INTERFERENCE, DIFFRACTION AND POLARIZATION

Interference:

When the two rays come to the point of a medium simultaneously, they superpose to give alternate dark and bright band**s,** this is known as interference. There are two methods to obtain interference pattern.

Q. How to obtain interference pattern by division of wavefront and division of amplitude?

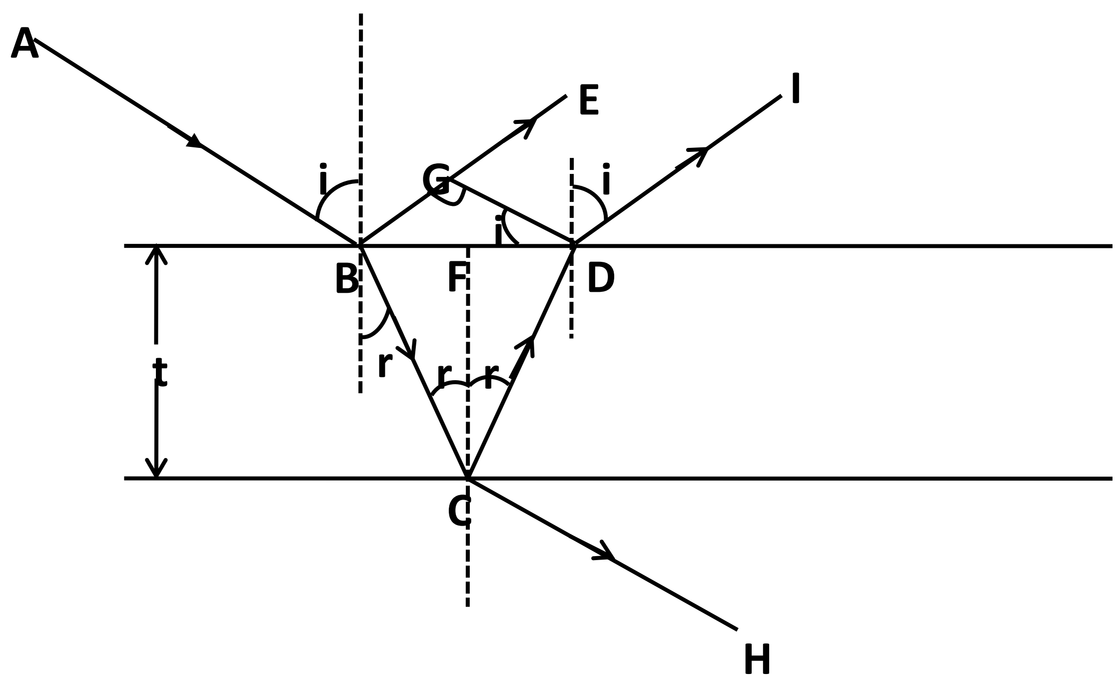
Ans. Division of Wavefront and division of Amplitude:

A wavefront emerging from slit S is divided into two parts by double slits as in Young's double slit experiment. These two wavefronts from two slits interfere and this is known as interference by division of wavefront.

When the beam is incident on a plane surface, it is partially reflected and partially refracted. Thus intensity of reflected light is less than that of incident light, it is known as division of amplitude and it is used in thin film interference.

Q. Explain thin Film Interference and obtain condition for constructive interference. OR Derive equation for dark in thin film interference.

Ans. Consider a thin transparent film of thickness t and refractive index μ.



Let, AB – incident beam

BE – reflected beam

BC – refracted beam

i – angle of incidence

r – angle of refraction

The refracted beam BC is partly reflected along CD and partly refracted along CH at the bottom surface and again reflected and refracted at point D on top surface as shown in fig. This continues and it gives reflected and transmitted systems.

When there is reflection at denser medium, an additional path of $\lambda/2$ is introduced in the reflected ray where λ is wavelength of light.

Draw DG $\perp$ BE. After GD the rays GE and DI have equal path. Hence path difference between BE and DI,

$$\delta = \mu(BC + CD) - \left(BG + \lambda/2\right) \text{-------------} Eq.(1)$$

From fig. $\cos r = \frac{CF}{BC} = \frac{CF}{CD}$

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

$\tan r = \frac{BF}{t}$

$\therefore$ $BF = t \cdot \tan r = FD$

$BG = BD \sin i = (BF + FD) \sin i$

$= 2t \cdot \tan r \sin i$

Snell's law $\mu = \frac{\sin i}{\sin r}$

$\therefore BG = \frac{2\mu t \sin^2 r}{\cos r}$------------------------Eq.(3)

