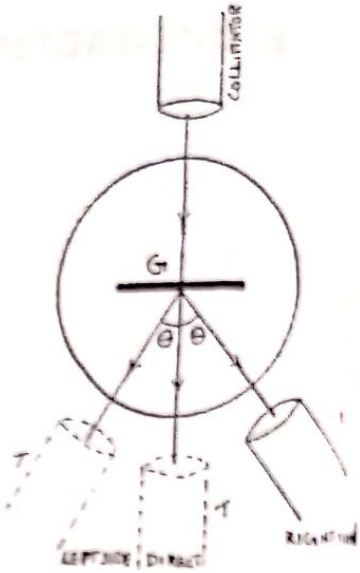
Fig

The grating is held with the rulings vertical and mounted in its holder on the prism table such that the plane of the grating passes through the centre of the table and the ruled surface towards the collimator. The prism table is released and rotated until the image of the slit is seen in the telescope by reflection on the ruled side of the grating. The prism table is fixed after adjusting the point or intersection of the cross-wires is on the image of the slit. Then the vernier table is fixed in this position and the telescope is brought back to the direct reading position. Now the light from the collimator strikes the grating normally.

2. Measurement of λ : The telescope is rotated so as to catch the first order diracted image on one side, say on the left. With sodium light two images of slit, very close to each other, can be seen. They are called D_1 and D_2 lines. The point of intersection of the crosswires is set on the D_1 line and its reading is noted on both the verniers. Similarly the reading corresponding to the D_2 line is noted. Then telescope is turned to the other side (i.e) right side and similarly the readings corresponding to D_1 and D_2 lines of the first order spectrum are noted. Half the difference in the readings corresponding to any one line gives the angle of of diffraction θ for that lines in the first order spectrum.

The experiment is repeated for the second order spectrum. The number of lines per cm of the grating (N) is noted and the wavelength λ of the spectral line is found by the relation.

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



Fig

Observations

No. of lines per cm (N) =

Precautions : 1. Always the grating should be held by the edges. The ruled surface should not be touched.

2. Light from the collimator should be uniformly incident on the entire surface of the grating.

Result : Mean value of λ for D_1 lines = ... cm

= .... A.U.

Mean value of λ for D_2 line = ... cm

= .... A.U.

Order of spectrum (n)	Line	Reading of Spectrometer				2θ			$\lambda = \frac{\sin\theta}{Nn}$
		Ver I		Ver II		Ver I	Ver II	Mean	
		Left	Right	Left	Right				

Precautions :

1. The grating should be vertical, with its lines parallel to the slit and in Normal-incidence position for incident light. These arrangements should be carefully attended to.
2. The vertical cross wire is to be coincided with the image of the slit without any parallex.
3. The readings are to be viewed in normal position on the circular scale to avoid parallax error.
4. To avoid the error due to the eccentricity of the base of circular scale we should take readings from both the verniers V_1 and V_2.
5. The side of the grating on which the lines are engraved is to be towards the telescope.
6. Grating should not be touched with hand. It should be handed only at the edges (with cover)

VIVA-VOCE QUESTIONS AND ANSWERS

1. **What kind of waves are those that are coming out of the slit ? What is the reason behind ?**

Ans : The waves are cylindrical in nature and the wave front is a cylindrical wave front. The reason is that the slit is a straight aperture. If the slit were in the shape of a point, we would have got spherical waves and a spherical wave front.

2. **To which class the diffraction in this experiment belongs to ? and why ?**

Ans : In a prism we get only one spectrum in which the entire light is concentrated.

On the oher hand, in a grating there are different orders of a spectra and that too on either side also. Maximum of the incident light is concentrated at the central maximum and the remaining is to be distributed over several orders. hence the grating spectra are of less intensity as compared to prism spectrum.

3. **What happens as the order of spectrum is increased ?**

Ans : As the order of the spectrum n is increased, the intensity decreases and the separation between spectral lines also increases.

4. **Does the grating spectrum depend on the material of the grating ?**

Ans : No. Grating spectrum does not depend on the grating material.

However, the prism spectrum depends on the material of the prism.

