Ray Optics

Introduction

It is the branch of physics which deals with the study of nature, production and propagation of light. The subject of optics can be divided into two main branches: rays optics and wave optics.

1. **Ray or geometrical optics:** It concerns itself with the particle nature of light and is based on

(i) The rectilinear propagation of light and

(ii) The laws of reflection and refraction of light.

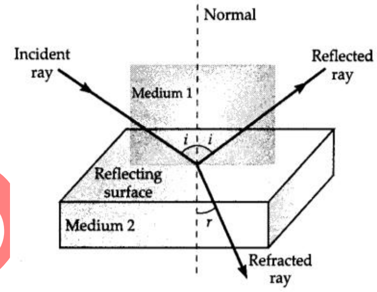
It explains the formation of images in mirrors and lenses, the aberrations of optical images and the working and designing of optical instruments.

2. **Wave or physical optics :** It concerns itself with the wave nature of light and is based on the phenomena like.

(i) Interference (ii) diffraction and (iii) polarization of light

Behaviour of light at the interface of two media

When light travelling in one medium falls on the surface of a second medium, the following three effects may occur :

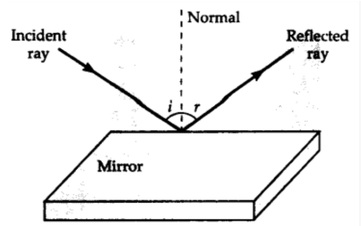


(i) A part of the incident light is turned back into first medium. This is called *reflection of light.*

(ii) A part of the incident light is transmitted into the second medium along a changed direction. This is called *refraction of light* .

(iii) The remaining third part of light energy is absorbed by the second medium. This is called *absorption of light.*

Laws of reflection of light : Reflection of light takes place according to the following two laws :

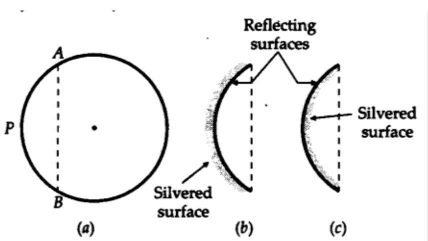


(i) The angle of incidence is equal to the angle of reflection, i.e., $\angle i = \angle r$.

(ii) The incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane.

Spherical mirrors

The section *APB*, cut by the plane, forms a part of a sphere and is known as a spherical surface. If either side of this spherical surface is silvered, we get a spherical mirror.



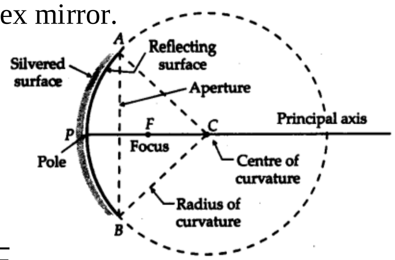
A spherical mirror : is a reflecting surface which forms part of a hollow sphere.

Spherical mirrors are of two types :

(i) **Convex mirror :** A spherical mirror in which the outer bulged surface is silvered polished and the reflection of light takes place from the inner hollow surface is called a concave mirror.

(ii) **Convex mirror :** A spherical mirror in which the inner hollow surface is silvered polished and the reflection of light takes place from the outer bulged surface is called a convex mirror.

Definitions in connection with spherical mirrors : Let *APB* be a principal section of a spherical mirror, i.e., the section cut by a plane passing through pole and centre of curvature of the mirror.



1. **Pole :** It is the middle point *P* of the spherical mirror.

2. **Centre of curvature :** It is the centre *C* of the sphere of which the mirror forms a part.

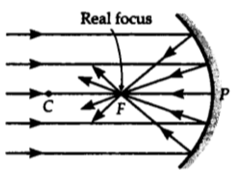
3. **Radius of curvature :** It is the radius ($R = AC$ or BC) of the sphere of which the mirror forms a part.

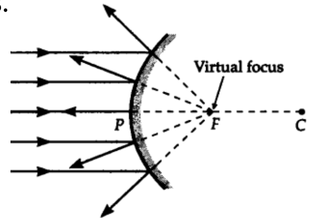
4. **Principal axis :** The line PC passing through the pole and the centre of curvature of the mirror is called its principal axis.

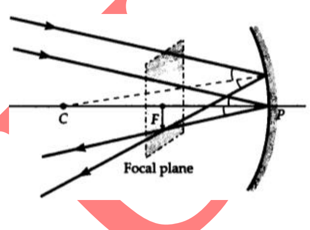
5. **Linear aperture :** It is the diameter AB of the circular boundary of the spherical mirror.

6. **Angular aperture :** It is the angle ACB subtended by the boundary of the spherical mirror at its centre of curvature C.

7. **Principal focus :** A narrow beam of light parallel to the principal axis either actually converges to or appears to diverge from a point F on the principal axis after reflection from the spherical mirror. This point is called the principal focus of the mirror. A concave mirror has a real focus while a convex mirror has a virtual focus.







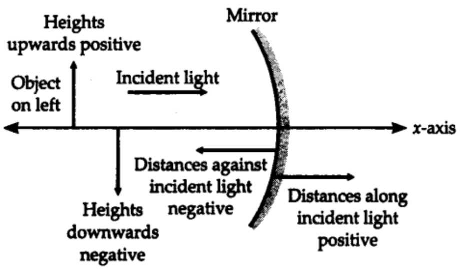
8. **Focal length :** It is the distance ($f = PF$) between the focus and the pole of the mirror.

9. **Focal plane :** The vertical plane passing through the principal focus and perpendicular to the principal axis is called focal plane. When a parallel beam of light is incident on a concave mirror at a small angle to the principal axis, it is converged to a point in the focal plane of the mirror, as shown in fig.

Note : A line joining any point of the spherical mirror to its centre of curvature, will be normal to the mirror at that point.

New Cartesian Sign convention for Spherical Mirror :

1. All ray diagrams are drawn with the incident light travelling from left to right.
2. All distances are measured from the pole of the mirror.
3. All distances measured in the direction of incident light are taken to be positive.
4. All distances measured in the opposite direction of incident light are taken to be *negative*.
5. Heights measured upwards and perpendicular to the principal axis are taken *positive*.
6. Heights measured downwards and perpendicular to the principal axis are taken *negative*.



According to this sign convention, the focal length and radius of curvature are negative for a concave mirror and positive for a convex mirror.

Relation between f and R

F is the focus of the mirror, C is the centre of curvature, CP = the radius of curvature and BC is a normal to mirror at point B.

According to the law of reflection, $\angle i = \angle r.$

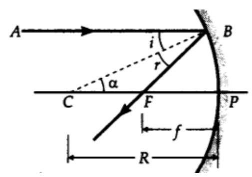
As AB is parallel to PC, $\angle\alpha = \angle i$

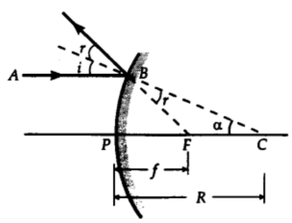
$\therefore$ In $\Delta\, BFC$, $\angle r = \angle\alpha$

$$\angle\theta = \angle r + \angle\alpha \quad \text{or} \quad \angle\theta = 2\angle\alpha$$

$$\text{or} \quad \frac{AP}{PF} = 2\frac{AP}{PC} \quad \text{or} \quad \frac{1}{f} = \frac{2}{R}$$

$$\text{or} \quad R = 2f \quad \text{or} \quad f = \frac{R}{2}$$



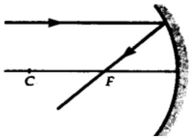


or Focal length = $\frac{1}{2}\times$ Radius of curvature.