Substituting equations (2) and (3) in equation (1)

$$\delta = \mu\left(\frac{t}{\cos r} + \frac{t}{\cos r}\right) - \left(\frac{2\mu t \sin^2 r}{\cos r} + \frac{\lambda}{2}\right)$$

$$= \frac{2\mu t}{\cos r} - \frac{2\mu t \sin^2 r}{\cos r} - \frac{\lambda}{2}$$

$$= \frac{2\mu t}{\cos r}\left(1 - \sin^2 r\right) - \frac{\lambda}{2}$$

$$= 2\mu t \cos r - \frac{\lambda}{2}$$

For constructive interference, $\delta = n\lambda$

$\therefore 2\mu t \cos r - \frac{\lambda}{2} = n\lambda$

$\therefore 2\mu t \cos r = (n \pm 1/2)\lambda$

For destructiveinterference, $2\mu t \cos r = n\lambda$

Interference in Wedge Shaped Film:

Consider a wedge shaped film formed by two surfaces XY and XY_1 inclined at an angle α as shown in figure. The thickness of the thin film increases from X to Y.

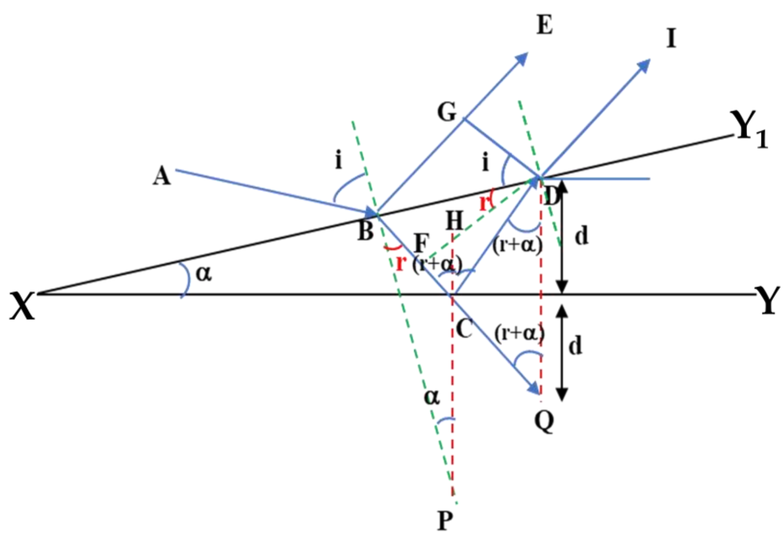


Fig.

Let, AB – incident beam

BE – reflected beam

BC – refracted beam

i – angle of incidence

r – angle of refraction

The refracted beam BC is again reflected along CD at the bottom surface. Draw DG ⊥ BE. The path difference δ is given by

$$\delta = \mu(BC + CD) - \left(BG + \lambda/2\right) - (Eq. 4.4)$$

$$= \mu(BF + FC + CD) - \left(\mu BF + \frac{\lambda}{2}\right) \quad \left[\because \sin i = \frac{BG}{BD}, \sin r = \frac{BF}{BD} \text{ and } \mu = \frac{\sin i}{\sin r}\right]$$

$$= \mu\,(FC + CD) - \frac{\lambda}{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(Eq.4.5)}$$

From geometry of figure,

$$\angle BCH = \angle CBP + \angle BPC = r + \alpha, \angle CQD = \angle CDQ = r + \alpha$$

Thus ΔCQD is an isosceles triangle and CD = CQ, equation (4.5) becomes,

$$\delta = \mu\,(FC + CQ) - \frac{\lambda}{2} = \mu FQ - \frac{\lambda}{2}$$

In right angle triangle FQD, FQ = 2d cos (r + α)   (DP = 2d)

$$\therefore \delta = 2\mu d\,\cos(r + \alpha) - \frac{\lambda}{2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(Eq.4.6)}$$

For constructive interference,

$$2\mu d\,\cos(r + \alpha) - \frac{\lambda}{2} = n\lambda$$

$$\therefore 2\mu d\,\cos(r + \alpha) = (2n + 1)\frac{\lambda}{2} \qquad n = 0,1,2,3\ldots\ldots$$

For destructive interference,

$$2\mu d\,\cos(r + \alpha) = n\lambda \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(Eq.4.7)$$

Fringe width:

For n^{th} dark fringe,

$$2\mu d\cos(r + \alpha) = n\lambda$$

Let X_n be the distance of n^{th} fringe from edge of the film, d = X_n tan α.