5. **What are the reasons for formation of spectrum (a) in a prism and b) in a grating.**

Ans : The formation of spectrum.

a) In a prism is due to the variation of refractive index of the material with colour. Different colours will be having different deviations and this gives rise to dispersion. This is the prism spectrum.

b) In a grating different colours will get diffracted through different angles and this disperson results in grating spectrum.

6. **As far as dispersive power is concerned, what is the difference between a grating and a prism?**

Ans : For a given order of the spectrum, the dispersive power of a grating $\left(\frac{d\theta}{d\lambda}\right)$ is almost a constant.

Hence, the grating spectrum is called a rational spectrum.

7. **Does the dispersive power of a grating depend on the material of the prism ?**

Ans : No. The dispersive power of a grating does not depend on the material of the prism. It depends on 1. Order of the spectrum. 2) Distance of separation between consecutive slits.

8. **Which out of a grating and a prism has got more resolving power ?**

Ans : The resolving power of grating is very large compared to that of the prism.

9. **Which spectral lines (of grating and prism) will be more sharp ?**

Ans : The spectral lines of a grating spectrum will be more sharp and straight.

—o—

7. RESOLVING POWER OF A TELESCOPE

Aim : To determine the resolving power of a telescope.

Apparatus : Telescope, sodium light, wire-gauze with fine uniform mesh, a rectangular slit whose width can be adjusted.

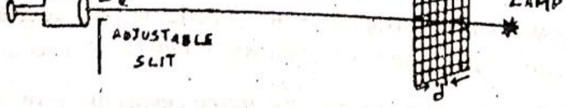
Principle : The resolving power of a telescope is its ability to separate two point objects situated very close together. The minimum angle which two distant objects have to subtend at the objective of the telescope in order that their images may just appear to be separate expresses the limit of resolution and is called the resolving power. Theoretically this should be equal to $\frac{1.22\lambda}{a}$ where a is the distance between two point objects and λ is the wavelength of light.

In the actual experiment the image of the wire gauze mesh is observed through the telescope. The mesh is placed at a sufficiently long distance from the telescope and the mesh is illuminated with sodium light. The objective of the telescope is provided with an aperture, whose width is gradually diminished until the images of the wires of the gauze become just industinguishable. If d is the distance between any two adjacent wires of the mesh and D is the distance between the wire gauze and the objective of the telescope then $\frac{d}{D}$ gives the angle subtended by two adjacent wires at the objective. Thus, when the images are just resolved $\frac{1.22\lambda}{a}$ can be calculated and its value compared with that of $\frac{d}{D}$

Procedure : The wire-gauze is fixed in a stand with one set of wires vertical with travelling microscope the average width between two adjacent cross-wires is determined as follows. The microscope is adjusted so that the point of intersection of the cross-wires at the middle of the image of a vertical wire, and the reading is noted. Moving the microscope in the same direction throughout the readings are noted when the point of intersection of the cross wires is set successively at the middle of the 6th, 11th etc vertical wire.

The observations are recorded as in table I and the average distance between any two adjacent wires is found.

Then as indicated in fig the telescope is kept at a distance of about three meters from the wire-gauze mesh. The wire-gauze is illuminated with sodium light. The adjustable slit arranged just in front of the objective such that its longer edges are vertical



Fig

With the slit wide open, the telescope is focussed on the wire-gauze so that a distinct image of the wire-gauze is seen in the plane of the cross-wires. Gradually the width of the slit is cut down until the (image of the) vertical wires just disappear from view. Now the slit is taken out and its width (a) is measured with a travelling microscope.

With a tape the distance D between the wire-gauze and the objective is measured. The experiment is repeated by increasing the distance D, each time by about 1 meter and four or five readings are taken.

The observations are tabulated as in table II

Observations

Table I. To find d between any two adjacent wires of the mesh.

No.of the vertical wire	Microscope reading (b)	No.of the vertical wire	Microscope reading (c)	Length of 10 widths (b-c)
1		11		
-		-		
-		-		
-		-		
-		-		
-		-		
10		20		

Average distance (d) between any two adjacent wires of the mesh $\frac{10\ widths}{10}$

Table II

Serial No.	Distance of wire gauge from the objective D	Microscope Reading of		Width of slit a	$\frac{d}{D}$	$\frac{1.22}{a}\lambda$
		Left edge of slit	Right edge of slit			

For each value of D, compare the results in the last two columns. They will be nearly equal.

