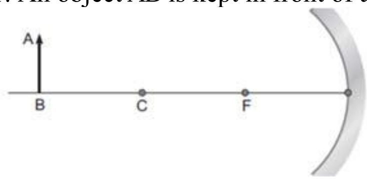
OPTICS

MIRRORS AND LENSES

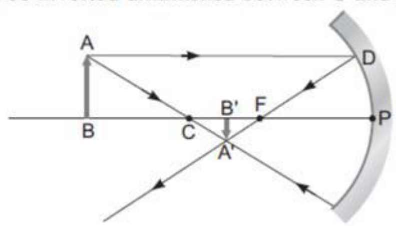
1. An object *AB* is kept in front of a concave mirror as shown in the figure.



(i)Complete the ray diagram showing the image formation of the object.
(*ii*) How will the position and intensity of the image be affected if the lower half of the mirror's reflecting surface is painted black?

Ans.

(*i*) Image formed will be inverted diminished between *C* and *F*.



(*ii*) No change in position of image and its intensity will get reduced.

2.How does focal length of a lens change when red light incident on it is replaced by violet light? Give reason for your answer.

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

$$f \propto \frac{1}{(\mu - 1)} \text{ and } \mu_v > \mu_R$$

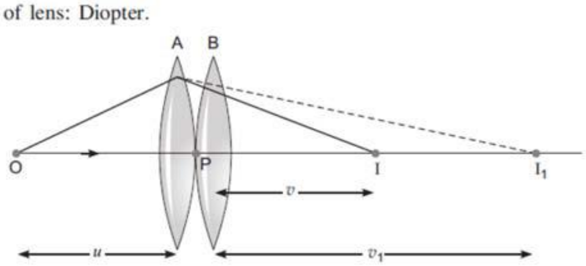
The increase in refractive index would result in decrease of focal length of lens. Hence, we can say by replacing red light with violet light, decreases the focal length of the lens used.

3.Define power of a lens. Write its units. Deduce the relation $1/f = 1/f_1 + 1/f_2$ = + for two thin lenses kept in contact coaxially.

Power of lens: It is the reciprocal of focal length of a lens.

$$P = \frac{1}{f} \text{ (}f\text{ is in metre)}$$

Unit of power of lens: Diopter.



An object is placed at point *O*. The lens *A* produces an image at I_1 which serves as a virtual object for lens *B* which produces final image at *I*.

Given, the lenses are thin. The optical centres (*P*) of the lenses *A* and *B* is co-incident.

For lens *A*, we have

$$\frac{1}{v_1} - \frac{1}{u} = \frac{1}{f_1} \quad ...(i)$$

For lens *B*, we have $\frac{1}{v} - \frac{1}{v_1} = \frac{1}{f_2}$ ...(*ii*)

Adding equations (*i*) and (*ii*),

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f_1}+\frac{1}{f_2} \qquad ...(iii)$$

If two lenses are considered as equivalent to a single lens of focal length *f*, then

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f} \qquad ...(iv)$$

From equation (*iii*) and equation (*iv*), we can write

$$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}$$

4.A convex lens of focal length 25 cm is placed coaxially in contact with a concave lens of focal length 20 cm. Determine the power of the combination. Will the system be converging or diverging in nature?

Convex lens and concave lens are in contact as shown in fig.

Power of convex lens P_1 $= \frac{1}{+f_1(\text{in m})} = \frac{100}{f_1(\text{in cm})}$

$= \frac{100}{+25}$

$= 4D$

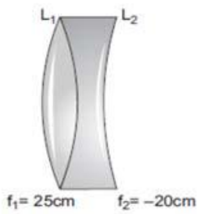
Power of convex lens P_2 $= \frac{1}{+f_2} = \frac{100}{-20}$

$= -5D$

Power of combination P $= P_1 + P_2$

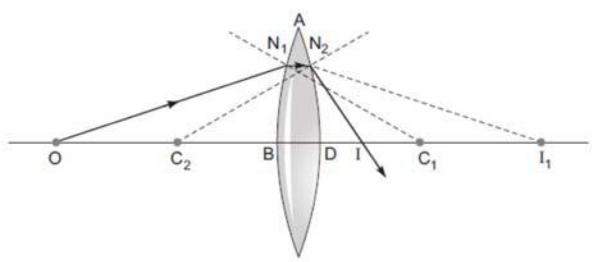
$= 4D + (-5D)$

$= -1D$



System of lenses is diverging in nature.

6.A thin convex lens having two surfaces of radii of curvature R_1 and R_2 is made of a material of refractive index μ_2. It is kept in a medium of refractive index μ_1. Derive, with the help of a ray diagram, the lens maker formula when a point object placed on the principal axis in front of the radius of curvature R_1 produces an image I on the other side of the lens.



Ray of light ON_1 strikes the convex lens ABCD of radii R_1 and R_2. First refraction occurs at face ABC and forms the image I_1 of the object O. The image I_1 acts as a virtual object for surface ADC that forms the image I.

On applying the condition of refractions on surfaces ABC and ADC.

$$\frac{\mu_1}{OB}+\frac{\mu_2}{BI_1}=\frac{\mu_2-\mu_1}{BC_1} \qquad ...(1)$$

and $$\frac{-\mu_2}{DI_1}+\frac{\mu_1}{DI}=\frac{\mu_2-\mu_1}{DC_2} \qquad ...(2)$$

For thin lens $BI_1 = DI_1$, and on adding equation (1) and (2).

$$\frac{\mu_1}{OB}+\frac{\mu_1}{DI}=(\mu_2-\mu_1)(\frac{1}{BC_1}+\frac{1}{DC_2})$$

Suppose object is at infinity and image at focus then

$OB = \infty$ and $DI = f$

$$\frac{\mu_1}{f}=(\mu_2-\mu_1)\left(\frac{1}{BC_1}+\frac{1}{DC_2}\right)$$

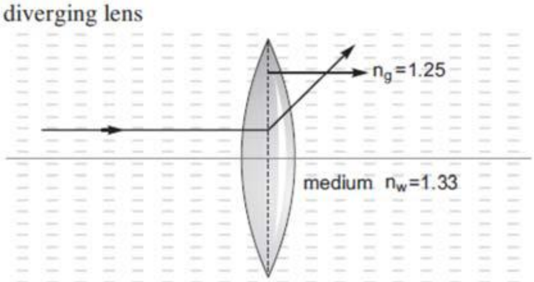
$$\therefore \frac{1}{f}=\left(\frac{\mu_2}{\mu_1}-1\right)\left(\frac{1}{BC_1}+\frac{1}{DC_2}\right)$$

On applying sign convention for convex lens $BC_1 = +R_1$ and $DC_2 = -R_2$.

$$\therefore \frac{1}{f} = (\mu_{21} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad \left(\because \mu_{21} = \frac{\mu_2}{\mu_1}\right)$$

8.A biconvex lens made of a transparent material of refractive index 1.25 is immersed in water of refractive index 1.33. Will the lens behave as a converging lens? Give reason.

As a diverging lens



As the light travels from rarer to denser, it diverges from its path.

10.A converging lens of refractive index 1·5 is kept in a liquid medium having same refractive index. What would be the focal length of the lens in this medium?

The focal length of lens in a liquid-medium is given by

$$\frac{1}{f_l} = ({}_l n_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{f_l} = \left(\frac{n_g}{n_l} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Given $n_l = n_g = 1{\cdot}5$

$$\therefore \quad \frac{1}{f_l} = 0 \quad \text{or} \quad f_l = \infty$$

i.e., focal length of converging lens is **infinity** *i.e.*, glass lens behaves as a glass plate.

Draw a plot showing the variation of power of a lens with the wavelength of the incident light. A diverging lens of refractive index 1·5 and of focal length 20 cm in air has the same radii of curvature for both sides. If it is immersed in a liquid of refractive index 1·7, calculate the focal length of the lens in the liquid.

Refractive index $n = A + \frac{B}{\lambda^2}$, where λ is the wavelength.

Power of a lens $P = \frac{1}{f} = (n_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

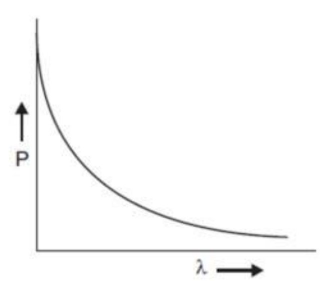
Clearly, power of a lens $\propto (n_g - 1)$. This implies that the power of a lens decreases with increase of wavelength $\left(P \propto \frac{1}{\lambda^2} \text{ nearly}\right)$. The plot is shown in figure.