Putting in above equation,

$$2\mu X_n \tan\alpha \cos(r + \alpha) = n\lambda \qquad \ldots\ldots\ldots\ldots\text{(Eq.4.8)}$$

Similarly For (n+1)th dark fringe,

$$2\mu X_{n+1} \tan\alpha \cos(r + \alpha) = (n+1)\lambda \qquad \ldots\ldots\ldots\ldots\text{(Eq.4.9)}$$

Subtracting equation (4.8) from (4.9), fringe width,

$$\beta = X_{n+1} - X_n = \frac{\lambda}{2\mu \tan\alpha \cos(r + \alpha)}$$

For normal incidence, i = r = 0

$$\therefore \beta = \frac{\lambda}{2\mu \sin\alpha}$$

For small value of α, sin α = α

$$\therefore \beta = \frac{\lambda}{2\mu\alpha}$$

Salient Features of interference pattern

- Fringe at the apex is dark
- Fringes are straight and parallel
- Fringes are equidistant and of equal thickness.

Applications of Interference:

Testing Of Flatness:

Surface irregularities on the surface of machine components act as a source of stress leading to fatigue crack. So, it is necessary to inspect the surface of component for smoothness and it is done by placing optically flat surface on the component making some angle and illuminating it with monochromatic light. It forms wedge shaped film. If interference fringes are straight, parallel and equidistant, the surface is smooth. If component surface is concave, fringes are curved towards the contact edge and for convex surface fringes curve away from contact edge.

Thickness of thin film coating:

Dielectric or metallic thin films are coated on optical components. Partially coated substrate is used to determine thickness of thin film. The glass plate is placed in contact with the substrate and interference pattern is observed from the regions of the substrate with and without coating. A shift occurs in the fringes from the region coated by thin film. Measuring the shift in interference fringes, thickness of the film can be calculated.

Q. What is diffraction? What are types of diffraction?

Ans. Diffraction:

"Phenomenon of bending of light around sharp obstacle and spreading it in geometrical shadow region is known as diffraction.'' The diffraction is due to failure of light beam to travel in a straight line when the beam just passes over the sharp edge and it can only be explained by the wave nature of light.

There are two types of diffraction.

	Fraunhofer's diffraction	**Fresnel's diffraction**
1.	The source and screen are at infinite distance from the obstacle.	The source and screen are at finite distance from the obstacle.
2.	The wavefront is plane wavefront.	The wavefront is spherical or cylindrical.
3.	Lens system is necessary	Lens system is not necessary.
4.	Theoretical treatment is easier.	Theoretical treatment is complicated.

5.	Centre of the diffraction pattern is always bright.	Centre of the diffraction pattern may or may not bebright.

Q. Explain construction of plane diffraction grating.

Ans. Plane diffraction grating :“The set of large number of parallel equidistant slits is known as plane diffraction grating.”

construction of grating :

The first diffraction grating was made by Joseph Fraunhofer using fine wires. Now a days grating is prepared by ruling fine lines extremely close together on the surface of glass with a fine sharp diamond point in which lines act as opaque portion and the transparent portion between two lines acts as a slit. This is transmission type of grating. If lines are drawn on silvered surface, it becomes reflection type of grating. But these ruled gratings are costlier. Hence their replicas are formed by pouring a colloidal solution on these ruled gratings and allowed to be hardened. This dried film can be served as a diffraction grating when placed between two glass plates.

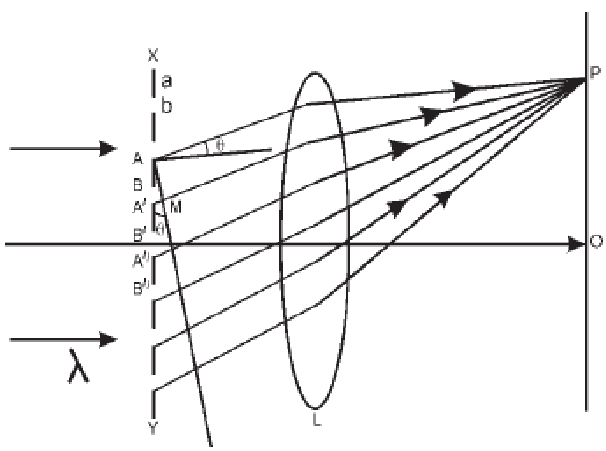
Diffraction grating is characterized by total number of slits N

The distance between the centres of the adjacent slits –is known as grating element = 1/N’ where N’ is number of slit per cm.

Typical transmission grating consists of 15000 to 20000 lines per inch. If spacing between the lines is of the order of wavelength of light, appreciable deviation of light is produced and diffraction pattern is obtained.

Q. What is diffraction grating? Explain how it is constructed. Define the term grating element.

Ans. Diffraction grating is set of large number of parallel and equidistant slits.