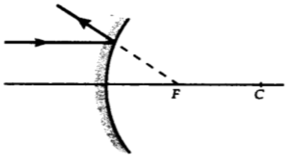
Rules for drawing images formed by spherical mirror

The position of the image formed by spherical mirrors can be found by considering any two of the following rays of light coming from a point on the object.

(i) A ray proceeding parallel to the principal axis will, after reflection, pass through the principal focus in the case of a concave mirror as shown in figure (a) and appear to come from focus in the case of a convex mirror, as shown in the figure (b) .

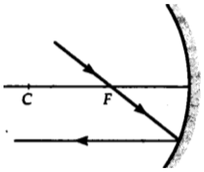


(a)

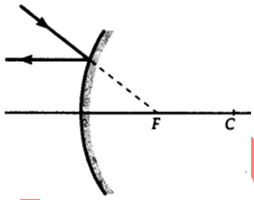


(b)

(ii) A ray passing through the principal focus in the case of a concave mirror as shown in figure (a), and directed towards the principal focus in the case of a convex mirror will (figure (b)) after reflection, become parallel to the principal axis.

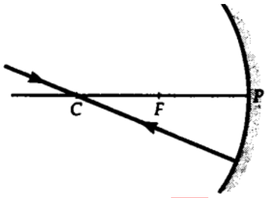


(a)

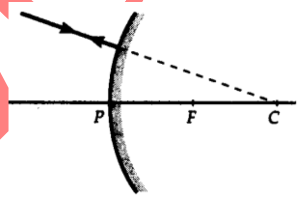


(b)

(iii) A ray passing through the centre of curvature in the case of concave mirror [Fig. (a)] and directed towards the centre of curvature in the case of a convex mirror [Fig. (b)] falls normally ($\angle i = \angle r = 0^o$) and is reflected back along the same path.



(a)

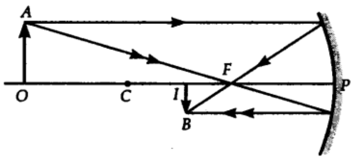


(b)

Formation of Images by concave Mirrors

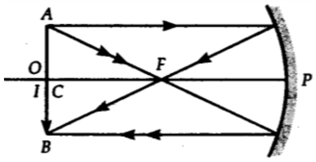
(a) Object beyond *C*. The image is

1.	Between *C* and *F*	2.	Real
3.	Inverted	4.	Smaller than object



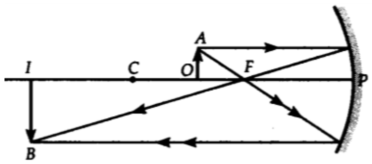
(b) Object at *C* . The image is

1.	At *C*	2.	Real
3.	Inverted	4.	Same size an object



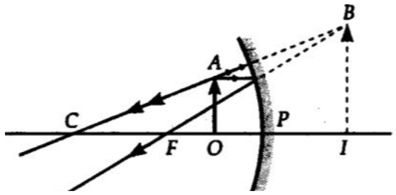
(c) Object between *F* and *C* : The image is

1.	Beyond *C*	2.	Real
3.	Inverted	4.	Larger than object



(d) Object between F and P : The image is

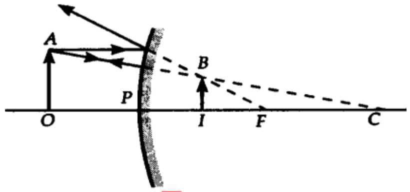
1. Behind the mirror 2. Virtual
3. Erect 4. Larger than object



Formation of image by convex mirror

For any position of the object between ∞ and pole P, the image is

1. Behind the mirror 2. Virtual
3. Erect 4. Smaller than object

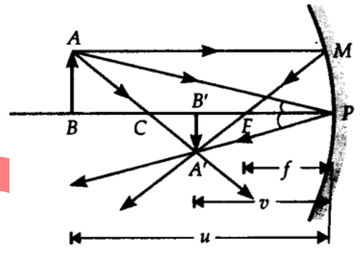


Derivation of mirror formula for a concave mirror

Case I : When it forms a real image :

Now, $\Delta A'B'C \sim \Delta ABC$

$$\therefore \quad \frac{A'B'}{AB} = \frac{CB'}{BC} = \frac{CP - B'P}{BP - CP} = \frac{-R + v}{-u + R} \quad \text{....(1)}$$



$\Delta A'B'P \sim \Delta ABP$.

$$\therefore \quad \frac{A'B'}{AB} = \frac{B'P}{BP} = \frac{-v}{-u} = \frac{v}{u} \quad \text{....(2)}$$

From equations (1) and (2), we get

$$\frac{-R+v}{-u+R} = \frac{v}{u} \quad \text{or} \quad -uR + uv = -uv + vR \quad \text{or} \quad vR + uR = 2uv$$

Dividing both sides by uvR, we get $\frac{1}{u} + \frac{1}{v} = \frac{2}{R}$

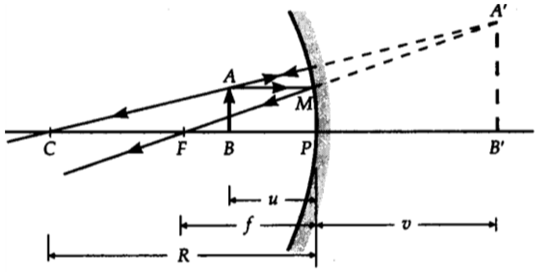
But $\quad R = 2f$

$$\therefore \quad \frac{1}{u} + \frac{1}{v} = \frac{1}{f}.$$

Case II : When the image formed is virtual

Now, $\Delta A'B'C \sim \Delta ABC$

$$\therefore \quad \frac{A'B'}{AB} = \frac{B'C}{BC} = \frac{PC - PB'}{BP + PC} = \frac{R - v}{-u + R} \quad \text{....(1)}$$



$\Delta A'B'P \sim \Delta ABP$.

$$\therefore \quad \frac{A'B'}{AB} = \frac{PB'}{BP} = \frac{v}{-u} \quad \text{....(2)}$$

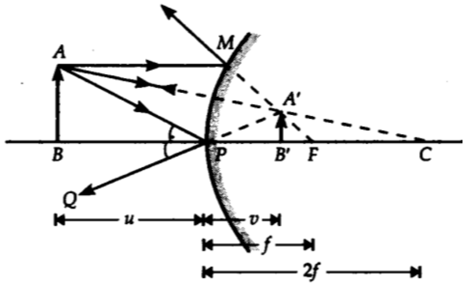
From equations (1) and (2), we get $\frac{R - v}{-u + R} = \frac{v}{-u}$

or $\quad -uR + uv = -uv + vR \quad$ or $\quad uR + uR = 2uv$

Dividing both sides by uvR, we get $\frac{1}{u} + \frac{1}{v} = \frac{2}{R}$. But $R = 2f$

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

Derivation of mirror formula for a convex mirror



Now, $\Delta A'B'C \sim \Delta ABC$

$$\therefore \quad \frac{A'B'}{AB} = \frac{B'C}{BC} = \frac{PC - PB'}{BP + PC} = \frac{R - v}{-u + R} \qquad \text{......(1)}$$

As $\angle APB' = \angle BPQ = \angle APB$

$\Delta A'B'P \sim \angle ABP$

$$\therefore \quad \frac{A'B'}{AB} = \frac{PB'}{BP} = \frac{v}{-u} \qquad \text{......(2)}$$

From equation (1) and (2), we get

$$\frac{R - v}{-u + R} = \frac{v}{-u} \quad \text{or} \quad -uR + uv = -uv + vR \quad \text{or} \quad vR + uR = 2uv$$

Dividing both sides by uvR, we get

$$\frac{1}{u} + \frac{1}{v} = \frac{2}{R}$$

But $R = 2f$ $\quad \therefore \quad \frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

Linear magnification

The ratio of the height of the image to that of the object is called *linear or transverse magnification* or just *magnification* and is denoted by m.

$$m = \frac{\text{Height of image}}{\text{Height of object}} = \frac{h_2}{h_1}. \quad , \quad m = \frac{h_2}{h_1} = -\frac{v}{u}$$

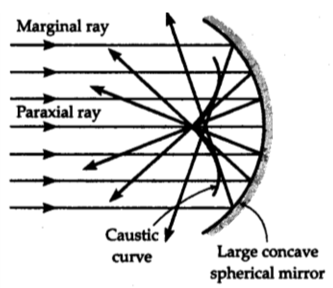
Linear magnification in terms of u and f: $m = -\frac{u}{v} = \frac{f}{f - u}$.