Precautions :

1. While taking readings with the travelling microscope, exact coincidence should be made without parallax.
2. The readings on the horizontal scale should be read without parallax.
3. Travelling microscope is to be moved on the horizontal scale along one direction only .... to avoid back-lash error.
4. The slit and the vertical wires of the wire-gause should be perfectly vertical and parallel to each other.
5. The critical width of the slit is to be arrived at with patience, precision and steadily.

VIVA-VOCE QUESTIONS AND ANSWERS

1. Is the resolving power of a telescope a constant ?

Ans.: No. Its dependence on the distance D as can be seen from the expression $\frac{d}{D}$. here d is a constant.

As D varies, $\frac{d}{D}$ also varies. (Accordingly a also varies and 1.22 $\frac{\lambda}{\alpha}$ also varies)

2. What is the difference between the resolving power of a grating and resolving power of a telescope?

Ans : The resolving power of a grating. $\frac{\lambda}{d\lambda}$ is a constant (for a given light of wave length). On the other hand the resolving power of a telescope $\frac{d}{D}$ varies with D.

The resolving power of grating is far higher than the resolving power of telescope.

3. **What is the difference between resolving power and magnification ?**

Ans : The ability of an optical instrument to show two objects that are very close to each other and at a distance is called the resolving power of the instrument.

The ability of an optical instrument to show the object magnified (in the form of the image) is called its magnification. Within a certain limit the resolving power increases with magnification. But, beyond a certain magnification, the resolving power will not increase with further magnification. This is called the maximum useful magnification.

4. **When will be the resolving power of a telescope be maximum ?**

Ans : As he operture of the objective of the telescope increases, the resolving power also increases. However, beyond a certain limit, the aberrations (especially spherical aberration) also increase with aperture and the resolution will be not of much use.

5. **What is the resolving power of normal eye ?**

Ans : It is about 1^1 or $\left(\frac{1^0}{60}\right)$.

6. **Is there any limit for resolution ?**

Ans : Yes. We cannot resolve objects that are closer (nearer) than the wavelength of light (λ) used for illuminating the object.

7. **In increasing the resolving power should we make the diffraction patterns larger or smaller?**

Ans : To increase the resolving power, we should make the diffraction patterns smaller.

8. **What is limit of resolution and how is it related to resolving power ?**

Ans : The minimum separation of two points that can be just resolved is called the limit of resolution. The smaller the limit of resolution, the greater is the resolving power.

9. **The ray optics or the wave optics - which is behind the resolving power ?**

Ans : It is the wave nature of light that gives rise to the resolution and resolving power which are due to diffraction.

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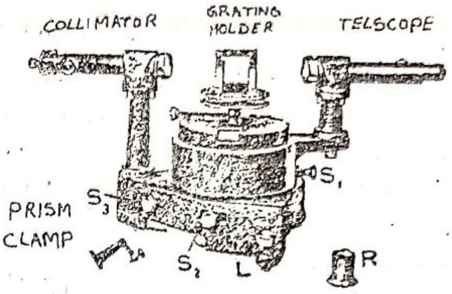
8. SPECTRO METER - HOLLOW PRISM

Aim : To determine the refractive index of a liquid using hollow prism.

Apparatus : Spectrometer, hollow prism, magnifying lens, sodium vapour lamp, spirit level.

Description : The spectrometer mainly consists of a) a collimator b) a telescope c) a prism table and d) a circular scale and the vernier.

a) The collimator Consists of a convergent lens fitted to the inner end of a hollow tube, fixed to the instrument. Another hollow tube, which exactly fits into the fixed tube and can be moved in or out by working a pinion, carries at its outer end a slit of adjustable width. The axis of the collimator is set perpendicular to the axis of rotation of the prism table. The collimator is fixed to the instrument and cannot be rotated. The collimator is used to obtain a parallel beam of light from a given source.