XY be the section of grating

AB, A’B’, A”B”…… are opaque regions.

a - Width of opaque region.

b - Width of transparent region.

$\therefore$ (a+b) = grating element.

It is constructed by drawing equidistant parallel lines on the glass plate with the help of diamond. The line becomes opaque region and region between two lines is transparent and thus it is slit. But these ruled gratings are costlier. Hence their replicas are formed by pouring a colloidal solution on these ruled gratings and allowed to be hardened. This dried film can be served as a diffraction grating when placed between two glass plates.

Diffraction grating is characterized by total number of slits N.

The distance between the centres of the adjacent slits –is known as grating element = 1/N’ where N’ is number of slits per cm.

Equation for grating is

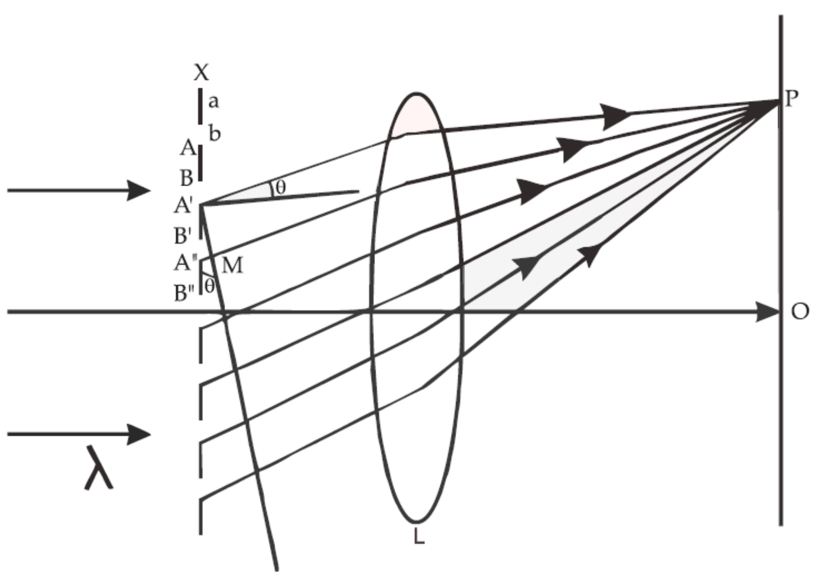
$(a+b) \sin \theta = n\lambda$ .... is condition for bright

And $N(a+b) \sin \theta = m\lambda$ is the condition for secondary minimum;

where m can take all the values except 0,N,2N,…….

Q. Explain the theory of diffraction grating OR obtain equation of diffraction grating OR show that angle of diffraction depends on wavelength of light.

Ans. “The set of large number of parallel equidistant slits is known as plane diffraction grating.” Consider the plane transmission grating with N number of slits. Parallel beam of monochromatic light of wavelength l is normally incident on grating.



XY be the section of grating

AB, A’B’, A”B”…… are opaque regions.

a - Width of opaque region.

b - Width of transparent region.

$\therefore$(a+b) = grating element.

When the beam is normally incident on grating, major part of the beam goes in straight line without any deviation and is focused at point O. O is a central maximum. Consider the rays diffracted at an angle θ and focused at point P. Intensity at point P is decided by path difference between the rays diffracted at θ by successive slits.

Draw AM perpendicular to diffracted rays. The path difference between the rays diffracted from A and A’ is

$A'M = AA'\sin\theta = (a+b)\sin\theta$

$(a+b)\sin\theta = n\lambda$ .... is condition for bright .... (Eq. 1)

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

If N' is number of lines per cm, $(a+b) = 1/N'$

Therefore equation (1) becomes,

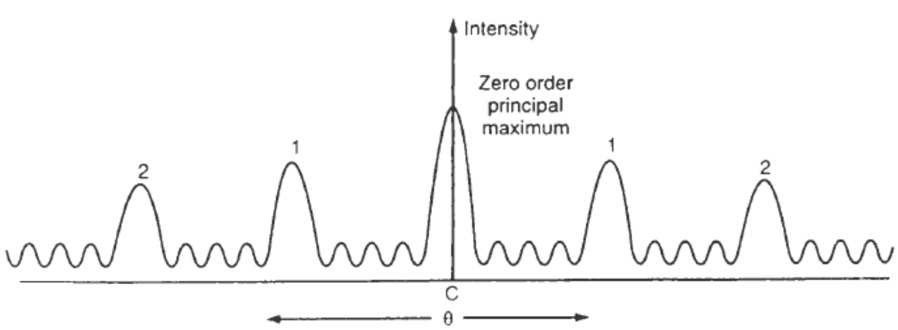
$\sin\theta = nN'\lambda$

Secondary Minima :

$N(a+b)\sin\theta = m\lambda$

where m can take all integral values except 0, N, 2N.......