Linear magnification in terms of v and f: $m = -\frac{v}{u} = \frac{f - v}{f}$.

Note :

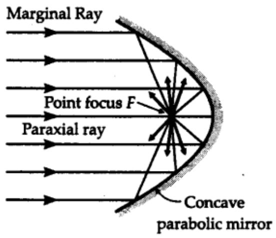
- The same mirror formula is valid for both concave and convex mirrors whether the image formed is real or virtual.
- If $|m| > 1$, the image is *magnified*.
- If $|m| < 1$, the image is *diminished*.
- If $|m| = 1$, the image is of the same size as the object.
- If m is positive (or v is positive), the image is virtual and erect.
- If m is negative (or v is negative), the image is real and inverted.

Spherical Aberration



The inability of a spherical mirror of large aperture to bring all the rays of wide beam of light falling on it to focus at a single point is called spherical aberration. Only the paraxial rays are focused at the principal focus F. The marginal rays meet the principal axis at a point closer to the pole than the principal focus. The different rays are reflected on to surface known as the caustic curve. This results in blurred image of the object.

Spherical aberration can be reduced by following methods :



1. By using spherical mirrors of small apertures.
2. By using stoppers so as to cut off the marginal rays.
3. By using parabolic mirrors.

A parabolic mirror : It focuses all the rays in a wide parallel beam to a single point on the principal axis and thus spherical aberration is reduced.

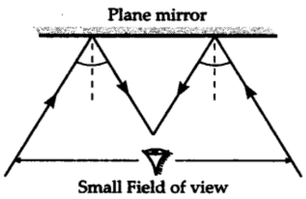
Uses of concave mirrors

1. A concave mirror is used as shaving or make–up mirror because it forms a magnified and erect image of the face when it is held closer to the face.
2. Doctors use concave mirrors as *head mirror*. The mirror is strapped to the doctor's forehead and light from a lamp after reflection from the mirror is focused into the throat or ear of the patient.
3. A small concave mirror with a small hole at its centre is used in the doctor's *ophthalmoscope*. The doctor looks through the hole from behind the mirror while a beam of light from a lamp reflected from it is directed into the pupil of patient's eye which makes the retina visible.
4. Concave mirrors are used as *reflectors* in head lights of cars, railway engines, torch lights, etc. The source is placed at the focus of a concave mirror. The light rays after reflection travel over a large distance as a parallel intense beam.

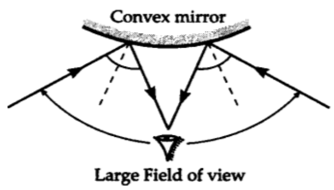
Uses of convex mirror

A convex mirror is used as a *rear view mirror* in automobiles. The reason is that it always forms a small and erect image and it has a larger field of view than that of a plane mirror of the same size.

(a)



(b)



Uses of parabolic mirrors :

1. A concave parabolic mirror can focus a wide parallel beam to a single point. This property is used by dish antennas to collect and bring to focus microwave signals from satellites.
2. When a source of light is placed at the focus of a paraboloidal mirror, the reflected beam is accurately parallel and is thrown over a very large distance. Due to this property, paraboloidal mirrors are used as reflectors in search lights, car head lights, etc.
3. They are used in astronomical telescopes of large aperture for overcoming spherical aberration.

Subjective Assignment – I

1. An object is placed (i) 10 cm , (ii) 5 cm in front of a concave mirror of radius of curvature 15 cm. Find the position, nature and magnification of the image in each case.
2. If you sit in a parked car, you glance in the rear view mirror R = 2m and notice a jogger approaching. If the jogger is running at a speed of 5 ms^{-1}, how fast is the image of the jogger moving when the jogger is (a) 39m (b) 29 m (c) 19 m (d) 9m away?
3. An object 0.05 m high is placed at a distance of 0.5 m from a concave mirror of radius of curvature 0.2m. Find the position, nature and the size of the image formed.
4. A square wire of side 3.0 cm is placed 25 cm away from a concave mirror of focal length 10 cm. What is the area enclosed by the image of the wire? (The centre of the wire is on the axis of the mirror, with its two sides normal to the axis).

5. An object is placed at a distance of 40 cm on the principal axis of a concave mirror of radius of curvature 30 cm. By how much does the image move if the object is shifted towards the mirror through 15 cm?
6. An object is placed exactly midway between a concave mirror of radius of curvature 40 cm and a convex mirror of radius of curvature 30 cm. The mirrors face each other and are 50 cm apart. Determine the nature and position of the image formed by successive reflections first at the concave mirror and then at the convex mirror.
7. An object is placed at a distance of 36 cm from a convex mirror. A plane mirror is placed in between so that the two virtual images so formed coincide. If the plane mirror is at a distance of 24 cm from the object, find the radius of curvature of the convex mirror.
8. An object is kept in front of a concave mirror of focal length 15cm. The image formed is three times the size of the object. Calculate the two possible distances of the object from the mirror.
9. When the distance of an object from a concave mirror is decreased from 15 cm to 9 cm, the image gets magnified 3 times than that in first case. Calculate the focal length of the mirror.
10. Two objects *A* and *B* when placed one after another in front of a concave mirror of focal length 10 cm, form images of same size. Size of object *A* is 4 times that of *B*. If object *A* is placed at a distance of 50 cm from the mirror, what should be the distance of *B* from the mirror?
11. A thin rod of length *f*/3 is placed along the optic axis of a concave mirror of focal length *f* such that its image which is real and elongated just touches the rod. What will be the magnification?
12. When an object is placed at a distance of 60 cm from a convex spherical mirror, the magnification produced is ½. Where should the object be placed to get a magnification of 1/3?
13. An object of 1 cm^2 face area is placed at a distance of 1.5 m from a screen. How far from the object should a concave mirror be placed so that if forms 4 cm^2 image of object on the screen? Also, calculate the focal length of the mirror.