Given $f_a = 15$ cm, $n_g = 1{\cdot}5$, $n_l = 1{\cdot}7$

Focal length of lens in liquid,

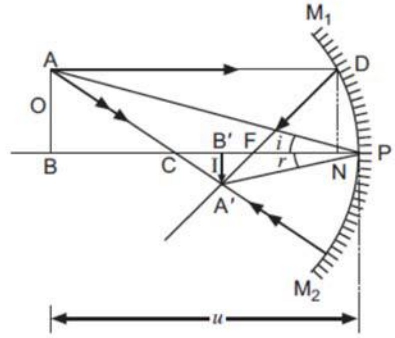
$$f_l = \frac{n_g - 1}{\frac{n_g}{n_l} - 1} \times f_a = \frac{1{\cdot}5 - 1}{\frac{1{\cdot}5}{1{\cdot}7} - 1} \times 15 \text{ cm}$$

$$= \frac{0{\cdot}5 \times 1{\cdot}7}{1{\cdot}5 - 1{\cdot}7} \times 15 \text{ cm} = \mathbf{-63{\cdot}75 \text{ cm}}$$



12. With the help of a suitable ray diagram, derive the mirror formula for a concave mirror.

Mirror Formula: M_1M_2 is a concave mirror having pole P, focus F and centre of curvature C.



An object AB is placed in front of mirror with point B on the principal axis. The image formed by mirror is $A'B'$. The perpendicular dropped from point of incidence D on principal axis is DN.

In ΔABC and $\Delta A'B'C$

$\angle ABC = \angle A'B'C$ (each equal to 90°)

$\angle ACB = \angle A'CB'$ (opposite angles)

Both triangles are similar.

$$\therefore \quad \frac{AB}{A'B'} = \frac{BC}{B'C} \quad \ldots(1)$$

Now in ΔDNF and $A'B'F$

$\angle DNF = \angle A'B'F$ (each equal to 90°)

$\angle DFN = \angle A'FB'$ (opposite angles)

$\therefore$ Both triangles are similar

$$\frac{DN}{A'B'} = \frac{FN}{B'F} \text{ or } \frac{AB}{A'B'} = \frac{FN}{B'F} \quad (\because \; AB = DN) \quad \ldots(2)$$

Comparing (1) and (2), we get

$$\frac{BC}{B'C} = \frac{FN}{B'F} \quad \ldots(3)$$

If aperture of mirror is very small, the point N will be very near to P, so $FN = FP$

$$\therefore \quad \frac{BC}{B'C} = \frac{FP}{B'F} \text{ or } \frac{PB - PC}{PC - PB'} = \frac{FP}{PB' - PF} \quad \ldots(4)$$

By sign convention

Distance of object from mirror $PB = -u$

Distance of image from mirror $PB' = -v$

Focal length of mirror $PF = -f$

Radius of curvature of mirror $PC = -R = -2f$

Substituting these values in (4), we get

$$\frac{-u-(-2f)}{-2f-(-v)} = \frac{-f}{-v-(-f)} \quad \Rightarrow \quad \frac{-u+2f}{-2f+v} = \frac{-f}{-v+f}$$

$$\Rightarrow \quad 2f^2 - vf = -uf + uv + 2f^2 - 2fv \quad \text{or} \quad fv + uf = uv$$

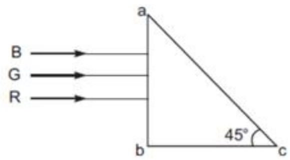
Dividing both sides by uvf, we get

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

The corresponding formula for thin lens is

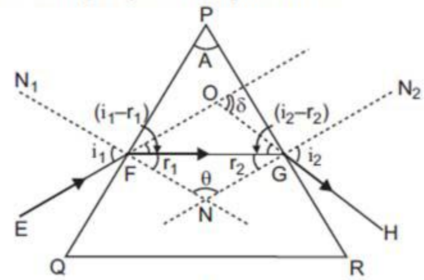
$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

1.(*i*) A ray of monochromatic light is incident on one of the faces of an equilateral triangular prismof refracting angle A. Trace the path of ray passing through the prism. Hence, derive anexpression for the refractive index of the material of the prism in terms of the angle minimumdeviation and its refracting angle.
(*ii*) Three light rays red (R), green (G) and blue (B) areincident on the right angled prism abc at face ab. The refractive indices of the material of the prism for red,green and blue wavelengths are respectively 1.39, 1.44 and 1.47. Trace the paths of these rays reasoning outthe difference in their behaviour.



ANS.

(*i*) Let *PQR* be the principal section of the prism. The refracting angle of the prism is *A*.



A ray of monochromatic light *EF* is incident on face *PQ* at angle of incidence i_1. The refractive index of material of prism for this ray is *n*. This ray enters from rarer to denser medium and so is deviated towards the normal *FN* and gets refracted along the direction *FG*. The angle of refraction for this face is r_1. The refracted ray *FG* becomes incident on face *PR* and is refracted away from the normal GN_2 and emerges in the direction *GH*. The angle of incidence on this face is r_2 (into prism) and angle of refraction (into air) is i_2. The incident ray *EF* and emergent ray *GH* when produced meet at *O*. The angle between these two rays is called angle of deviation 'δ'.

$$\angle OFG = i_1 - r_1 \quad \text{and} \quad \angle OGF = i_2 - r_2$$

In Δ *FOG*, δ is exterior angle

$$\therefore \quad \delta = \angle OFG + \angle OGF = (i_1 - r_1) + (i_2 - r_2)$$
$$= (i_1 + i_2) - (r_1 + r_2) \quad \text{...(i)}$$

The normals FN_1 and GN_2 on faces *PQ* and *PR* respectively, when produced meet at *N*. Let $\angle FNG = \theta$

In Δ *FGN*, $\quad r_1 + r_2 + \theta = 180° \quad$ ...(*ii*)

In quadrilateral *PFNG*, $\angle PFN = 90°$, $\angle PGN = 90°$

$\therefore \quad A + 90° + \theta + 90° = 360° \quad$ or $\quad A + \theta = 180° \quad$ ...(*iii*)

Comparing (*ii*) and (*iii*), $\quad r_1 + r_2 = A \quad$ ...(*iv*)

Substituting this value in (*i*), we get

$$\delta = i_1 + i_2 - A \quad \text{...(v)}$$

or $\quad i_1 + i_2 = A + \delta \quad$ ...(*vi*)

From Snell's law $\quad n = \dfrac{\sin i_1}{\sin r_1} = \dfrac{\sin i_2}{\sin r_2} \quad$ ...(*vii*)

For minimum deviation i_1 and i_2 become coincident, *i.e.*, $i_1 = i_2 = i$ (say)

So from (*vii*) $\quad r_1 = r_2 = r$ (say)

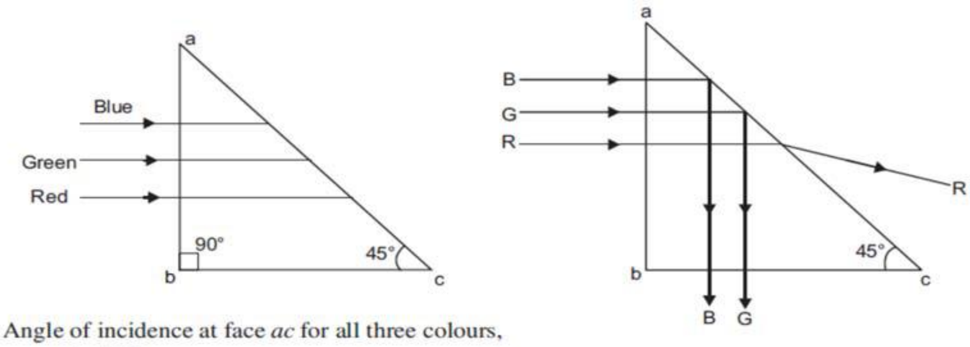
Hence from (*iv*) and (*vi*), we get

$$r + r = A \quad \text{or} \quad r = A/2$$

and $\quad i + i = A + \delta_m \quad$ or $\quad i = \dfrac{A + \delta_m}{2}$

Hence from Snell's law, $\quad n = \dfrac{\sin i}{\sin r} = \dfrac{\sin\left(\dfrac{A + \delta_m}{2}\right)}{\sin\left(\dfrac{A}{2}\right)}$

(ii)



Angle of incidence at face ac for all three colours,

$i = 45°$

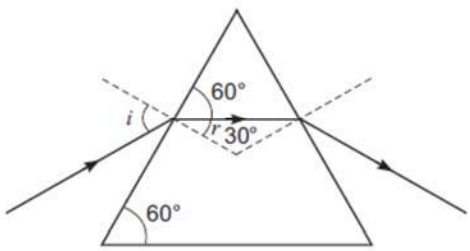
Refractive index corresponding to critical angle 45° is

$$\mu = \frac{1}{\sin 45°} = \sqrt{2} = 1\cdot414$$

The ray will be transmitted through face 'ac' if $i < i_c$. This condition is satisfied for red colour ($\mu = 1\cdot39$). So only red ray will be transmitted, Blue and Green rays will be totally reflected.