Diffraction pattern is as shown.



Q. Define diffraction grating. Describe the experiment to determine of wavelength using grating.

Ans.“The set of large number of parallel equidistant slits is known as plane diffraction grating.”

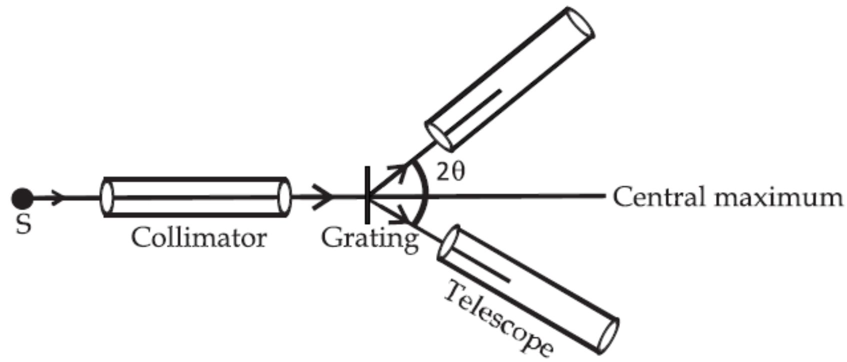
Principle :The equation for grating

(a+b) $\sin\theta = n\lambda$

shows that angle of diffraction depends on wavelength of light and it is the principle used in this experiment.

Construction and working:

The experimental arrangement is as shown in fig.



The collimator and telescope of spectrometer are adjusted for parallel rays. Fine beam of monochromatic light is normally incident on grating that gives diffraction. Diffracted rays are made incident on telescope which can be rotated about the axis of spectrometer. Then position of telescope is adjusted on first order principal maximum on either side of central maximum and angle 2θ between the two positions of telescope is recorded on circular scale. Using the equation,

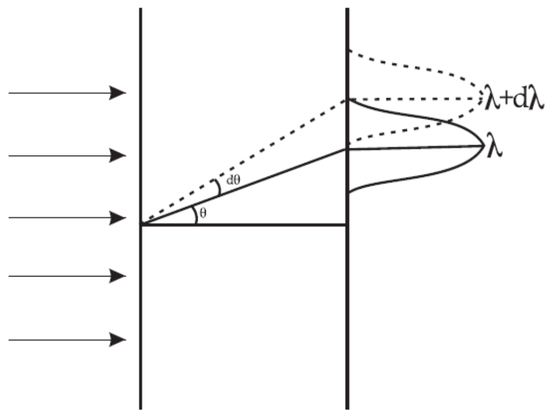
(a+b) $\sin\theta = \lambda$ (n = 1)Wavelength can be calculated.

Q. What is resolving power of grating? Derive an expression for resolving power of grating. OR show that resolving power of grating depends on order of spectrum.

Ans. Resolving power of grating is defined as, "Ratio of wavelength of a line in spectrum to the least difference in the wavelength of next line that can be just separated."

$$\text{R. P.} = \frac{\lambda}{d\lambda}$$

Let a parallel beam of light of two wavelengths λ and (λ +dλ) be normally incident on grating.



n^{th} order principal maximum for λ

(a+b) sinθ= nλ .... (Eq. 1)

similarly for (λ +dλ)

(a+b) sin (θ+dθ) = n (λ +dλ) .... (Eq. 2)

Two lines are separated if Rayleigh's criterion is satisfied. i.e. (θ+dθ) corresponds to secondary minimum for wavelength λ. This is possible if additional path difference λ/N is introduced, where N is total number of slits.

∴ (a+b) sin (θ +dθ) = nλ + $\frac{\lambda}{N}$ .... (Eq. 3)

Equating equations (2) and (3),

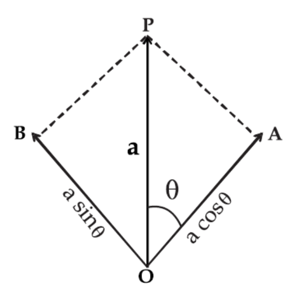
n(λ + dλ) = nλ + $\frac{\lambda}{N}$

$$\therefore \frac{\lambda}{d\lambda} = nN$$

Thus resolving power depends on order of diffraction.

Q. State and Explain law of Malus.

Ans. Statement: "The intensity of light emerging out of analyzer is directly proportional to square of cosine of the angle between polarizer and analyzer."



Let OP = a be the amplitude of incident plane polarized light

θ be the angle between optic axes of polarizer and analyzer.