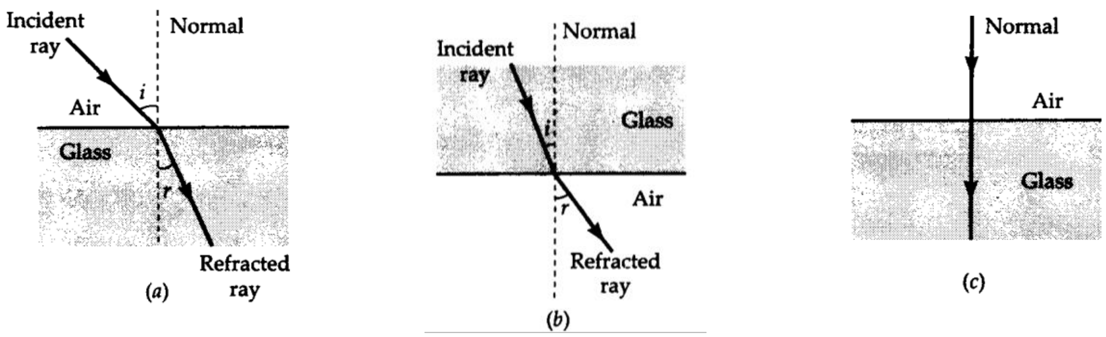
Answers

1.	– 30 cm, + 15 cm	2.	$\frac{1}{280}ms^{-1}$, $\frac{1}{150}ms^{-1}$, $\frac{1}{60}ms^{-1}$ and $\frac{1}{10}ms^{-1}$		
3.	– 12.5 cm , – 1.25 cm, real	4.	4 cm^2	5.	– 13.5 cm
6.	(i) – 100 cm (ii) + 21.43 cm	7.	36 cm	8.	– 20 cm , – 10 cm
9	– 6 cm	10.	– 20 cm	11.	1.5
12.	– 120 cm	13.	– 1.5 cm, – 1m		

Refraction of Light

The phenomenon of the change in the path of light as it passes obliquely from one transparent medium to another is called refraction of light.

The path along which the light travels in the first medium is called *incident ray* and that in the second medium is called *refracted ray*. The angles which the incident ray and the refracted ray make with the normal at the surface of separation are called *angle of incidence (i) and angle of refraction (r)* respectively.



It is observed that

1. When a ray of light passes from an optically rarer medium to a denser medium, it bends towards the normal ($\angle r < \angle i$) as shown in figure.
2. When a ray of light passes from an optically denser to a raer medium, it bends away from the normal ($\angle r > \angle i$), as shown in figure.
3. A ray of light travelling along the normal passes undeflected, as shown figure. Here $\angle i = \angle r = 0^o$

Laws of Refraction of Light

The phenomenon of refraction of light obeys the following *two* laws:

First law : The incident ray, the refracted ray and the normal to the interface at the point of incidence all lie in the same plane.

Second law : The ratio of the sine of the angle of incidence and the sine of the angle of refraction is constant for a given pair of media.

$$\textit{Mathematically, } \frac{\sin i}{\sin r} = {}^1\mu_2, \textit{ a constant}$$

The ratio ${}^1\mu_2$ is called ***refractive index*** of second medium with respect to first medium. It is also known as ***Snell's law of refraction.***

Refractive index :

Refractive index in terms of speed of light : The refractive index of a medium for a light of given wavelength may be defined as the radio of the speed of light in vacuum to its speed in that medium.

$$\text{Refractive index} = \frac{\textit{Speed of light in vacuum}}{\textit{Speed of light in medium}} \quad \text{or} \quad \mu = \frac{c}{v}$$

Refractive index of a medium with respect to vacuum is also called ***absolute refractive index.***

Refractive index in terms of wavelength. Since the frequency (v) remains unchanged when light passes from one medium to another, therefore,

$$\mu = \frac{c}{v} = \frac{\lambda_{vac} \times v}{\lambda_{med} \times v} = \frac{\lambda_{vac}}{\lambda_{med}}$$

The refractive index of a medium may be defined as the radio of wavelength of light in vacuum to its wavelength in that medium.

Relative refractive index. The relative refractive index of medium 2 with respect to medium 1 is defined as the ratio of speed of light (v_1) in medium 1 to the speed of light (v_2) in medium 2 and is denoted by ${}^1\mu_2$

Thus $${}^1\mu_2 = \frac{v_1}{v_2}$$

Factors on which the refractive index of a medium depends :

1. Nature of the medium
2. Wavelength of the light used
3. Temperature
4. Nature of the surrounding medium

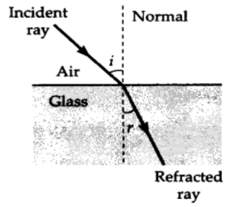
It may be noted that refractive index is a characteristic of the pair of the media and also depends on the wavelength of light, but is independent of the angle of incidence.

Note :

Optical density is a quantity quite different from mass density. Optical density is the ratio of the speed of light in two media while mass density is the mass per unit volume. Interestingly, an optically denser medium may have mass density less than an optically rarer medium. For example, the mass density of turpentine is less than that of water but turpentine is optically more denser that water.

Cause of Refraction

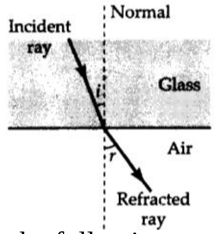
Cause of refraction of light: Light travels with different speeds in different media. *The bending of light or refraction occurs due to the change in the speed of light as it passes from one medium to another.* Larger the change in the speed of light as it passes from one medium to another, the more is the bending due to refraction. The Snell's law of refraction may be written as



$$^1\mu_2 = \frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$

From the above equation, we can note the following results:

(i) If $v_1 > v_2$, then $^1\mu_2 > 1$ and $\sin i > \sin r$ or $i > r$ i.e., the refracted ray bends towards the normal. The medium 2 is said to be ***optically denser*** than medium 1. Hence *a ray of light bends towards the normal as it refracts from a rarer medium into a denser medium.*



(ii) If $v_1 < v_2$, then $^1\mu_2 < 1$ and $\sin i < \sin r$ or $i < r$ i.e., the refracted ray bends away from the normal. The medium 2 is said to *optically rarer* than medium 1. Here *a ray of light bends away from the normal as it refracts from a denser medium into a rarer medium.*

Physical Significance of Refractive Index: The refractive index of a medium gives the following *two* informations:

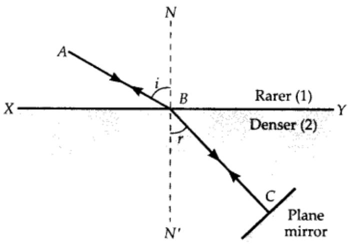
(i) The value of refractive index gives information about the direction of bending of refracted ray. It tells whether the ray will bend towards or away from the normal.

(ii) The refractive index of a medium is related to the speed of light. It is the ratio of the speed of light in vacuum to that in the given medium.

Principle of Reversibility of Light

This principle states that if the final path of a ray of light after it has suffered several reflections and refractions is reversed, it retraces its path exactly.

Consider a ray of light *AB* incident on a plane surface *XY*, separating rarer medium 1 (air) from denser medium 2 (water). It is refracted along *BC*.



Let angle of incidence, $\angle ABN = i$

and angle of refraction, $\angle CBN' = r$

From Snell's law of refraction

$$\frac{\sin i}{\sin r} = {}^1\mu_2 \qquad \text{... (1)}$$

Suppose a plane mirror is placed perpendicular to the path of ray BC.

This reverses the beam along its own path. Therefore, for the reversed ray, we have

Angle of incidence, $\angle CBN' = r$

Angle of refraction, $\angle ABN = i$

Again, from Snell's law

$$\frac{\sin r}{\sin i} = {}^{2}\mu_1 \qquad \ldots (2)$$

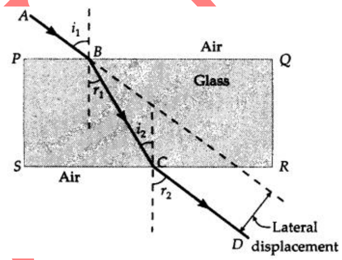
Multiplying equations (1) and (2), we get

$$\frac{\sin r}{\sin i} \times \frac{\sin i}{\sin r} = {}^{1}\mu_2 \times {}^{2}\mu_1 \qquad \text{or} \qquad 1 = {}^{1}\mu_2 \times {}^{2}\mu_1 \quad \text{or} \quad {}^{1}\mu_2 = \frac{1}{{}^{2}\mu_1}$$

Thus the refractive index of medium 2 with respect to medium 1 is reciprocal of the refractive index of medium 1 with respect to medium 2.