Q2

A ray of light, incident on an equilateral glass prism ($\mu_g = \sqrt{3}$) moves parallel to the base line of the prism inside it. Find the angle of incidence for this ray.



From the figure, we see

$r = 30°$

We know

$$\Rightarrow \quad n_{21} = \frac{\sin i}{\sin r} \quad \Rightarrow \quad \sqrt{3} = \frac{\sin i}{\sin 30°}$$

$$\Rightarrow \quad \sin i = \sqrt{3} \sin 30° = \sqrt{3} \times \frac{1}{2}$$

$$\Rightarrow \quad i = 60°$$

3.Define magnifying power of a telescope. Write its expression.

(a) Magnifying power of telescope is the ratio of the angle subtended at the eye by the image to the angle subtended at the unaided eye by the object.

$$m = \frac{\beta}{\alpha} = \frac{f_0}{f_e} \quad \text{or} \quad m = \frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$$

4.a)How is the working of a telescope different from that of a microscope?

b)The focal lengths of the objective and eyepiece of a microscope are 1.25 cm and 5 cmrespectively. Find the position of the object relative to the objective in order to obtain an angularmagnification of 30 in normal adjustment.

(a) **Difference in working of telescope and microscope**

(i) Objective of telescope forms the image of a very far off object at or within the focus of its eyepiece. The microscope does the same for a small object kept just beyond the focus of its objective.

(ii) The final image formed by a telescope is magnified relative to its size as seen by the unaided eye while the final image formed by a microscope is magnified relative to its absolute size.

(iii) The objective of a telescope has large focal length and large aperture while the corresponding for a microscope have very small values.

(b) Given $f_o = 1.25$ cm, $f_e = 5$ cm

Angular magnification $m = 30$

Now, $m = m_e \times m_o$

In normal adjustment, angular magnification of eyepiece

$$m_e = \frac{d}{f_e} = +\frac{25}{5} = 5$$

Hence $m_0 = 6$

But $m_0 = \frac{v_0}{u_0}$

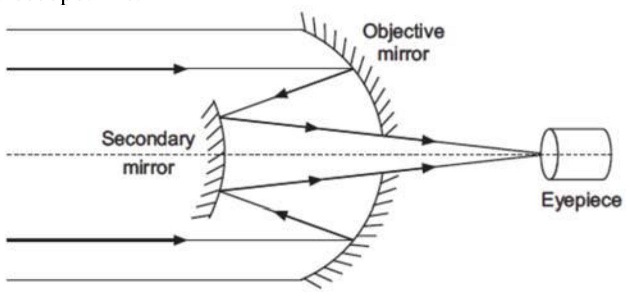
$\Rightarrow \quad -6 = \frac{v_0}{u_0} \quad \Rightarrow \quad v_0 = -6u_0$

Applying lens equation to the objective lens

$$\frac{1}{f_0} = \frac{1}{v_0} - \frac{1}{u_0} \Rightarrow \frac{1}{1.25} = \frac{1}{-6u_0} - \frac{1}{u_0}$$

$\Rightarrow \quad u_0 = -1.46\,\text{cm} = -1.5\text{ cm}$

5.Draw a labelled ray diagram of a reflecting telescope. Mention its two advantages over therefracting telescope.Ans.



Advantages:

(*i*) It is free from chromatic aberration.

(*ii*) Its resolving power is greater than refracting telescope due to larger aperture of mirror.

7.Draw a ray diagram showing the image formation by a compound microscope. Hence obtainexpression for total magnification when the image is formed at infinity. SEE DIA Q.NO.12

If image A′ B′ is exactly at the focus of the eyepiece, then image A″ B″ is formed at infinity.

If the object AB is very close to the focus of the objective lens of focal length f_o, then magnification M_o by the objective lens

$$M_e = \frac{L}{f_o}$$

where L is tube length (or distance between lenses L_o and L_e)

Magnification M_e by the eyepiece

$$M_e = \frac{D}{f_e}$$

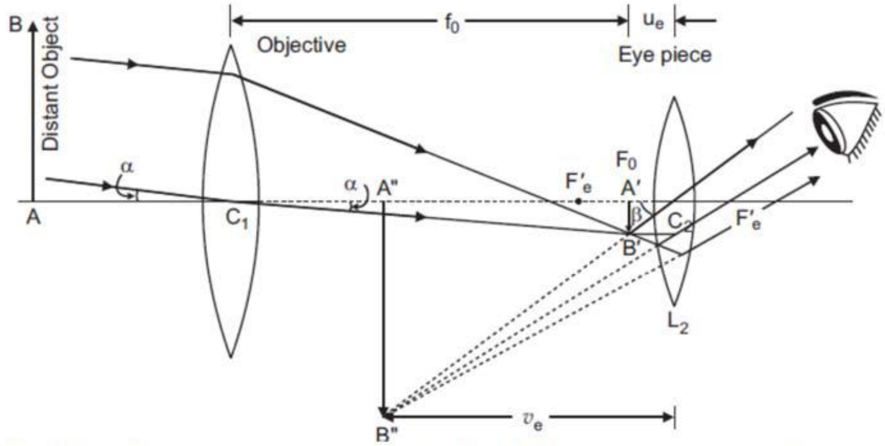
where D = Least distance of distinct vision

Total magnification $\quad m = M_o M_e$

$$= \left(\frac{L}{f_o}\right)\left(\frac{D}{f_e}\right)$$

8.Draw a labelled ray diagram of a refracting telescope. Define its magnifying power and write the expression for it.

Write two important limitations of a refracting telescope over a reflecting type telescope.



It is defined as the ratio of the angle (β) subtended by the final image on the eye to the angle(α) subtended by the object on eye.

$$M = \frac{\tan\beta}{\tan\alpha} = \left(\frac{\beta}{\alpha}\right)$$

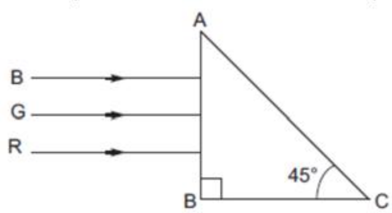
Magnifying power $M = \frac{-f_0}{f_e}$ (for comfortable view)

$$= \frac{-f_0}{f_e}\left(1+\frac{f_e}{D}\right)$$ (for strained eye)

Limitations: (i) Image is not free from chromatic aberration and spherical aberration.

(ii) Aperture of the objective lens should be large for high resolving power.

9.Three rays of light, red (R), green (G) and blue (B), are incident on the face AB of a right angledprism, as shown in the figure. The refractive indices of the material of the prism for red, green andblue are 1.39, 1.44 and 1.47 respectively. Which one of the three rays will emerge out of the prism?Give reason to support your answer.



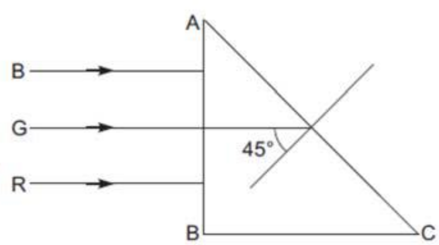
ANS.

If angle of incidence '*i*' is less than the critical angle of glass-air interface AC then it will emerge out.

Critical angle $\sin i_C = \frac{1}{\mu}$

$$\therefore \mu = \frac{1}{\sin i_C} = \frac{1}{\sin 45^\circ} = \sqrt{2} = 1.414$$

Since $\mu_R = 1.39$, $\mu_G = 1.44$ and $\mu_B = 1.47$, so from equation (1) angle of incidence for red colour $i_C > 45°$ while angle of incidence for blue and green colours $i_C < 45°$, hence blue and green colour rays will emerge out.

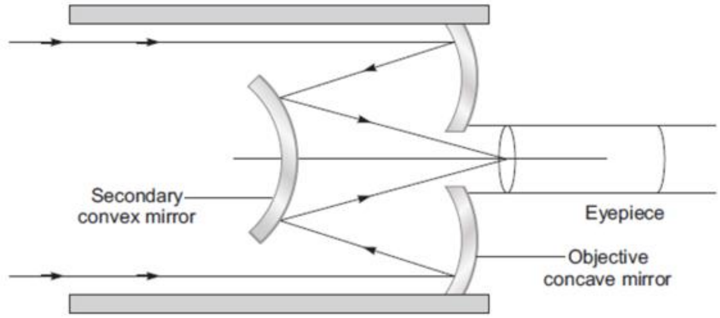


10.(i) Draw a schematic labelled ray diagram of a reflecting type telescope.

(ii) Write two important advantages justifying why reflecting type telescopes are preferred over refracting telescopes.