OP can be resolved into two components acosθ along OA (parallel to analyzer) and asinθ along OB (perpendicular to analyzer). Both these components are incident on analyzer, but only parallel component acosθ will pass through it and perpendicular component asinθ is blocked off.

Therefore intensity of transmitted light,

$$I_1 = (a\cos\theta)^2 = a^2 \cos^2\theta$$
$$= I\cos^2\theta \qquad (I = a^2 \text{ - intensity of incident light})$$
$$\therefore I_1 \ \alpha \ \cos^2\theta$$

When polarizer and analyzer are parallel,

$\theta = 0$, $\cos\theta = 1$, $I_1 = I$ - maximum intensity.

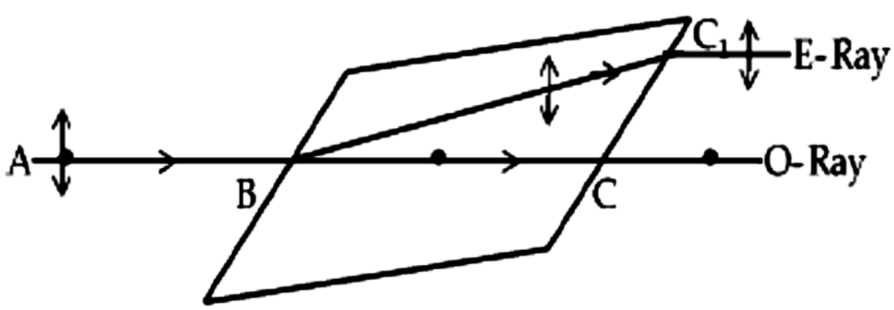
when polarizer and analyzer are perpendicular,

$\theta = 90^0$, $\cos\theta = 0$, $I_1 = 0$

Q. Explain the term"Double refraction".

Ans: An anisotropic medium gives two refracted beams for one incident beam. This is known as double refraction and the crystal is doubly refracting crystal. One ray is called ordinary and other is extraordinary.

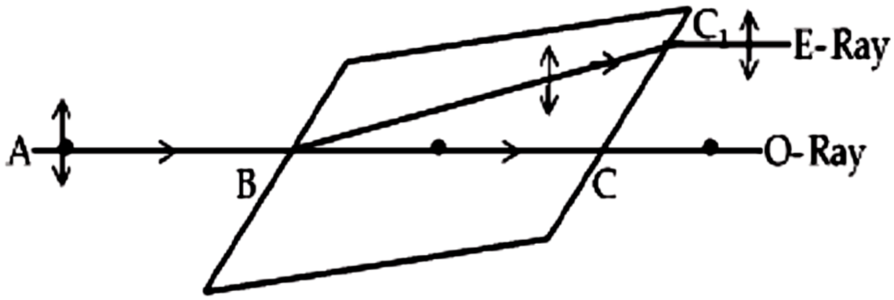
Both O – and E – rays are plane polarized and their vibrations are perpendicular to each other.



AB – incident unpolarized beam
It is doubly refracted, along BC – ordinary
Along BC1 – extraordinary
Both O – ray and E – ray are plane polarized and their vibrations are perpendicular to each other.

Q. What is double refraction? Explain Huygens' theory of double refraction.

Ans : An anisotropic medium gives two refracted beams for one incident, it is known as double refraction. The two rays are ordinary and extra ordinary.



AB – incident unpolarized beam
It is doubly refracted, along BC – ordinary
Along BC1 – extraordinary
Both O – ray and E – ray are plane polarized and their vibrations are perpendicular to each other.

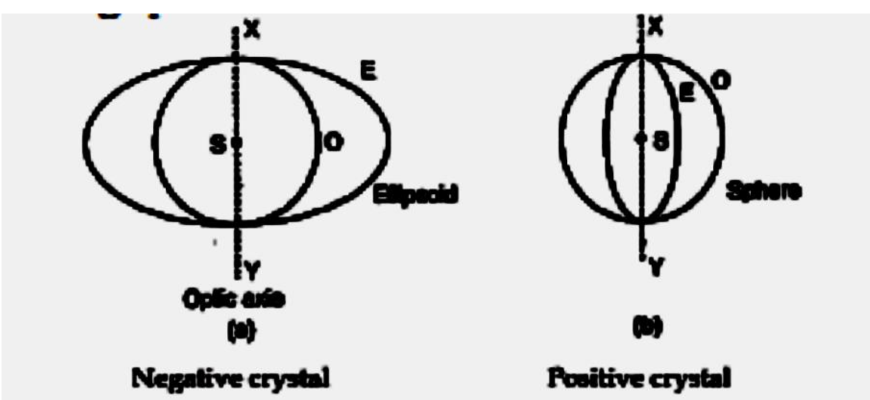
Huygens' theory of double refraction :

Huygens explained the phenomenon of double refraction on the basis of principle of secondary wavelets.