Refraction through a rectangular glass slab

Consider a rectangular glass slab *PQRS*, as shown in figure. A ray *AB* is incident on the face *PQ* at an angle of incidence i_1. On entering the glass slab, it bends towards normal and travels along *BC* at an angle of refraction r_1. The refracted ray *BC* is incident on face SR at an angle of incidence i_2. The emergent ray *CD* bends away from the normal at an angle of refraction r_2.



Using Snell's law for refraction at face *PQ*

$$\frac{\sin i_1}{\sin r_1} = {}^{a}\mu_g \qquad \ldots (1)$$

For refraction at face SR,

$$\frac{\sin i_2}{\sin r_2} = {}^{g}\mu_a = \frac{1}{{}^{a}\mu_g} \qquad \ldots (2)$$

Multiplying (1) and (2), we get $\quad \dfrac{\sin i_1}{\sin r_1} \times \dfrac{\sin i_2}{\sin r_2} = 1$

As PQ || SR, therefore, $i_2 = r_1$; hence $\quad \dfrac{\sin i_1}{\sin r_1} \times \dfrac{\sin r_1}{\sin r_2} = 1 \quad$ or $\quad \sin i_1 = \sin r_2$ or $i_1 = r_2$

Thus the emergent ray CD is parallel to the incident ray AB, but it has been laterally displaced with respect to the incident ray. *This shift in the path of light on emerging from a refracting medium with parallel faces is called lateral displacement.*

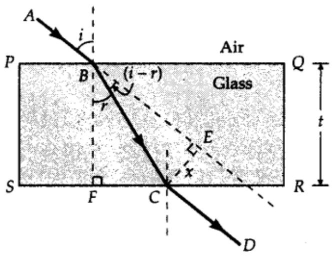
Hence **lateral shift** is the perpendicular distance between the incident and emergent rays, when light is incident obliquely on a refracting slab with parallel faces.

Expression for Lateral Displacement

Let t be the thickness of the slab and x, the lateral displacement of the emergent ray. Then from right Δ BEC, we have

$$\frac{x}{BC} = \sin(i - r) \quad \text{or} \quad x = BC \sin(i - r)$$

From right Δ BFC, we have



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

$$\therefore \qquad x = \frac{t}{\cos r}\sin(i - r)$$

$$= \frac{t}{\cos r}[\sin i \cos r - \cos i \sin r]$$

$$= t[\sin i - \cos i \tan r]$$

From Snell's law,

$$\mu = \frac{\sin i}{\sin r} \quad \text{or} \quad \sin r = \frac{\sin i}{\mu} \quad \therefore \quad \tan r = \frac{\sin i}{\sqrt{\mu^2 - \sin^2 i}}$$

$$\therefore \quad x = t\left[\sin i - \frac{\cos i . \sin i}{\sqrt{\mu^2 - \sin^2 i}}\right]$$

$$\therefore \quad x = t \sin i \left[1 - \frac{\cos i}{\sqrt{(\mu^2 - \sin^2 i)}}\right] \qquad \text{...(1)}$$

Clearly, x tends to a maximum value when i $\rightarrow 90^o$, so that sin i $\rightarrow$ 1 and cos $i \rightarrow 0$. Thus x_{max} = t sin 90^o = t, i.e., the displacement of the emergent ray cannot exceed the thickness of the glass slab.

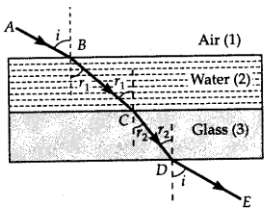
Hence the lateral shift produced by a glass slab increases with

(i) the increase in the thickness of the glass slab, (ii) increase in the value of the angle of incidence, and

(iii) the increase in the value of the refractive index of the slab.

Refraction thought a Combination of Media

As shown in the figure, the refraction of a ray of light from air (1) to water (2), glass (3) and finally to air. As all boundaries are parallel planes, emergent ray is parallel to the incident ray. Thus the angle of emergence is equal to the angle of incidence.



For the ray going from medium 1 to medium 2,

$$^1\mu_2 = \frac{\sin i}{\sin r_1}$$

For the ray going from medium 2 to medium 3,

$$^2\mu_3 = \frac{\sin r_1}{\sin r_2}$$

For the ray going from medium 3 to medium 1,

$$^3\mu_1 = \frac{\sin r_2}{\sin i}$$

Multiplying the above three equations, we get

$$^1\mu_2 \times {}^2\mu_3 \times {}^3\mu_1 = 1$$

$$^1\mu_2 \times {}^2\mu_3 = \frac{1}{^3\mu_1} \quad \text{or} \quad {}^1\mu_2 \times {}^2\mu_3 = {}^1\mu_3 \qquad \left[\because \; {}^3\mu_1 = \frac{1}{^1\mu_3}\right]$$

$$\therefore \quad {}^a\mu_w \times {}^w\mu_g = {}^a\mu_g$$

Practical Applications of Refraction

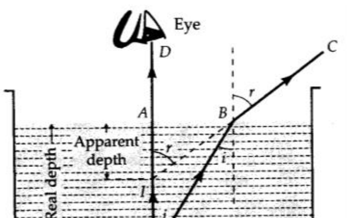
Real and apparent depths: It is on account of refraction of light that the apparent depth of an object placed in denser medium is less than the real depth.

From Snell's law, we have

$$^w\mu_a = \frac{\sin i}{\sin r} = \frac{\sin \angle AOB}{\sin \angle AIB} = \frac{AB/BO}{AB/BI} = \frac{BI}{BO}$$

As the size of the pupil is small, the ray BC will enter eye only if B is close to A. Then

$$BI \simeq AI \quad \text{and} \quad BO \simeq AO$$



$\therefore \qquad {}^{a}\mu_{w} = \dfrac{1}{{}^{w}\mu_{a}} = \dfrac{AO}{AI}$

or $\qquad$ Refractive index = $\dfrac{\text{Real depth}}{\text{Apparent depth}}$

or $\qquad$ Apparent depth = $\dfrac{\text{Real depth}}{\text{Refractive index}}$

As the refractive index of any medium (other than vacuum) is greater than unity, so *the apparent depth is less than the real depth.*

Normal Shift : The height through which an object appears to be raised in a denser medium is called normal shift. Clearly

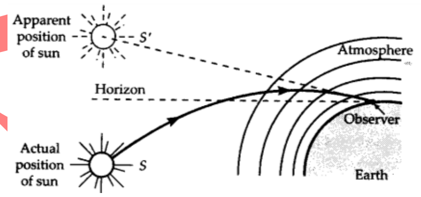
Normal shift = Real depth – Apparent depth

or $\qquad d = AO - AI = AO - \dfrac{AO}{\mu} = AO\left(1 - \dfrac{1}{\mu}\right)$ $\qquad$ or $\qquad d = t\left(1 - \dfrac{1}{\mu}\right)$

Clearly, normal shift in position of an object when seen through a denser medium depends on two factors:

1. The real depth of the object or the thickness (t) of the refracting medium.
2. The refractive index of the denser medium. Higher value of μ, greater is the apparent shift 'd'.