(iii) The objective of a telescope is of larger focal length and of larger aperture (compared to the eyepiece). Why? Give reasons.ANS.

(i)



(ii) Advantages : (a) Parabolic mirror is used to remove the spherical aberration.

(b) No chromatic aberration in mirror.

(c) Light mechanical support is required, because mirror weighs much less than a lens of equivalent optical quality.

(iii) In normal adjustment, magnifying power of the telescope $M = \frac{F_0}{F_e}$.

(a) If focal length of the objecctive lens is large in comparison to the eyepiece, magnifying power increases.

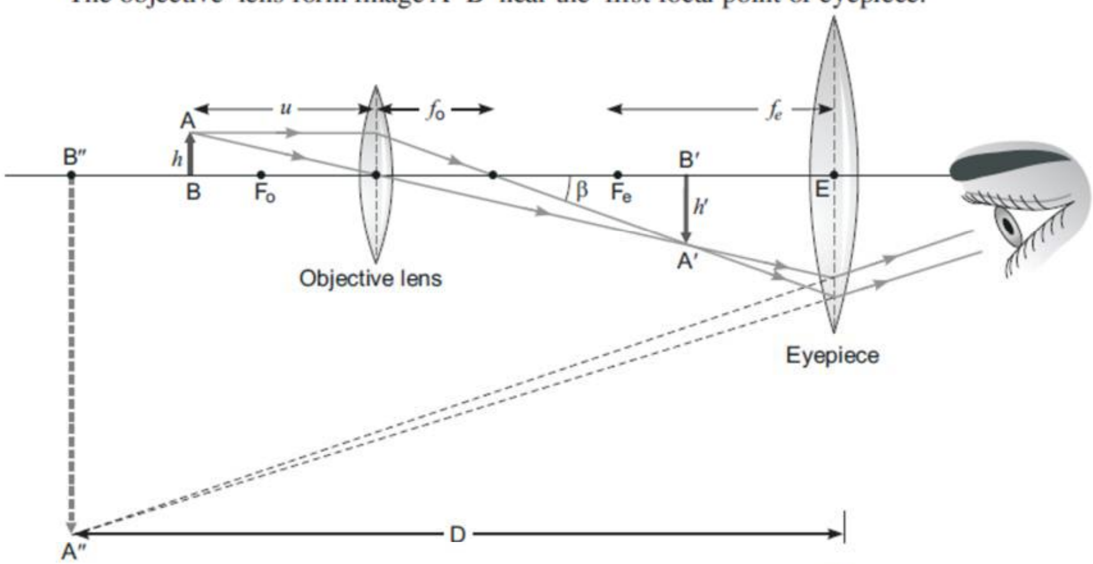
(b) Resolving power of the telescope $RP = \frac{a}{1.22\lambda}$.

To increase the resolving power of the telescope, large aperture of the objective lens is required.

11.(a) Draw a labelled ray diagram of a compound microscope.
(b) Derive an expression for its magnifying power.
(c) Why is objective of a microscope of short aperture and short focal length? Give reason.

(a) Labelled diagram of compound microscope.

The objective lens form image A′ B′ near the first focal point of eyepiece.



b) Angular magnification of objective lens m_0 = linear magnification $\frac{h'}{h}$

Since $\tan\beta = \frac{h'}{L} = \frac{h}{f_0}$

$$m_0 = \frac{h'}{h} = \frac{L}{f_0} \quad \dots (1)$$

where L is the distance between second focal point of the objective and first focal point of eyepiece.

If the final image A″ B″ is formed at the near point.

$$\text{Angular magnification } m_e = \left(1 + \frac{D}{f_e}\right)$$

If the final image A″ B″ is formed at infinity, then angular magnification $m_e = \frac{D}{f_e}$ ... (2)

Thus, total magnification of the compound microscope

$$M = m_0 \times m_e$$
$$= \frac{L}{f_0} \times \frac{D}{f_e}$$

c) Aperture and focal length increase or decrease the resolving power of the compound microscope.

Resolving power of microscope is given by

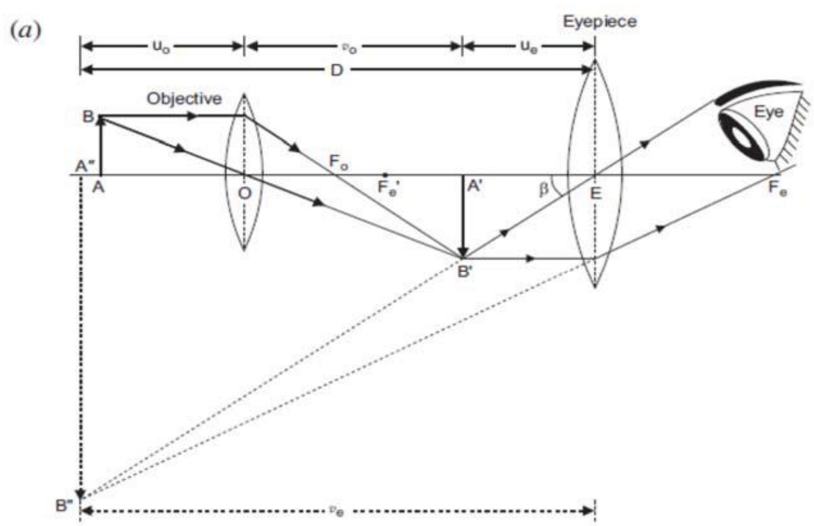
$$R.P. = \frac{2n \sin\theta}{1.22\ \lambda}$$

(i) On decreasing the aperture (diameter) of the objective lens, value of sin θ decreases, and hence resolving power decreases.

(ii) On decreasing the focal length of the objective lens, value of sin θ increases and hence resolving power increases.

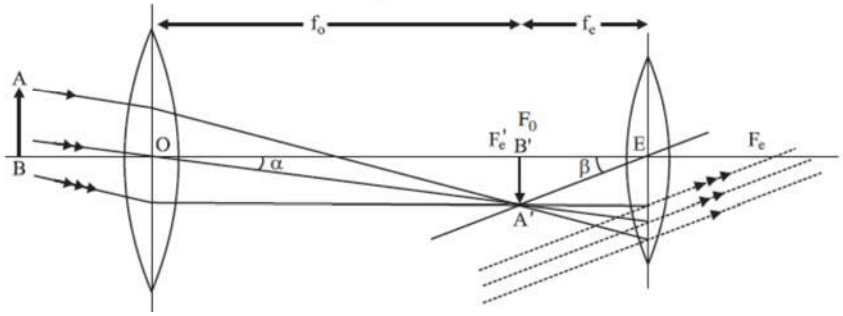
12.(*a*) Draw a labelled ray diagram showing the formation of a final image by a compound microscope at least distance of distinct vision.

(*a*)



13.Draw a labelled ray diagram to show the image formation by an astronomical telescope. Derive the expression for its magnifying power in normal adjustment.

Astronomical Telescope: Magnifying power of astronomical telescope in normal adjustment is defined as the ratio of the angle subtended at the eye by the final image to the angle subtended at the eye, by the object directly, when the final image and the object both lie at infinite distance from the eye.



$$\text{Magnifying power, } m = \frac{\beta}{\alpha} \qquad (1)$$

As angles α and β are small, therefore, $\alpha \approx \tan\alpha$ and $\beta \approx \tan\beta$.

From equation (1), $$m = \frac{\tan\beta}{\tan\alpha} \qquad (2)$$

In $\Delta A'B'C_2$, $$\tan\beta = \frac{A'B'}{C_2B'}$$

In $\Delta A'B'C_1$, $$\tan\alpha = \frac{A'B'}{C_1B'}$$

Put in equation (2), $$m = \frac{A'B'}{C_2B'} \times \frac{C_1B'}{A'B'} = \frac{C_1B'}{C_2B'}$$

or $$m = \frac{f_0}{-f_e}$$

where $C_1B' = f_0$ = focal length of objective lens,
$C_2B' = -f_e$ = focal length of eye lens.

Negative sign of m indicates that final image is inverted.

The diameter of objective is kept large to increase (*i*) intensity of image, (*ii*) resolving power of telescope.

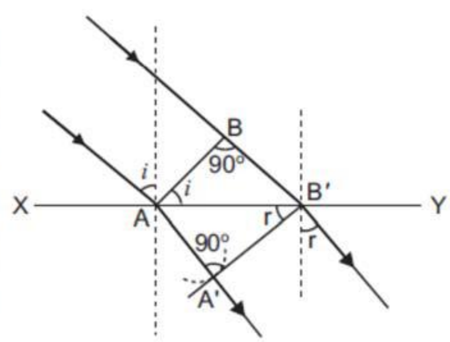
WAVE OPTICS

HUYGEN PRINCIPLE

1.How is a wavefront defined ? Using Huygen's construction draw a figure showing the propagation of a plane wave refracting at a plane surface separating two media. Hence verify Snell's law of refraction.
ANS:

Wavefront: A wavefront is a locus of all particles of medium vibrating in the same phase.