Assumptions of Huygens' theory -

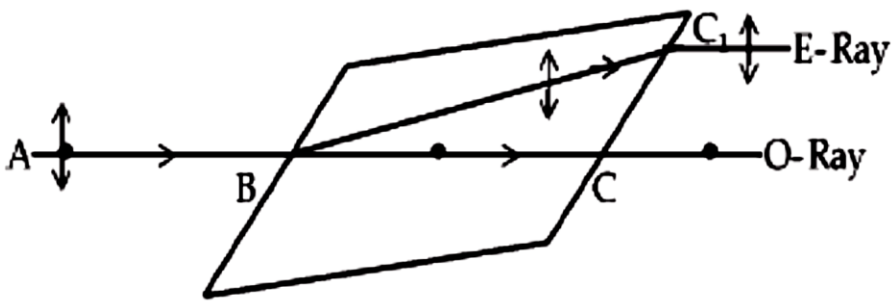
- Secondary source in doubly refracting crystal is the origin for two wavefronts, one for ordinary and second for extraordinary.
- For O-ray, velocity is same in all directions and wavefront is spherical.
- For E-ray, velocity is different in different directions and wavefront is ellipsoid.
- The velocities of O-ray and E-ray are same along optic axis.

Hence spherical and ellipsoid wavefronts touch each other.



Q. What is double refraction? Distinguish between positive and negative crystal.

Ans: An anisotropic medium gives two refracted beams for one incident, it is known as double refraction. The two rays are ordinary and extra ordinary.



AB – incident unpolarized beam
It is doubly refracted, along BC – ordinary
Along BC1 – extraordinary
Both O – ray and E – ray are plane polarized and their vibrations are perpendicular to each other.

Positive crystal	**Negative crystal**
1. Velocity of O – ray is greater than E – ray.	1. Velocity of O – ray is less than E – ray.
2. Refractive index of E – ray is greater than that of O – ray.	2. Refractive index of E – ray is less than that of O – ray.
3. Spherical wavefront is outside the ellipsoid.	3. Ellipsoid wavefront is outside the Spherical.
4. Ex. Quartz	4. Ex. Calcite

Q. What is optical activity? Define specific rotation.

Ans: Optical activity "The property of substance to rotate the plane of polarization of plane polarized light is called optical activity and the substance is optically active." There are two types of optically activesubstances.

- Dextrorotatory : It rotates the plane of polarization of light in clockwise direction while looking towards source.

- Laevorotatory : It rotates the plane of polarization of light in anticlockwise direction while looking towards source.

Specific rotationfor a given wavelength of light at given temperature is defined as, "The rotation produced by one decimetre length of the solution containing one gram of the optically active substance per cm3 of solution."

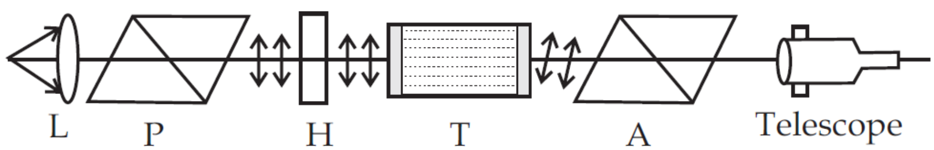
$$S = \frac{\theta}{l c} \ \ ^{o}/dm.gm/cm^3$$

Q. Explain the use of Laurent's half shade polarimeter to measure specific rotation of the substance OR Demonstrate / Illustrate the experiment to determine specific rotation of optically active substance.

Ans: Polarimeter is an instrument used for finding optical rotation of different solutions.

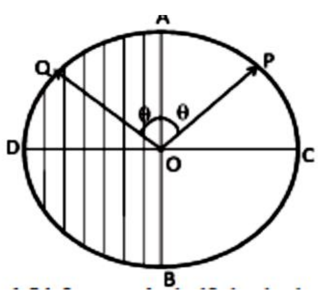
Construction and working:

Experimental arrangement is as shown in figure.



Plane polarized light is made incident on Laurent's half shade device and then passed through tube containing optically active solution. It is passed through analyzer which can be rotated and its rotation is measured on circular scale. Light is observed through eyepiece.

Laurent's half shade device: It is circular plate made of glass and quartz. Incident vibrations are along OP. Vibrations in glass remain as OP and in quartz, it becomes OQ.



If analyzer is parallel to OP, light emerging from glass half will pass through it and glass half will appear bright while quartz half will appear dark. Similarly if analyzer is parallel to OQ, quartz half will appear bright. If it is parallel to AOB both halves will be equally bright.