Apparent shift in the position of the sun at sunrise and sunset



Due to the atmospheric refraction, the sun is visible before actual sunrise and after actual sunset. With altitude, the density and hence refractive index of air–layers decreases. The light rays starting from the sun S travel from rarer to denser layers. They bend more and more toward the normal.

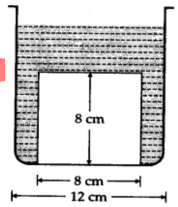
However, an observer sees an object in the direction of the rays reaching his eyes. So to an observer standing on the earth, the sun which is actually in a position S below the horizon, appears in the position S', above the horizon. The apparent shift in the direction of the sun is by about 0.5^{o}. Thus the sun appears to rise early by about 2 minutes and for the same reason, it appears to set late by about 2 minutes. This increases the length of the day by about 4 minutes.

Apparent flattening of the sun at sunrise and sunset : The sun near the horizon appears flattened. This is due to atmospheric refraction. The density and the refractive index of the atmosphere decrease with altitude, so the rays from the top and bottom portions of the sun on the horizon are refracted by different degrees. This cause the apparent flattening of the sun.

Subjective Assignment – II

1. A ray of light of frequency 5×10^{14} Hz is passed through a liquid. The wavelength of light measured inside the liquid is found to be 450×10^{-9} m. Calculate the refractive index of the liquid.
2. A light of wavelength 6000 Å in air, enters medium with refractive index 1.5. What will be the wavelength of light in that medium?
3. The refractive index of glass is 1.5 and that of water is 1.3. If the speed of light in water is 2.25×10^{8} ms^{-1}, what is the speed of light in glass?
4. A ray of light passes through a plane boundary separating of two whose refractive indices are $\mu_1 = 3/2$ and $\mu_2 = 4/3$. (i) If the ray travels from medium 1 to medium 2 at an angle of incidence of 30^{o}, what is the angle of refraction? (ii) If the ray travels from medium 2 to medium 1 at the same angle of incidence what is the angle of refraction?
5. A ray of light is incident at an angle of 60^{o} on one face of a rectangular glass slab of thickness 0.1m and refractive index 1.5.Calculate the lateral shift produced.

6. The apparent depth of an object at the bottom of tank filled with a liquid of refractive index 1.3 is 7.7 cm. What is the actual depth of the liquid in the tank?
7. The velocity of light in glass is $2 \times 10^8\ ms^{-1}$ and that in air $3 \times 10^8\ ms^{-1}$. By how much would an ink dot appear to be raised, when covered by a glass plate 6.0 cm thick?
8. A mark is made on the bottom of a beaker and a microscope is focused on it. The microscope is raised through 1.5 cm. To what height water must be poured into the beaker to bring the mark again into focus? Given that μ for water is 4/3.
9. The bottom of a container is 4.0 cm thick glass (μ = 1.5) slab. The container contains two immiscible liquids A and B of depths 6.0 cm and 8.0 cm respectively. What is the apparent position of a scratch on the outer surface of the bottom of the glass slab when viewed through the container? Refractive indices of A and B are 1.4 and 1.3 respectively.
10. A transparent cube of side 210 mm contains a small air bubble. Its apparent distance, when viewed through one face of the cube is 100 mm and when viewed through the opposite face is 40 mm. What is the actual distance of the bubble from the second face and what is the refractive index of the material of the cube?
11. A cylindrical vessel of diameter 12 cm contains 800 π cm^3 of water. A cylindrical glass piece of diameter 8.0 cm and height 8.0 cm is placed in the vessel. If the bottom of the vessel under the glass piece is seen by the paraxial rays (figure), locate its image. The index of refraction of glass is 1.50 and that of water is 1.33.



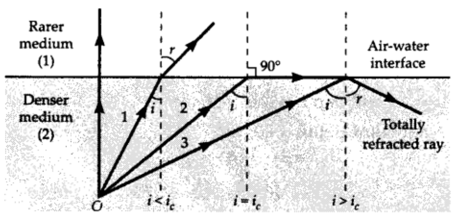
12. A film of oil of refractive index 1.20, lies on water of refractive index 1.33. A light ray is incident at 30^o in the oil on the oil–water boundary. Calculate the angle of refraction in water.
13. A printed page is kept pressed by a glass cube (μ = 1.5) of edge 6.0 cm. By what amount will the printed letters appear to be shifted when viewed from the top?
14. While determining the refractive index of a liquid experimentally, the microscope was focused at the bottom of a beaker, when its reading was 3.965 cm. On pouring liquid upto a height 2.537 cm inside the beaker, the reading of the refocused microscope was 3.348 cm. Find the refractive index of the liquid.
15. A vessel contains water upto a height of 20 cm and above it an oil upto another 20 cm. The refractive indices of water and oil are 1.33 and 1.30 respectively. Find the apparent depth of vessel when viewed from above.

Answers

1.	1.33	2.	5×10^{14} Hz, 4000 Å	3.	$1.95 \times 10^8\ ms^{-1}$
4.	(i) $34^o14'$, (ii) $26^o24'$	5.	0.0513 m	6.	10.01 cm
7.	2.0 cm	8.	6.0 cm	9.	4.89 cm
10.	60 mm, 1.50	11.	7.1 cm	12.	27^o
13.	2.0 cm	14.	1.321	15.	30.4 cm

Total Internal Reflection

As shown in figure, when a ray of light (ray 1) travels at a small angle of incidence from a denser medium to a rarer medium, say from water to air, the refracted ray bends away from the normal. As the angle of incidence increases, the corresponding angle of refraction also increases. Then for a certain angle of incidence (ray 2), the angle of refraction becomes 90^o, i.e., the refracted ray goes along the surface of separation.



The angle of incidence in the denser medium for which the angle of refraction in the rarer medium is 90^o is called **critical angle** of the denser medium and is denoted by i_c.

The phenomenon in which a ray of light travelling at an angle of incidence greater than the critical angle from denser to a rarer medium is totally reflected back into the denser medium is called **total internal reflection.**

Necessary conditions for total internal reflection

1. Light must travel from an optically denser to an optically rarer medium.
2. The angle of incidence in the denser medium must be greater than the critical angle for the two media.

Relation between critical angle and refractive index.

From Snell's law $\quad \dfrac{\sin i}{\sin r} = {}^2\mu_1 = \dfrac{1}{{}^1\mu_2}$

When $i = i_c$, $r = 90^o$. Therefore, $\quad \dfrac{\sin i_c}{\sin 90^o} = \dfrac{1}{{}^1\mu_2}$ or $\quad {}^1\mu_2 = \dfrac{1}{\sin i_c}$

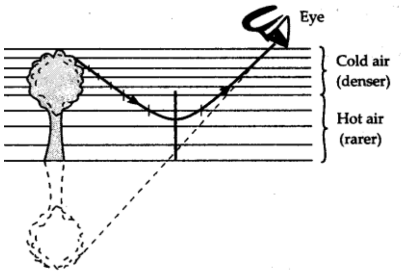
If the rarer medium is air, then $\mu_1 = 1$ and $\mu_2 = \mu$ (say) and we get $\mu = \dfrac{1}{\sin i_c}$

Thus the refractive index of any medium is equal to the reciprocal of the sine of its critical angle.