Fig

b) The telescope : This is an astronomical telescope whose objective is fitted to the inner end of a hollow tube. Exactly fiting into this tube there is another hollow tube which can be moved in or out by working a ponion. At the outer end, the tube carries the Ramsden's eye-piece, with cross-wires. The cross wires consists, generally of the fibres from a spider's web, fixed across the tube one vertically and another horizontally in front of the eye-piece towards the objective side. The distance of the cross-wires from the eyepiece can be altered by pushing in or drawing out the eye-piece. The axis of the telescope is set perpendicular to the axis of rotation of the prism table. The telescope can be turned about an axis coinciding with the axis of rotation of the prism table and can be clamped on any position by the screw S1. The angle of rotation can be measured, on a circular scale which is fixed to the telescope and moves along with it. By means of the tangent screw the telescope, after it is clamped, can be turned, through very small angles and thus fine adjustment can be made. The telescope is used to receive the parallel beam of light from the collimator.

c) The prism table : It is a small circular table provided with three leveling screws and is used for keeping the prism on it. The prism table can be raised or lowered and clamped in any position by a screw. By means of another screw it can be fixed to the vernier table and the two will then turn together. The vernier is provided with a clamping screw and a tangent screw for fine adjustment. The prism table can be rotated about a vertical axis passing through its centre.

d) The circular scale : This is a circular metal plate attached to the telescope and rotates with it. Usually graduated into half degrees and the reading can be noted on two verniers which are fixed diametrically opposite to each other.

Adjustments : Before the instrument is used for measurement purpose, the following adjustments are made.

a) Eye-piece : The telescope is turned towards a white surface say a wall and the eye-piece is moved in or out until the cross-wires are seen clearly.

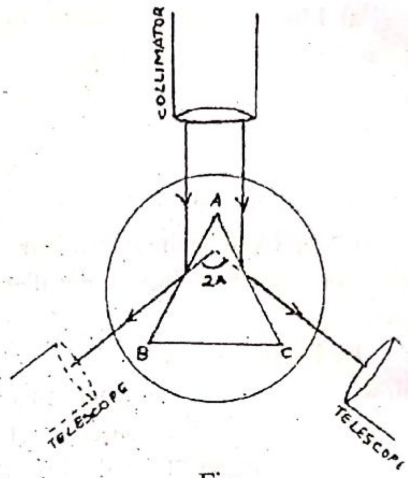
b) Telescope : The telescope is directed towards a distant object, say a telegraph post or a tree and by working the pinion, the telescope is adjusted until the image of the object is formed in the plane of the cross-wires with no parallax between the image and the cross wires. Now the telescope is ready to receive a parallel beam of light.

c) Collimator : The slit of the collimator is illuminated with sodium light. The telescope is brought in line with the collimator and the distance of the slit from the collimating lens is adjusted until a clear image of the slit with well-defined edges is formed in the plane of the cross wires without any parallax error. And also the slit is adjusted to be vertical and narrow.

d) Prism table : A spirit level is kept on the prism table parallel to the line joining two the levelling screws. The two screws are adjusted until the air bubble of the spirit level comes to the centre. Then the spirit level is turned on the table perpendicular to this position and the third screw is adjusted until the ai bubble comes to the centre. Now the surface of the prism table will be-horizontal.

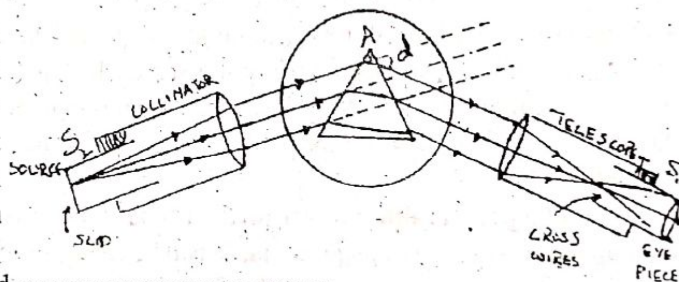
After making the adjustments of the spectrometer, the least count of the vernier is found by th relation $L.C = \frac{l.m.s.d}{N}$ where N is the number of divisons on the vernier scale.