Proof of Snell's law of Refraction using Huygen's wave theory: When a wave starting from one homogeneous medium enters the another homogeneous medium, it is deviated from its path. This phenomenon is called **refraction.** In transversing from first medium to another medium, the frequency of wave remains unchanged but its speed and the wavelength both are changed. Let XY be a surface separating the two media '1' and '2'. Let v_1 and v_2 be the speeds of waves in these media.



Suppose a plane wavefront AB in first medium is incident obliquely on the boundary surface XY and its end A touches the surface at A at time $t = 0$ while the other end B reaches the surface at point B' after time-interval t. Clearly $BB' = v_1 t$. As the wavefront AB advances, it strikes the points between A and B' of boundary surface. According to Huygen's principle, secondary spherical wavelets originate from these points, which travel with speed v_1 in the first medium and speed v_2 in the second medium.

First of all secondary wavelet starts from A, which traverses a distance $AA'(=v_2t)$ in second medium in time t. In the same time-interval t, the point of wavefront traverses a distance $BB'(=v_1t)$ in first medium and reaches B', from, where the secondary wavelet now starts. Clearly $BB'=v_1t$ and $AA'=v_2t$.

Assuming A as centre, we draw a spherical arc of radius $AA'(=v_2t)$ and draw tangent $B'A'$ on this arc from B'. As the incident wavefront AB advances, the secondary wavelets start from points between A and B', one after the other and will touch $A'B'$ simultaneously. According to Huygen's principle $A'B'$ is the new position of wavefront AB in the second medium. Hence ***A′ B′ will be the refracted wavefront***.

Let the incident wavefront AB and refracted wavefront $A'B'$ make angles i and r respectively with refracting surface XY.

In right-angled triangle $AB'B$, $\angle ABB' = 90°$

$$\therefore \qquad \sin i = \sin \angle BAB' = \frac{BB'}{AB'} = \frac{v_1t}{AB'} \qquad ...(1)$$

Similarly in right-angled triangle $AA'B'$, $\angle AA'B' = 90°$

$$\therefore \qquad \sin r = \sin \angle AB'A' = \frac{AA'}{AB'} = \frac{v_2t}{AB'} \qquad ...(2)$$

Dividing equation (1) by (2), we get

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \text{constant} \qquad ...(3)$$

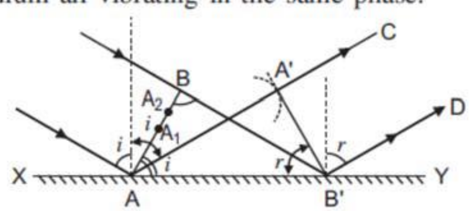
The ratio of sine of angle of incidence and the sine of angle of refraction is a constant and is equal to the ratio of velocities of waves in the two media. This is the second law of refraction, and is called the Snell's law.

2.How is a wavefront defined ? Using Huygen's construction draw a figure showing the Propagation of a plane wave reflecting at the interface of the two media. Show that the angle of incidence is equal to the angle of reflection.

ANS:-

Wavefront: A wavefront is a locus of particles of medium all vibrating in the same phase.

Law of Reflection: Let XY be a reflecting surface at which a wavefront is being incident obliquely. Let v be the speed of the wavefront and at time $t=0$, the wavefront touches the surface XY at A. After time t, the point B of wavefront reaches the point B' of the surface.



According to Huygen's principle each point of wavefront acts as a source of secondary waves. When the point A of wavefront strikes the reflecting surface, then due to presence of reflecting surface, it cannot advance further; but the secondary wavelet originating from point A begins to spread in all directions in the first medium with speed v. As the wavefront AB advances further, its points A_1, A_2, A_3 ... etc. strike the reflecting surface successively and send spherical secondary wavelets in the first medium.

First of all the secondary wavelet starts from point A and traverses distance AA' $(=vt)$ in first medium in time t. In the same time t, the point B of wavefront, after travelling a distance BB', reaches point B' (of the surface), from where the secondary wavelet now starts. Now taking A as centre we draw a spherical arc of radius AA' $(=vt)$ and draw tangent $A'B'$ on this arc from point B'. As the incident wavefront AB advances, the secondary wavelets starting from points between A and B', one after the other and will touch $A'B'$ simultaneously. According to Huygen's principle wavefront $A'B'$ represents the new position of AB, *i.e.*, $A'B'$ is the reflected wavefront corresponding to incident wavefront AB.

Now in right-angled triangles ABB' and $AA'B'$

$$\angle ABB' = \angle AA'B' \qquad \text{(both are equal to } 90°\text{)}$$

$$\text{side } BB' = \text{side } AA' \qquad \text{(both are equal to } vt\text{)}$$

and side AB' is common

i.e., both triangles are congruent.

$$\therefore \qquad \angle BAB' = \angle AB'A'$$

i.e., incident wavefront AB and reflected wavefront $A'B'$ make equal angles with the reflecting surface XY. As the rays are always normal to the wavefront, therefore the incident and the reflected rays make equal angles with the normal drawn on the surface XY, *i.e.*,

angle of incidence i = angle of reflection r

INTERFERENCE

3.Describe Young's double slit experiment to produce interference pattern due to a monochromatic source of light. Deduce the expression for the fringe width.

Young's Double slit experiment:

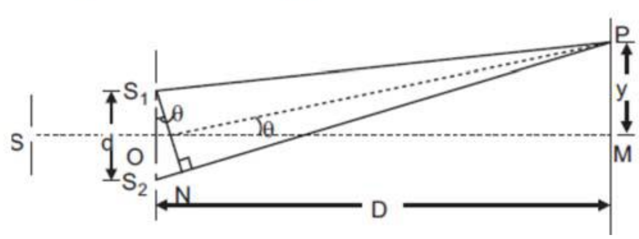
Coherent sources are those which have exactly the same frequency and are in this same phase or have a constant difference in phase.

Conditions: (*i*) The sources should be monochromatic and originating from common single source.

(*ii*) The amplitudes of the waves should be equal.

Expression for Fringe Width: Let S_1 and S_2 be two coherent sources separated by a distance d.

Let the distance of the screen from the coherent sources be D. Let M be the foot of the perpendicular drawn from O, the midpoint of S_1 and S_2 on the screen. Obviously point M is equidistant from S_1 and S_2. Therefore the path difference between the two waves at point M is zero. Thus the point M has the maximum intensity. Consider a point P on the screen at a distance y from M. Draw S_1N perpendicular from S_1 on S_2P.



The path difference between two waves reaching at P from S_1 and S_2 is $\Delta = S_2P - S_1P \approx S_2N$

As $D >> d$, therefore $\angle S_2S_1N = \theta$ is very small

$\therefore$ $$\angle S_2S_1N = \angle MOP = \theta$$

In ΔS_1S_2N, $$\sin\theta = \frac{S_2N}{S_1S_2}$$

In ΔMOP, $$\tan\theta = \frac{MP}{OM}$$

As θ is very small

$\therefore$ $$\sin\theta = \theta = \tan\theta$$

$\therefore$ $$\frac{S_2N}{S_1S_2} = \frac{MP}{OM}$$

$\therefore$ $$S_2N = S_1S_2\frac{MP}{OM} = d\cdot\frac{y}{D}$$

$\therefore$ Path difference $$\Delta = S_2P - S_1P = S_2N = \frac{yd}{D} \qquad ...(i)$$

(*i*) **Positions of bright fringes (or maxima):** For bright fringe or maximum intensity at P, the path difference must be an integral multiple of wavelength (λ) of light used. *i.e.* $\Delta = n\lambda$

$\therefore$ $$\frac{yd}{D} = n\lambda,\ n = 0, 1, 2, 3, \ldots$$

$\therefore \qquad y = \frac{nD\lambda}{d}.$

This equation gives the distance of nth bright fringe from the point M. Therefore writing y_n for y, we get

$$y_n = \frac{nD\lambda}{d}. \qquad ...(ii)$$

(*ii*) **Positions of dark fringes (or minima):** For dark fringe or minimum intensity at P, the path difference must be an odd number multiple of half wavelength. *i.e.* $\Delta = (2n-1)\frac{\lambda}{2}$

$\therefore \qquad \frac{y\,.\,d}{D} = (2n-1)\frac{\lambda}{2}$ where $n = 1, 2, 3, ...$

or $\qquad y = \frac{(2n-1)\,\lambda D}{2d} = (n - \frac{1}{2})\frac{D\lambda}{d}.$