Applications of total internal reflection

1. Sparkling of diamond: The brilliancy of diamonds is due to total internal reflection. As the refractive index of diamond is very large, its critical angle is very small, about 24.4^o. The faces of diamond are so cut that the light entering the crystal suffers total internal reflections repeatedly, and hence gets collected inside but it comes out through only a few faces. Hence the diamond sparkles when seen in the direction of emerging light.

2. Mirage: It is an optical illusion observed in deserts or over hot extended surfaces like a cool–tarred road, due to which a traveler sees a shimmering pond of water some distance ahead of him and in which the surrounding objects like trees, etc., appear inverted.

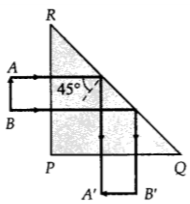


On a hot summer day, the surface of the earth becomes very hot. The layers of air near the earth are more heated than the higher ones. Hence the density and refractive index of air layers increase as we move high up. As the rays of light from a distant object like a tree travel towards the earth through layers of decreasing refractive index, they bend more and more away from the normal. A stage is reached when the angle of incidence becomes greater than the critical angle, rays are totally reflected.

These rays then move up through layers of increasing refractive index, and therefore undergo refraction in a direction opposite to that in the first case. These rays reach the observer's eyes and he sees an inverted image to the object, as if formed in a pond of water.

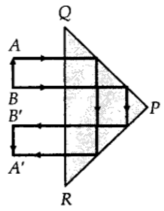
Totally Reflecting Prism

A right–angled isosceles prism, i.e., a 45^o–90^o–45^o prism is called a totally reflecting prism. Whenever a ray falls normally on any face of such a prism, it is incident on the inside face at 45^o, that is at an angle greater than the critical angle of glass (about 42^o); hence this ray is always totally internally reflected.

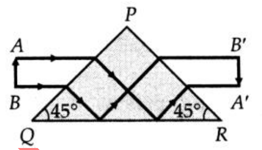


(i) To deviate a ray through 90^o: As shown in figure, as the light is incident normally on one of the faces containing right angle, it enters the prism without deviation. It is incident on the hypotenuse face at an angle of 45^o, greater than the critical angle. The light is totally internally reflected.

(ii) To invert an image with deviation of rays through 180°: As shown in figure, the light is incident normally on the hypotenuse face, it first suffers total internal reflection from one shorter face and then from the other shorter face. The final beam emerges through the hypotenuse face, parallel to the incident beam.



(iii) To invert an image without deviation of rays (erecting prism): As shown in figure, the light enters at one shorter face at an angle. After refraction, it is totally reflected from the hypotenuse face and then refracted out of the other shorter face to become parallel to the incident beam. The rays do not suffer any deviation, only their order is reversed.

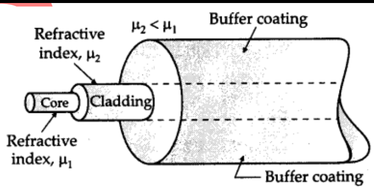


Advantages of totally reflecting prism over plane mirrors :

1. In prisms, the light is *totally* reflected, while there is always some loss of intensity in case of plane mirrors.
2. The reflecting properties of prisms are permanent, while these are affected by tarnishing in case of plane mirrors.
3. No multiple images are formed in prisms, while a plane mirror forms a number of faint images in addition to a prominent image.

Optical Fibres

The working of optical fibres is based on the phenomenon of total internal reflection. As optical fibre is a hair–thin long strand of quality glass or quartz surrounded by a glass coating of slightly lower reflective index. It is used as a guided medium for transmitting an optical signal from one place to another.



Construction: An optical fibre consists of *three* main parts:

(i) **Core:** The central cylindrical core is made of high quality glass/silica/plastic of refractive index μ_1 and has a diameter about 10 to 100 μm.

(ii) **Cladding:** The core is surrounded by a glass/ plastic jacket of refractive index $\mu_2 < \mu_1$. In a typical optical fibre, the refractive indices of core and cladding may be 1.52 and 1.48 respectively.

(iii) **Buffer coating:** For providing safety and strength, the core cladding of optical fibres is enclosed in a plastic jacket.

Application of optical fibres: Some of the important applications are as follows:

1. *As a light pipe, optical fibres are used in medical and optical examination.* A light pipe is inserted into the stomach through the mouth. Light transmitted through the outer layers of the light pipe is scattered by the various parts of stomach into the central portion of the light pipe to produce a final image with excellent details. The technique is called endoscopy.
2. *They are used in transmitting and receiving electrical signals in telecommunication.* The electrical signals are first converted to light by suitable transducers. Each fibre can transmit about 1200 telephone conversations without much loss of intensity.
3. They are used for transmitting optical signals and two dimensional pictures.
4. In the form of *photometric sensors*, they are used for measuring the blood flow in the heart.
5. In the form of *refractometers*, they are used to measure refractive indices of liquids.

Subjective Assignment – III

Q.1 Find the value of critical angle for a material of refractive index $\sqrt{3}$.

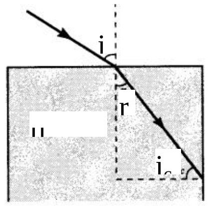
Q.2 Calculate the speed of light in a medium, whose critical angle is 45°.

Q.3 The velocity of light in a liquid is 1.5×10^8 ms^{-1} and in air, it is 3×10^8 ms^{-1}. If a ray of light passes from this liquid into air, calculate the value of critical angle.

Q.4 Determine direction in which a fish under water sees setting sun. Refractive index of water is 1.33.

Q.5 The critical angle of incidence in a glass slab placed in air 45^o. What will be the critical angle when it is immersed in water of refractive index 1.33?

Q.6 For a situation shown in figure, find the maximum angle *i* from which the light suffers total internal reflection at the vertical surface.



Q.7 A point source of light S is placed at the bottom of a vessel containing a liquid of refractive index 5/3. A person is viewing the source from above the surface. There is an opaque disc of radius 1 cm floating on the surface. The centre of the disc lies vertically above the source O. The liquid from the vessel is gradually drained out through a tap. What is the maximum height of the liquid for which the source cannot be seen at all?

Q.8 The refractive index of water is 4/3. Obtain the value of the semi–vertical angle of the cone within which the entire outside view would be confined for a fish under water.

Q.9 Find the critical angle for a ray of light going from paraffin oil to air. Given the refractive index of paraffin oil with respect to air is 1.44.

Q.10 An optical fibre (μ = 1.72) is surrounding by a glass coating (μ = 1.50). Find the critical angle for total internal reflection at the fibre–glass interface.

Q.11 What is the small index of refraction of the material of a right–angled prism with equal sides for which a ray of light entering one of the sides normally will be totally reflected?

Q.12 A luminous object O is located at the bottom of a big pool of liquid of refractive index μ and depth h. The object O emits rays upwards in all directions, so that a circ le of light is formed at the surface of the liquid by the rays which are refracted into the air. What happens to the rays beyond the circle? Determine the radius and the area of the circle.

Q.13 Glycerine (refractive index 1.4) is poured into a large jar of radius 0.2 m to a depth of 0.1 m. There is a small light source at the centre of the bottom of the jar. Find the area of the surface of glycerine through which the light passes.