Determination of Angle of the prism (A) :



Fig

Procedure : The primary adjustments of spectrometer are to be done as explained. Then hollow prism is filled with expermental liquid. Then the hollow prism is placed at the centre of prism table such that both refracting edges of the prism is placed at the centre of prism table such that both refracting edges of the prism are facing the collimator symetrically as shown in fig. Then the prism is fixed. The telescope is released and rotated to observe reflected image of the slit from one face say AB. The tangent screw of the telescope is worked until the reflected image coincides with vertical cross wire. The readings of the two verniers are noted. The telescope is rotated such that the reflected image of the slit from second face AC is focussed. Then readings of both verniers are noted. Then difference between the respective readings of the vernier gives the value of 2A, from which th refracting angle can be determined.



Determination of Angle of minimum deviation (D) : The vernier table is clamped and the prism table is released. The prism is clamped centrally on the prism table such that the surface of the ground glass is almost parallel to the axis of the collimator and the light from collimator incident on the polished surface of the prism emerges out from the other polished surface as shown in the fig.

The telescope is turned to observe the refracted image of the slit looking at the image the prisr table is slowly turned such that the image moves towards the direct position. The telescope is also move so as to keep the image of the slit in the field of view. At certain stage it will be found that the imag changes its direction of motion even though the prism is continued to move in the same direction.

The position of the prism is fixed when refracted image of the slit just retraces its path; which is th position of minimum deviation. The telescope is focussed such that the image coincides with the vertic crosswire. The reading of two verniers are noted. Then prism is removed and the telescope rotated suc that the direct image of the slit coincides with vertical cross wire. Then the reading of two verniers ar noted. The difference between the respective readings of the verniers gives the angle of minimum deviatio of the prism (D). Then refractive index of the prism is found by the formula

$$\mu = \frac{Sin\left(\frac{A+D}{2}\right)}{Sin\frac{A}{2}} = ...$$

Precautions :

1. The optical adjustments must be done carefully before starting the experiment.
2. The slit should be narrow as possible.
3. The prism must be set synnetrically on the prism table.
4. Reading on both verniers are to be taken.

5. The polished surface should not be touched. It should be handled by its edges.

Table 1 : Angle of prism (A)

S.No.	Readings of reflected image				Difference in vernier readings (2A)		A
	Left		Right				
	Ver 1	Ver 2	Ver 1	Ver 2	Ver 1	Ver 2	

Table 2 : Angle of Minimum deviation (D)

S.No.	Readings of minimum deviation		Direct readings		Differences in readings		D
	Ver 1	Ver 2	Ver 1	Ver 2	Ver 1	Ver 2	

The refractive index of the liquid in hollow prism = $\mu = \dfrac{Sin\left(\dfrac{A+D}{2}\right)}{Sin\dfrac{A}{2}}$ =......

VIVA-VOCE QUESTIONS AND ANSWERS

1. **Why should we take readings from the two verniers on the circular scale ? is not one sufficient?**

Ans : The base of the circular scale may have some eccentricity - that is one side up and the other side down. To eleminate the error due to this eccentricity we read from both the verniers on either side.

2. **When the prism is in the minimum deviation position, how will be the path of the light ray inside the prism ?**

Ans : When the prism is in the minimum deviation prism, the light ray will tavel parallel to the base inside the prism. That is the path inside the prism will be parallel to BC.

3. **What is the need for adjusting the collimator to render light rays parallel and telescope to catch the parallel light rays ?**

Ans : This is all necessary to get a pure spectrum - no overlap of different colours after dispersion.

4. **What is a pure spectrum ?**

Ans : If the different colours in the resulting spectrum (due to dispersion) do not overlap one over the other, it is called a pure spectrum.

If the different colours get overlapped one over the other, it is called an impure spectrum.

The spectrometer is a convenient device used in the laboratory to get a pure spectrum.

5. **What is a source of monochromatic light ? Is the sodium vapour lamp such a source of monochromatic light ?**

Ans : Light consisting of a single wavelength (λ) or a single frequency (υ) is valled a monochromatic (single coloured) light. A source that produces such a light of single wavelength or frequency is called a monochromatic sources.