This equation gives the distance of nth dark fringe from point M. Therefore writing y_n for y, we get

$$y_n = (n - \frac{1}{2})\frac{D\lambda}{d} \qquad ...(iii)$$

(*iii*) **Fringe Width β:** *The distance between any two consecutive bright fringes or any two consecutive dark fringes is called the* **fringe width.** It is denoted by ω

For Bright Fringes: If y_{n+1} and y_n denote the distances of two consecutive bright fringes from M, then we have

$$y_{n+1} = (n+1)\frac{D\lambda}{d} \text{ and } y_n = \frac{nD\lambda}{d}$$

$\therefore$ *Fringe width,* $\beta = y_{n+1} - y_n = (n+1)\frac{D\lambda}{d} - \frac{nD\lambda}{d} = \frac{D\lambda}{d}. \qquad ...(iv)$

For Dark Fringes: If y_{n+1} and y_n are the distances of two consecutive dark fringes from M, then we have

$$y_{n+1} = (n + \frac{1}{2})\frac{D\lambda}{d},\ y_n = (n - \frac{1}{2})\frac{D\lambda}{d}$$

$\therefore$ *Fringe width,* $\qquad \beta = y_{n+1} - y_n$

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

$$= \frac{D\lambda}{d}(n + \frac{1}{2} - n + \frac{1}{2}) = \frac{D\lambda}{d} \qquad ...(v)$$

Thus, fringe width is the same for bright and dark fringes equal to

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

The condition for the interference fringes to be seen is

$$\frac{s}{b} < \frac{\lambda}{d}$$

5.How does the fringe width of interference fringes change, when the whole apparatus of Young's experiment is kept in a liquid of refractive index 1.3 ? ANS:-

Fringe width, $\beta = \frac{D\lambda}{d} \Rightarrow \beta \propto \lambda$ for same D and d. When the whole apparatus is immersed in a transparent liquid of refractive index $n = 1\cdot3$, the wavelength decreases to $\lambda' = \frac{\lambda}{n} = \frac{\lambda}{1\cdot3}$. So, **fringe width decreases to $\frac{1}{1\cdot3}$ times.**

6.How will the angular separation and visibility of fringes in Young's double slit experiment changewhen (i) screen is moved away from the plane of the slits, and (ii) width of the source slit isincreased?
ANS:-

(i) Angular separation $\beta_\theta = \frac{\beta}{D} = \frac{\lambda}{d}$

It is independent of D; therefore, angular separation remains unchanged if screen is moved away from the slits. But the actual separation between fringes $\beta = \frac{\lambda D}{d}$ increases, so **visibility of fringes increases.**

(ii) When width of source slit is increased, then the angular fringe width remains unchanged but fringes becomes less and less sharp; so visibility of fringes decreases. If the condition $\frac{s}{S} < \frac{\lambda}{d}$ is not satisfied, the interference pattern disappears.

7.How would the angular separation of interference fringes in Young's double slit experiment change when the distance between the slits and screen is doubled?

Angular separation between fringes

$$\beta_\theta = \frac{\lambda}{d}$$

where λ = wavelength, d = separation between coherent sources, β_θ is independent of distance between the slits and screen; so angular separation (β_θ) will remain unchanged.

8.In Young's double slit experiment, monochromatic light of wavelength 630 nm illuminates the pair of slits and produces an interference pattern in which two consecutive bright fringes are separated by 8.1 mm. Another source of monochromatic light produces the interference pattern in which the two consecutive bright fringes are separated by 7.2 mm. Find the wavelength of light from the second source.
What is the effect on the interference fringes if the monochromatic source is replaced by a source of white light?

$$\beta_1 = \frac{\lambda_1 D}{d} \qquad ...(1)$$

$$\beta_2 = \frac{\lambda_2 D}{d} \qquad ...(2)$$

$$\therefore \qquad \frac{\beta_2}{\beta_1} = \frac{\lambda_2}{\lambda_1}$$

$$\Rightarrow \qquad \lambda_2 = \frac{\beta_2}{\beta_1}\lambda_1$$

Given $\beta_1 = 8 \cdot 1$ mm, $\beta_2 = 7 \cdot 2$ mm, $\lambda_1 = 630$ mm

$$\therefore \qquad \lambda_2 = \left(\frac{7 \cdot 2 \text{ mm}}{8 \cdot 1 \text{ mm}}\right) \times 630 \text{ mm}$$

$$= \mathbf{560 \text{ mm}}$$

Use of white light: When white light is used to illuminate the slit, we obtain an interference pattern consisting of a central white fringe having on both sides symmetrically a few coloured fringes and then uniform illumination.

9.In Young's double slit experiment, the two slits 0·15 mm apart are illuminated by monochromatic light of wavelength 450 nm. The screen is 1.0 m away from the slits.
(*a*) Find the distance of the second (i) bright fringe, (ii) dark fringe from the central maximum.
(*b*) How will the fringe pattern change if the screen is moved away from the slits?
ANS.

Given $d = 0 \cdot 25$ mm $= 0 \cdot 15 \times 10^{-3}$ m,

$\lambda = 450$ nm $= 450 \times 10^{-9}$ m, $D = 1 \cdot 0$ m

(*a*) Distance of second bright maximum from central maximum ($n = 2$)

$$y_2 = \frac{nD\lambda}{d} = \frac{2 \times 1 \cdot 0 \times 450 \times 10^{-9}}{0 \cdot 15 \times 10^{-3}} \text{ m} = 6 \times 10^{-3} \text{ m} = \mathbf{6 \text{ mm}}$$

Distance of second dark fringe from central maximum ($n = 2$)

$$y'_2 = \left(n - \frac{1}{2}\right)\frac{D\lambda}{2} = \left(2 - \frac{1}{2}\right)\frac{1 \cdot 0 \times 450 \times 10^{-9}}{0 \cdot 15 \times 10^{-3}}$$

$$= 4 \cdot 5 \times 10^{-3} \text{ m} = \mathbf{4 \cdot 5 \text{ mm}}$$

(*b*) If screen is moved away from the slits, D increases, **so fringe width** $\beta = \frac{D\lambda}{d}$ **increases.**

DIFFRACTION

10.(*a*) Describe briefly how a diffraction pattern is obtained on a screen due to a single narrow slit illuminated by a monochromatic source of light. Hence obtain the conditions for the angular width of secondary maxima and secondary minima.

(*a*) **Diffraction of light at a single slit :** When monochromatic light is made incident on a single slit, we get diffraction pattern on a screen placed behind the slit. The diffraction pattern contains bright and dark bands, the intensity of central band is maximum and goes on decreasing on both sides.

Explanation : Let *AB* be a slit of width '*a*' and a parallel beam of monochromatic light is incident on it. According to Fresnel the diffraction pattern is the result of superposition of a large number of waves, starting from different points of illuminated slit.

Let θ be the angle of diffraction for waves reaching at point *P* of screen and *AN* the perpendicular dropped from *A* on wave diffracted from *B*.

The path difference between rays diffracted at points *A* and *B*,

$$\Delta = BP - AP = BN$$

In $\Delta\ ANB$, $\angle ANB = 90°$ $\quad\therefore$ and $\angle BAN = \theta$

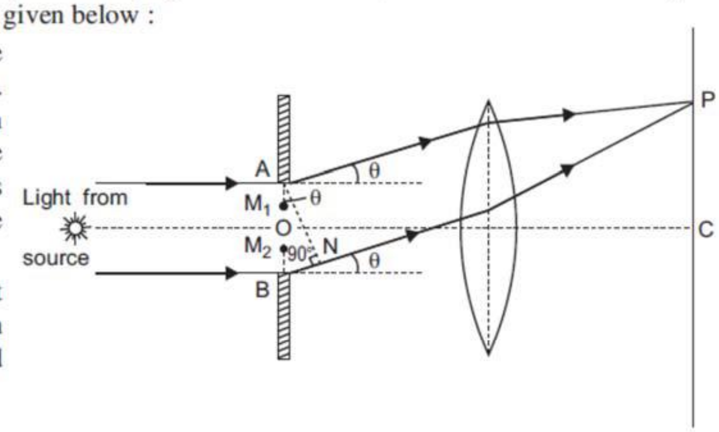
$\therefore \quad \sin\theta = \dfrac{BN}{AB}$ or $BN = AB\sin\theta$

As AB = width of slit $= a$

$\therefore$ Path difference,

$$\Delta = a\sin\theta \qquad ....(i)$$

To find the effect of all coherent waves at *P*, we have to sum up their contribution, each with a different phase. This was done by Fresnel by rigorous calculations, but the main features may be explained by simple arguments given below :



At the central point *C* of the screen, the angle θ is zero. Hence the waves starting from all points of slit arrive in the same phase. This gives maximum intensity at the central point *C*.