Tube is filled with distilled water and rotate analyzer to see equally bright plates. Now tube is filled with optically active solution and again analyzer is adjusted to equally bright plates. Reading θ_1 and θ_2 is recorded. Difference between two readings ($\theta_1 - \theta_2$) give angle of rotation θ. Specific rotation is calculated using formula,

$S = \theta / l\ c$

Q. State applications of polarization.

Ans: 1. To study stress distribution in engineering structures using photoelastic model.

2. Polaroids are used in sunglasses, window panes of luxurious trains, aeroplanes to control intensity of light.

3. To study nature of rocks and composition of minerals.

4. It is used in production of three dimensional movie.

5. In saccharimeter to find concentration of sugar solution.

6. In photography, polarizing camera filters are used to take cloud picture. The light from the cloud is unpolarized while that from blue sky is partially polarized. By filtering out the light from blue sky using polarizer, cloud picture can be taken.

7. It is used in liquid crystal display.

8. For diagnostic purpose, in detection of pathogen.

Problems for practice

1) A soap film of 6×10^{-5} cm thickness is viewed at an angle of 30^0 to the normal.Find the wavelengths in the visible region that will be absent in the reflectedlight. ($\mu = 1.22$)

(6677 A^0 and 4450 A^0)

2) A beam of light of wavelength 5500A^0 is incident on thin film of thickness 44μm. It gives destructive interference in second order. What is angle of incidence? (μ=1.33)

($\angle$r=$19^0$59', $\angle$i=$27^0$1')

3) A beam of light of wavelength 4785A^0 is incident on thin film of refractive index 1.26 and thickness 13.3×10^{-5}cm. If angle of refraction is 64.72, find order of dark fringe.

(n=3)

4) In a plane diffraction grating, the angle of diffraction forsecond orderprincipal maximum for the wavelength6000A^0 is 30^0. Calculate the numberof lines per cm of grating. (4166 lines /cm)

5) A diffraction grating used at normal incidence gives a line(λ = 6000 A^0) in a certain spectral order superimposed onblue line (λ = 4800 A^0) of next higher order. If the angle ofdiffraction is sin-1(3/4), calculate grating element.

(3.2×10^{-4}cm)

6) A plane transmission grating has 13500 lines/inch withwidth of two inches. Find

(i) The resolving power of grating.

(ii) Smallest wavelength that can be resolved with a light ofwavelength 4500A^0in second order. (54000, 0.083 A^0)

7) A grating has 3000 lines per cm drawn on it. If its width is 5cm, calculate

(i) resolving power in second order.

(ii) Smallest wavelength difference that can be resolved inthird order in 6000A^0 wavelength region. (30000, 0.13 A^0)

8) A plane transmission grating has 12500 lines per inch. Findthe angularseparation between 5408 A^0 and 5016 A^0 linesof helium in second order.

(θ_1-θ_2= 2^0 34′)

9) What is the highest order spectrum which may be seen withlight of wavelength 5000 A^0 by means of a grating with 3000lines per cm. (n= 6)

10) A 20 cm tube containing sugar solution (specific rotation65^0/dm gm/cm^3) shows optical rotation of 10^0. Calculatethe strength of solution. (7.6%)

11) Two polarizing sheets are oriented with their polarizingdirections parallel to each other. Through what angle eithersheet be rotated so as to reduce theintensity to one half theinitial value. (45^0, 135^0)

12) The refractive index of glass is 1.5. Calculate the angle ofrefraction for a rayof light incident at polarizing angle. (33^0 41′)

13) Calculate specific rotation if plane of polarization is turnedthrough 26^0 15′ travelling 20 cm length of optically activesolution with concentration 30%.

(43.75 ^{0}/dm gm/cm^3)

14) Two Nicols have parallel polarizing directions so thatintensity of transmitted light is maximum. Through whatangle analyzer be rotated so asto reduce the intensity toone fourth of intensity of incident unpolarized light ? (45^0)

15)A glass wedge of angle 0.57^O is illuminated by 6000 A^O incident at an angle of 30^O. Find the thickness of film for tenth bright fringe. (R.I. of glass = 1.5) (2.13 μm)

16) A glass wedge of angle 0.45^O is illuminated by 5000 A^O incident normally. Find the distance from edge of film will the fifth fringe appears. (R.I. of glass = 1.5) (2.12 mm)

17) A wedge shaped thin film of angle 0.01 rad is illuminated by 6000 A^O is viewed at an angle of 30^O. Find order of dark fringe at thickness 2x10^{-4} cm. (R.I. of thin film = 1.5) (10th order)