Actually the light produced by a sodium vapour lamp consists of two wavelengths $\lambda_1 = 5896\ A^0$ and $\lambda_2 = 5890\ A^0$ (D_1 and D_2 lines). Hence, perfectly speaking it is not a monochromatic source. However, as the two wavelengths are very close to each other, for all practical purposes we consider it as a source of monochromatic light.

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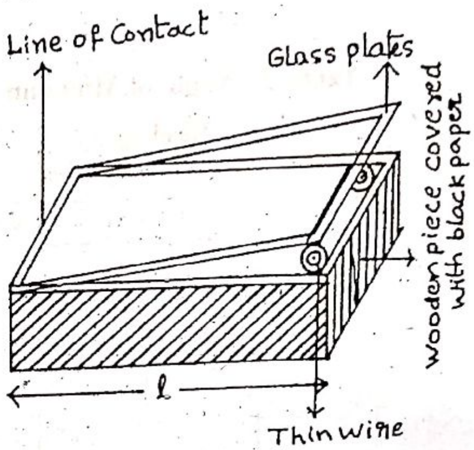
9. THICKNESS OF THE WIRE - WEDGE METHOD

Aim : To determine the thickness of the given wire by wedge method.

Apparatus : Two optically plane glass plates of the same size, a small wooden piece, black paper, thin wire; another plane glass plate of 6 "long and 3" wide fixed to a stand and travelling microscope ; sodium vapour lamp.

Procedure : The two optically place glass plates are cleaned well and in between them the given wire is fixed with one of the edges so that the two glass plates touch at one end and are separated at the other end as shown in the figure forming a wedge.



Fig

Then the set is placed on a wooden piece covered with black paper under the objective of the microscope. Another glass plate is fixed to a stand at about 450 to the horizontal so that the light falling on it will be reflected down to fall on the wedge. The interence fringes are observed through the microscope. The readings of the microscope for the different fringes are noted and tabulated from which the fringe width β is determined. The distance of the wire from the point of contact of the two plates 'l' is measured. The thickness of the wire is calculated by using the formula.

$$d = \left(\frac{\lambda l}{2\beta}\right) \text{ cms}$$

where λ is the wave length of the light used

No.of the Fringes	Microscope readings	No.of the fringe	Microscope reading 5 fringes	Width of
1		6		
2		7		
3		8		
4		9		
5		10.		

Average width of the five fringes = x

Average fringe width = $\frac{x}{5} = \beta =$

Wave length the light used = λ

Distance between the point of contact of the two glass plates and the axis of the thin wire fixed in between them = l

Thickness of the wave = d = $\frac{\lambda l}{2\beta}$ = ... cms

Precautions :

1. The two plane glass plates forming the wedge should be completely free from any dust and impurities.

2. The reflecting glass plate 'G' should be carefully arranged to make 45^0 of angle of incidence with incident sodium light so that after reflection the light falls vertically down on the wedge.
3. The wedge placed on the platform of the travelling microscope should remain fixed in position throughout the experiment.
4. Care should be taken to avoid the back-lash error while taking readings with the travelling microscope. For this, the tavelling microscope should be moved only in one direction - from left to right - from m^{th} fringe to $m + 30^{th}$ fringe focussing. It should never be moved to and fro.
5. The wire whose thickness (diameter) is to be found should be very thin.

VIVA-VOCE QUESTIONS AND ANSWERS

1. Why do we get the bright and dark fringes in this experiments ?

Ans : This is because of the two coherent light beams interfering with each other. The two beams of light getting reflected from the upper glass plate and the lower glass plate are from the same source and hence they are coherent sources.

2. How are the fringes formed in this experiment ?

Ans : These inerference fringes are of equal width, parallel to each oher and are equidistant from one another. They are parallel to the tangential line at the joining of the two plates on the left side. They are alternately bright and dark.

3. What is the disadvantage if the plates are not plane?

Ans : Then, the fringes will be of unequal width.

4. Are the two light beams coherent ? If so how ?

Ans : Yes. These two beams are coherent. They are derived from the same source and one is reflected from the upper plane glass plate, while the other is reflected from the lower plane glass plate.

5. To which class of interference - Division of amplitude or division of wave from - the interference in this experiment belongs ?

Ans : The interference in this experiment is due to division of amplitude.