If point *P* on screen is such that the path difference between rays starting from edges *A* and *B* is λ, then path difference

$a\sin\theta = \lambda \Rightarrow \sin\theta = \dfrac{\lambda}{a}$

If angle θ is small, $\quad \sin\theta = \theta = \dfrac{\lambda}{a} \qquad ...(ii)$

Minima : Now we divide the slit into two equal halves *AO* and *OB*, each of width $\dfrac{a}{2}$. Now for every point, M_1 in *AO*, there is a corresponding point M_2 in *OB*, such that $M_1M_2 = \dfrac{a}{2}$; Then

path difference between waves arriving at P and starting from M_1 and M_2 will be $\frac{a}{2}\sin\theta = \frac{\lambda}{2}$.
This means that the contributions from the two halves of slit AO and OB are opposite in phase and so cancel each other. Thus equation (2) gives the angle of diffraction at which intensity falls to zero. Similarly it may be shown that the intensity is zero for $\sin\theta = \frac{n\lambda}{a}$, with n as integer.

Thus the general condition of **minima** is

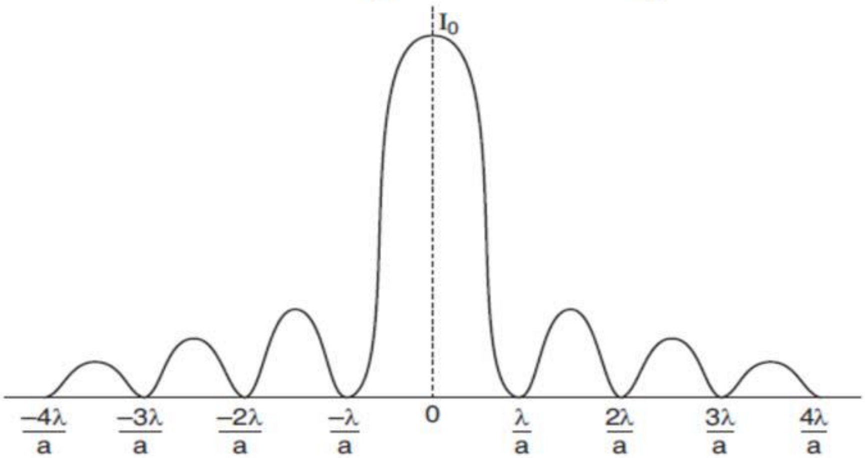
$$a\sin\theta = n\lambda \qquad ...(iii)$$

Secondary Maxima : Let us now consider angle θ such that

$$\sin\theta = \theta = \frac{3\lambda}{2a}$$

which is midway between two dark bands given by

$$\sin\theta = \theta = \frac{\lambda}{a} \text{ and } \sin\theta = \theta = \frac{2\lambda}{a}$$



Let us now divide the slit into three parts. If we take the first two of parts of slit, the path difference between rays diffracted from the extreme ends of the first two parts

$$\frac{2}{3}a\sin\theta = \frac{2}{3}a \times \frac{3\lambda}{2a} = \lambda$$

Then the first two parts will have a path difference of $\frac{\lambda}{2}$ and cancel the effect of each other. The remaining third part will contribute to the intensity at a point between two minima. Clearly there will be a maxima between first two minima, but this maxima will be of much weaker intensity than central maximum. This is called *first secondary maxima.* In a similar manner we can show that there are secondary maxima between any two consecutive minima; and the intensity of maxima will go on decreasing with increase of order of maxima. In general the position of nth maxima will be given by

$$a\sin\theta = \left(n + \frac{1}{2}\right)\lambda, \quad [n = 1, 2, 3, 4, \ldots] \qquad ...(iv)$$

The intensity of secondary maxima decrease with increase of order n because with increasing n, the contribution of slit decreases.

For $n = 2$, it is one-fifth, for $n = 3$, it is one-seventh and so on.

11.(a) In a single slit diffraction experiment, a slit of which '*d*' is illuminated by red light of wavelength 650 nm. For what value of '*d*' will:

(i) the first minimum fall at an angle of diffraction of 30°, and

(ii) the first maximum fall at an angle of diffraction of 30°?

(b) Why does the intensity of the secondary maximum become less as compared to the central maximum?

(a) (i) For nth minima, $d \sin\theta = n\lambda$

Given $\lambda = 650\text{ nm} = 650\times10^{-9}$ m, $n = 1, \theta = 30°$

$$\therefore \quad d = \frac{n\lambda}{\sin\theta} = \frac{1\times650\times10^{-9}}{\sin 30°} = \frac{650\times10^{-9}}{0\cdot5}$$

$$= 1300\times10^{-9}\text{ m} = 1\cdot3\times10^{-6}\text{ m}$$

$$= 1\cdot3\,\mu\text{m}$$

(ii) For nth maxima, $d\sin\theta = (2n+1)\frac{\lambda}{2}$

$n = 1, \theta = 30°, \lambda = 650\times10^{-9}$ m

$$\therefore \quad d = \frac{(2n+1)\lambda}{2\sin\theta} = \frac{3\times650\times10^{-9}}{2\times0\cdot5} = 1\cdot95\times10^{-6}\text{ m} = 1\cdot95\,\mu\text{m}$$

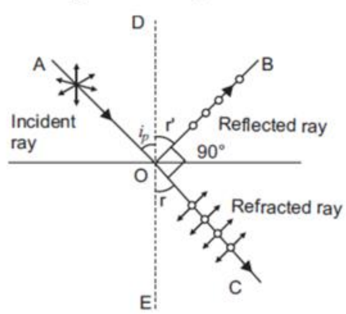
(b) To produce secondary maxima, the wavelets from lesser and lesser part of slit produce constructive interference.

12.(a) Why do we not encounter diffraction effects of light in everyday observations?
(b) In the observed diffraction pattern due to a single slit, how will the width of central maximum be affected if(i) the width of the slit is doubled;(ii) the wavelength of the light used is increased?Justify your answer in each case.

POLARISTION

14.(*a*) How does an unpolarised light incident on a polaroid get polarised? Describe briefly, with the help of a necessary diagram, the polarisation of light by reflection from a transparent medium.
(*b*) Two polaroids '*A*' and '*B*' are kept in crossed position. How should a third polaroid '*C*' be placed between them so that the intensity of polarised light transmitted by polaroid B reduces to 1/8th of the intensity of unpolarised light incident on *A*?

ANS:- A polaroid consists of long chain molecules aligned in a particular direction. The electric vectors along the direction of the aligned molecules get absorbed. So, when an unpolarised light falls on a polaroid, it lets only those of its electric vectors that are oscillating along a direction perpendicular to its aligned molecules to pass through it. The incident light thus gets linearly polarised.



Whenever unpolarised light is incident on the boundary between two transparent media, the reflected light gets partially or completely polarised. When reflected light is perpendicular to the refracted light, the reflected light is a completely polarised light.

(*b*) Let the angle between the pass axis of A and $C = \theta$

Intensity of light passing through $A = \frac{I_0}{2}$

Intensity of light passing through $C = \frac{I_0}{2}\cos^2\theta$

Intensity of light passing through $B = \frac{I_0}{2}\cos^2\theta.\cos^2(90-\theta)$

$$= \frac{I_0}{2}\cos^2\theta.\sin^2\theta = \frac{I_0}{2}(\cos\theta.\sin\theta)^2$$

According to question

$$\frac{I_0}{2}(\cos\theta\sin\theta)^2 = \frac{I_0}{8}$$

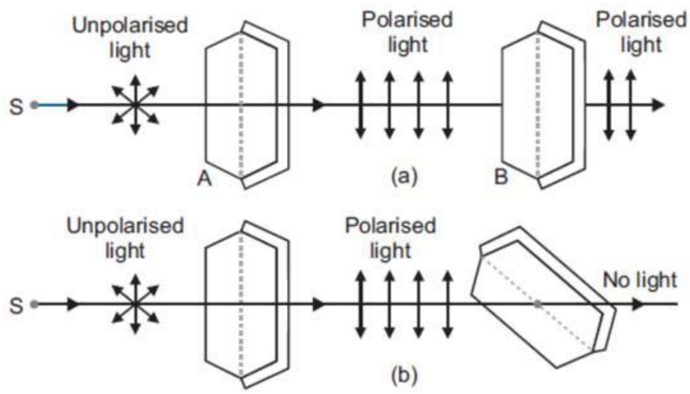
$$\frac{I_0}{2}\left(\frac{2\sin\theta\cos\theta}{2}\right)^2 = \frac{I_0}{8}$$

$$\sin 2\theta = 1$$

or, $2\theta = 90°$ $\Rightarrow$ $\theta = 45°$

The third polaroid is placed at $\theta = 45°$.