6. If white light is used in place of sodium light, how will be the fringes look like ?

Ans : When a composite (white) light is used we get coloured fringes of various colours (instead of bright and dark fringes).

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10. REFRACTIVE INDEX OF A LENS AND OF A LIQUID - BOY'S METHOD

Aim : To determine the refractive index of the material of a convex lens and that a liquid.

Apparatus : Convex lens, needle, mercury, watch glass retort stand.

Theory : The focal length 'f' of lens is given by

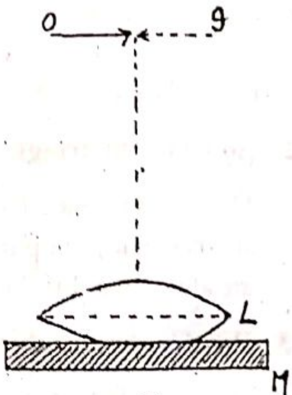
$$\frac{1}{f}=(\mu-1)\left(\frac{1}{r_1}+\frac{1}{r_2}\right)$$ where r_1 and r_2 are radii of curvatures of the curved surfaces of the lens, μ

is the refractive index of the material of the lens.

Knowing r_1, r_2 and f, μ can be calculated.

Procedure :

i) To determine 'f' of a convex lens : The given convex lens is placed on a plane mirror, placed on a table. A needle is clamped horizontally to a retort stand and the position of the needle is adjusted so that it is above the lens. Looking down from above the needle the reflected image of the needle is observed through the lens and the height of the needle is adjusted so that the tip of the needle and its reflected image coincide without any parallax, when the eye is moved side ways. The distances of the needle from the top and bottom of the lens are measured. The average of the two readings gives the focal length f_1 of the convex lens.

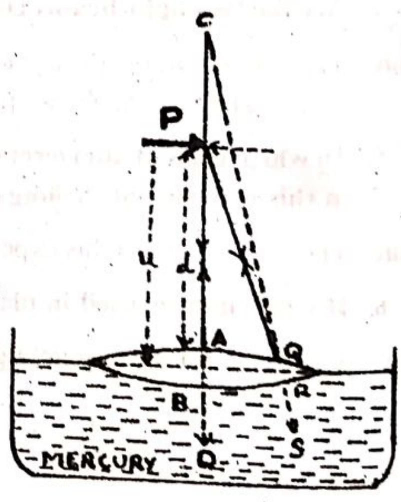


Fig

ii) To determine radii of curvature of the two surfaces of the convex lens : The lens is floated in a dish of mercury. The needle is held horizontally in the clamp of a retort stand and is kept such that its tip is vertically above the centre of the lens. Looking down from above the height of the needle is adjust such that its tip coincides with reflected image of the needle, without any parallax error, when the eye is moved side ways. The distance between the tip of the needle and top of the lens is measured. To this distances half the thickness of the lens is added let it be d_1.

The radius of curvature of the surface of the lens in contact with mercury is calculated from the formula

$$r_1=\frac{fd_1}{f-d_1} \qquad \text{-----(i)}$$



Fig

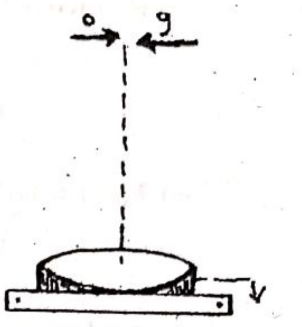
Similarly radius of curvature r_2 of the others surface of the lens is also determined by measuring d_2, then

$$r_2=\frac{f\,d_2}{f-d_2} \qquad \text{-----(ii)}$$

iii) To calculate R.I. of the material of the lens (μ) : Knowing f_1, r_1, r_2 of the lens, its μ is calculated from the formula

$$\frac{1}{f_1}=(\mu-1)\left(\frac{1}{r_1}+\frac{1}{r_2}\right) \qquad \text{-----(iii)}$$

iv) To determine the focal length of the liquid lens and hence the refractive index of liquid (ω) : Few drops of the given liquid are placed on the plane mirror and the convex lens is placed above the liquid the liquid drops such that its surface whose radius of curvature is (r_1) is in contact with the liquid. The height of the needle is again adjusted so that there is no parallax between the needle and its reflected image when seen vertically down from above into the liquid. The distances of the needle from the top and bottom surfaces of the lens are measured. The average of the two readings gives the combined focal length F of the convex lens and the plane concave liquid lens.



(LIQUID LENS

Fig

The focal length f_2 of the plano concave liquid lens is calculated from the formula.

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2} \qquad ....(iv)$$

Value of f_2 will be - ve since the liquid lens is plano concave. If μ_ω is the refractive index of the liquid

$$\frac{1}{f_2}=(\mu_\omega-1)\left(\frac{1}{r_1}+\frac{1}{r_2}\right)$$

If r_1 is the radius of curvature the lens surface in contact with the liquid then $r_2=0$

$$\therefore \frac{1}{f_2}=\frac{(\mu_\omega-1)}{r_1} \quad \text{Or } \mu_\omega=1+\frac{r_1}{f_2}$$

Observations :

i) 'f' of convex lens :

Distance from the top of the lens to the needle = d^1

Distance from the bottom of the lens = d^{11}

Focal length of the lens = $f_1=\dfrac{d^1+d^{11}}{2}$

Thickness of the lens : $t = d^{11} - d^1$

ii) Radii of curvature of the convex lens :

Distance from the top of the needle = x

Half the thickness of the lens = $\dfrac{t}{2}=\dfrac{d^{11}-d^1}{2}$ = y

$\therefore\ d_1 = x + y$

$$r_1=\frac{f\,d_1}{f-d_1}$$

Similarly $r_2=\dfrac{f\,d_2}{f-d_2}$

iii) Refractive index of the convex lens :

$$\frac{1}{f_1} = (\mu - 1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

iv) Focal length of the liquid lens and hence its μ .

Distance from the top of the lens to the needle = d^{I}

Distance from the bottom of the lens to the needle = d^{II}

Combinated focal length of the convex lens and liquid lens = $\frac{d^{I} + d^{II}}{2}$

Focal length of convex lens (from i) = f_1 = ...cms

If f_2 in the focal length of plano concave liquid lens them $\frac{1}{f_2} = \frac{1}{F} - \frac{1}{f_1}$

$\therefore$ f_2 = ... cm

Refractive index of the liquid lens : $\mu_{\omega} = 1 + \frac{r_1}{r_2}$

Precautions :

1. The convex lens used shold be of a small focal length ($f_g \sim 20$ cm). The approximate focal length is to be first determined by distant object method. This helps further adjustments.
2. The convex lens and the plane mirror should be perfectly clean and dry.
3. There should not be any parallax between the needle and its image while taking readings x_1, x_2, y, d_1 and d_2.
4. The distances are to be measured with the metre scale avoiding parallax error.
5. The mercury and the liquid (water) taken should be highly pure and clean.
6. the drop of liquid should be a very small drop.
7. The needle used should be bright. If necessary it should be polished with a sand paper and chalk is to be applied.

VIVA-VOCE QUESTIONS AND ANSWERS

1. What is the difference between a mirror and a lens ?

Ans : In a mirror the light gets reflected (into the same incident medium)
In a lens, the incident light is refracted through the lens (into a different medium)

2. What is the difference between reflection and refraction ?

Ans : While the light is tavelling through a medium, if any obstacle is placed on its path, some of the light gets back into the same medium. This is called reflection.
When light travels from one medium into a different medium, it gets bent at the common surface. This is called refraction.

3. What is the radius of curvature of a plane surface ?

Ans : Infinity.

4. What is parallax ? Has it got any uses ?

Ans : Suppose there are two objects plaed at a distance away from us and one behind the other. To be specific let us say B is behind A. Now if we place our eye infront of A and move across. A will appear to move across before B. This is called the parallax.
When A and B are at the same position, when we more our eye across, both will move across at the same time. That is, if the positions of A and B coincide there will be no parallax.
This principle is used in focussing the objects in optical instruments. We adjust until the image coincides with the vertical cross wire without any parallax.

5. What is a lens ?

Ans : A lens is a portion of a transparent refracting medium, usually glass, bounded by two surfaces, generally curved.

—O—