15 (*a*) Describe briefly, with the help of suitable diagram, how the transverse nature of light can be demonstrated by the phenomenon of polarization.
(*b*) When unpolarized light passes from air to a transparent medium, under what condition does the reflected light get polarized?
ANS:- (*a*) Light from a source *S* is allowed to fall normally on the flat surface of a thin plate of a tourmaline crystal, cut parallel to its axis. Only a part of this light is transmitted through *A*.
If now the plate *A* is rotated, the character of transmitted light remains unchanged. Now another similar plate *B* is placed at some distance from *A* such that the axis of *B* is parallel to that of *A*. If the light transmitted through *A* is passed through *B*, the light is almost completely transmitted through *B* and no change is observed in the light coming out of *B*.

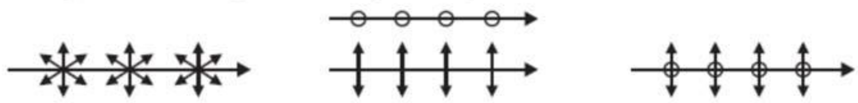


If now the crystal *A* is kept fixed and *B* is gradually rotated in its own plane, the intensity of light emerging out of *B* decreases and becomes zero when the axis of *B* is perpendicular to that of *A*. If *B* is further rotated, the intensity begins to increase and becomes maximum when the axes of *A* and *B* are again parallel. Thus, we see that the intensity of light transmitted through *B* is maximum when axes of *A* and *B* are parallel and minimum when they are at right angles.
From this experiment, it is obvious that light waves are transverse and not longitudinal; because, if they were longitudinal, the rotation of crystal B would not produce any change in the intensity of light.
(*b*) The reflected ray is totally plane polarised, when reflected and refracted rays are perpendicular to each other.

15.What is plane polarised light? Two polaroids are placed at 90° to each other and the transmitted intensity is zero. What happens when one more polaroid is placed between these two, bisecting the angle between them ? How will the intensity of transmitted light vary on further rotating the third polaroid? (b) If a light beam shows no intensity variation when transmitted through a polaroid which is rotated, does it mean that the light is unpolarised ? Explain briefly.
ANS

(a) **Plane Polarised Light:** The light having vibrations of electric field vector in only one direction perpendicular to the direction of propagation of light is called plane polarised light.

The unpolarised and polarised light is represented as



(a) Unpolarised light (b) Polarised light (c) Partially polarised light

If ordinary unpolarised light of intensity I_0' is incident on first polaroid (A, say)

Intensity of light transmitted from first polaroid is $I_0 = \frac{I_0'}{2}$

Given angle between transmission axes of two polaroids A and B is initially 90°.

According to Malus law, intensity of light transmitted from second polaroid (B, say) is

$$I = I_0 \cos^2 \theta \Rightarrow I = I_0 \cos^2 90° = 0$$

When one more polaroid (C say) is placed between A and B making an angle of 45° with the transmission axis of either of polaroids, then intensity of light transmitted from A is

$$I_A = \frac{I_0'}{2} = I_0$$

Intensity of light transmitted from C is

$$I_C = I_0 \cos^2 45° = \frac{I_0}{2}.$$

Intensity of light transmitted from polaroid B is

$$I_B = I_C \cos^2 45° = \frac{I_0}{2} \times \frac{1}{2} = \frac{I_0}{4}$$

This means that the intensity becomes one-fourth of intensity of light that is transmitted from first polaroid.

On further rotating the polaroid C such that if angle between their transmission axes increases, the intensity decreases and if angle decreases, the intensity increases.

Yes, the incident light (of intensity I_0) is unpolarised.

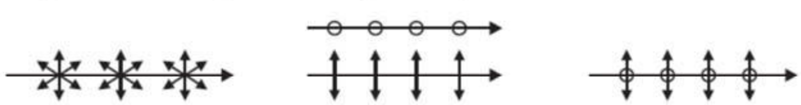
Reason: If incident light is unpolarised, the intensity of transmitted light through a polaroid is always $I_0 / 2$, which is constant.

But if incident light is polarised, the intensity variation $I = I_0 \cos^2 \theta$, necessarily takes place.

16.Define the term 'linearly polarised light.' When does the intensity of transmitted light become maximum, when a polaroid sheet is rotated between two crossed polaroids?

Linearly Polarised Light: The light having vibrations of electric field vector in only one direction perpendicular to the direction of propagation of light is called plane (or linearly) polarised light.

The unpolarised and polarised light is represented as



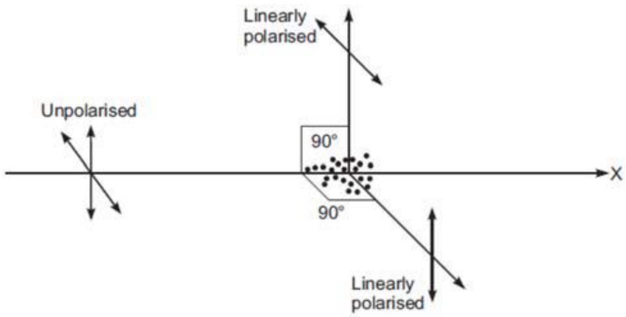
(a) Unpolarised light (b) Polarised light (c) Partially polarised light

Intensity of transmitted light is maximum when the polaroid sheet makes an angle of 45° with the pass axis.

This is maximum when $\sin 2\theta = 1$ or $\theta = 45°$.

17.(a) What is linearly polarized light? Describe briefly using a diagram how sunlight is polarised.

ANS:- (*a*) Molecules in air behave like a dipole radiator. When the sunlight falls on a molecule, dipole molecule does not scatter energy along the dipole axis, however the electric field vector of light wave vibrates just in one direction perpendicular to the direction of the propagation. The light wave having direction of electric field vector in a plane is said to be linearly polarised. In figure, a dipole molecule is lying along x-axis. Molecules behave like dipole radiators and scatter no energy along the dipole axis.



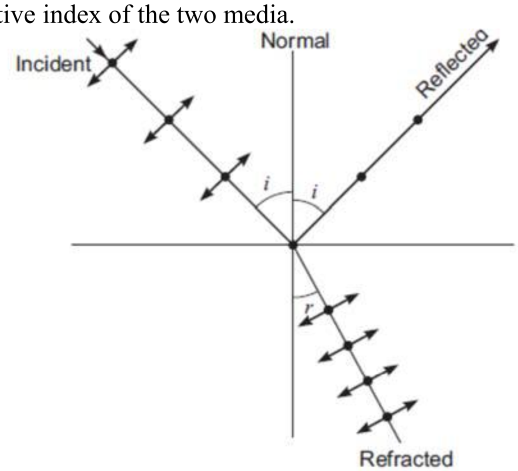
The unpolarised light travelling along x-axis strikes on the dipole molecule get scattered along y and z directions. Light traversing along *y* and *z* directions is plane polarised light.

18 . When unpolarised light is incident on the boundary separating the two transparent media, explain, with the help of a suitable diagram, the conditions under which the reflected light gets polarised. Hence define Brewster's angle and write its relationship in terms of the relative refractive index of the two media.

When unpolarised light incident on the water molecules, the oscillating electrons in the water produces the reflected wave.

The double arrows are parallel to the direction of the reflected wave, so they do not contribute to the reflected wave; while dots are perpendicular to the plane of incidence and they get reflected and becomes linearly polarised light. This polarisation can be checked through an analyser.

The angle of incidence of unpolarised light at which (i) refracted wave and reflected wave becomes perpendicular to each other or (ii) reflected wave becomes totally polarised wave is called Brewster's angle.



Let i_p be the angle of polarisation and $i_p + r = \frac{\pi}{2}$

Then from Snell's law

$$\mu = \frac{\sin i_p}{\sin r} = \frac{\sin i_p}{\sin(90^\circ - i_p)} = \tan i_p$$

19. Two polaroids *P*1 and *P*2 are placed with their pass axes perpendicular to each other. Unpolarised light of intensity *Io* is incident on *P*1. A third polaroid *P*3 is kept in between *P*1 and *P*2 such that its pass axis makes an angle of 30° with that of *P*1. Determine the intensity of light transmitted through *P*1, *P*2 and *P*3 .

(*b*) If light of intensity I_0 passes through the first polaroid.

The intensity of light transmitted through $P_1 = I_1 = \frac{I_0}{2}$

If axis of polaroids P_1 and P_3 are at 30°.

So intensity of light transmitted through P_3 is given by

$$I_3 = I_1 \cos^2 30^\circ$$

$$= \frac{I_0}{2}\left(\frac{\sqrt{3}}{2}\right)^2 = \frac{3I_0}{8}$$

Light transmitted through P_3 is allowed to pass through P_2.

So intensity of light transmitted through $P_2 = I_2 = I_3 \cos^2 60^\circ$

$$= \frac{3I_0}{8} \times \left(\frac{1}{2}\right)^2 = \frac{3I_0}{32}$$