Answers

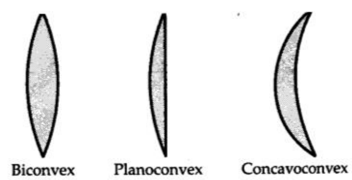
1.	$\simeq 35.3^o$	2.	2.121×10^8 ms^{-1}	3.	30^o
4.	41.3^o	5.	$70^o36'$	6.	$i < 48.6^o$
7.	1.33 cm	8.	48.6^o	9.	44^o
10.	60.7^o	11.	1.414		

12. Rays beyond the circle are totally reflected into the liquid, radius = $\frac{h}{\sqrt{\mu^2-1}}$, $Area = \frac{\pi h^2}{\mu^2 - 1}$

13. 0.0327 m^2

Spherical Lenses

*A **lens** is a piece of a refracting medium bounded by two surfaces, at least one of which is a curved surface.* The commonly used lenses are the spherical lenses. These lenses have either both surfaces spherical or one spherical and the other a plane one. Lenses can be divided into *two* categories:



(i) Convex or converging lenses, and

(ii) Concave or diverging lenses

(i) Convex or converging lens : It is thicker at the centre than at the edges. It converges a parallel beam of light on refraction through it. It has a real focus.

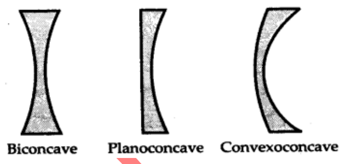
Types of convex lenses

(a) *Double convex or biconvex lens.* In this lens, both surfaces are convex.

(b) *Planoconcave lens.* In this lens, one side is convex and the other is plane.

(c) *Concavoconvex.* In this lens, one side is convex and the other is concave.

(ii) Concave or diverging lens : It is thinner at the centre than at the edges. It diverges a parallel beam of light on refraction through it. It has a virtual focus.



Types of concave lenses:

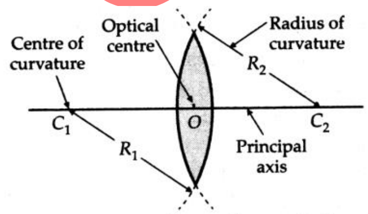
(a) *Double concave or biconcave lens.* In this lens, both sides are concave.

(b) *Plano concave lens.* In this lens, one side is plane and the other is concave.

(c) *Convexoconcave lens.* In this lens, one side is convex and the other is concave.

Definitions in Connection with Spherical Lenses

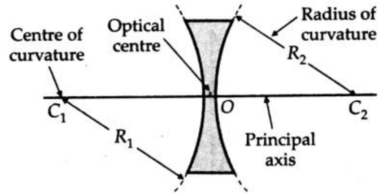
(i) Centre of curvature (C): The centre of curvature of the surface of a lens is the centre of the sphere of which it forms a part. Because a lens has two surfaces, so it has two centres of curvature.



(ii) Radius of curvature (R): The radius of curvature of the surface of a lens is the radius of the sphere of which the surface forms a part.

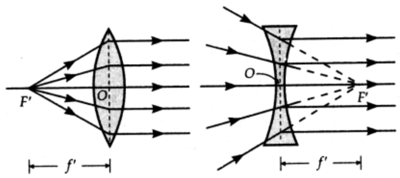
(iii) Principal axis (C_1C_2): It is the line passing through the two centres of curvature of the lens.

(iv) Optical centre: If a ray of light is incident on a lens such that after refraction through the lens the emergent ray is parallel to the incident ray, then the point at which the refracted ray intersects the principal axis is called the optical centre of the lens.

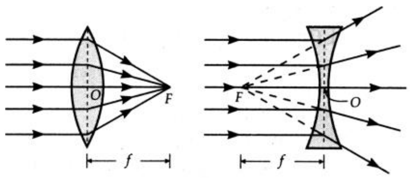


(v) Principal foci and focal length :

First principal focus: It is a fixed point on the principal axis such that rays starting from this point (in convex lens) or appearing to go towards this point (in concave lens), after refraction through the lens, become parallel to the principal axis. It is represented by F_1 or F.



The plane passing through this point and perpendicular to the principal axis is called the ***first focal plane.*** The distance between first principal focus and the optical centre is called ***first focal length.*** It is denoted by f_1 or f'.



Second principal focus: It is fixed point on the principal axis such that the light rays incident parallel to the principal axis, after refraction through the lens, either converge to this point (in convex lens) or appear to diverge from this point (in concave lens). The plane passing through this point and perpendicular to principal axis is called the **second focal plane.** The distance between the second principal focus and optical center is called the **second focal length.** It is denoted by f_2 or f.

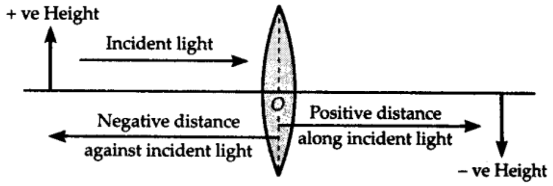
The focal length of a convex lens is taken positive and the focal length of a concave lens is taken negative.

If the medium on both sides of a lens is same, then the numerical values of the first and second focal lengths are equal. Thus $f = f'$

(vi) **Aperture :** It is the diameter of the circular boundary of the lens.

New Cartesian Sign Convention for Spherical Lenses

1. All distances are measured from the *optical center of the lens.*
2. The distances measured in the *same direction* as the incident light are taken *positive.*
3. The distances measured in the direction *opposite to the direction* of the incident light are taken *negative.*
4. Heights measured *upwards* and perpendicular to the principal axis are taken *positive.*
5. Heights measured *downwards* and perpendicular to the principal axis are taken *negative.*



Consequences of the sign convention

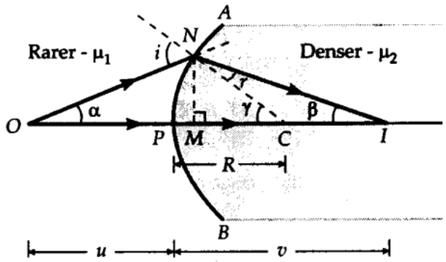
1. The focal length of a converging lens is positive and that of a diverging lens is negative.
2. Object distance is always negative.
3. The distance of *real image* is positive and that of *virtual image is negative.*
4. The object height h_1 is always positive. Height h_2 of virtual erect image is positive and that of real inverted image is negative.
5. The linear magnification $m = h_2/ h_1$ is positive for a virtual image and negative for a real image.

Refraction at a convex spherical surface

(i) **The object lies in rarer medium and the image formed is real**

Suppose a point object O is placed on the principal axis in the rarer medium. Starting from the point object O, a ray ON is incident at an angle *i*. After refraction, it bends towards the normal CN at an angle of refraction r. Another ray OP is incident normally on the convex surface and passes undeviated. The two refracted rays meet at point I. So I is the real image of point object O.

Draw NM perpendicular to the principal axis. α, β and γ be the angles, as shown in figure.



In ΔNOC, i is an exterior angle, therefore,

$$i = \alpha + \gamma$$

Similarly, from Δ NIC, we have

$$\gamma = r + \beta \qquad \text{or} \qquad r - \gamma - \beta$$

Suppose all the rays are *paraxial.*

Then the angles i, r, α, β and γ will be small.

$$\therefore \quad \alpha \approx \tan\alpha = \frac{NM}{OM} \approx \frac{NM}{OP} \quad [\because P \text{ is close to } M]$$

$$\beta \approx \tan\beta = \frac{NM}{MI} \approx \frac{NM}{PI} \qquad \text{and} \qquad \gamma \approx \tan\gamma = \frac{NM}{MC} \approx \frac{NM}{PC}$$

From Snell's law of refraction, $\dfrac{\sin i}{\sin r} = \dfrac{\mu_2}{\mu_1}$

As i and r are small, therefore $\dfrac{i}{r} = \dfrac{\mu_2}{\mu_1}$

or $\mu_1 i = \mu_2 r$ or $\mu_1 (\alpha + \gamma] = \mu_2 [\gamma - \beta]$

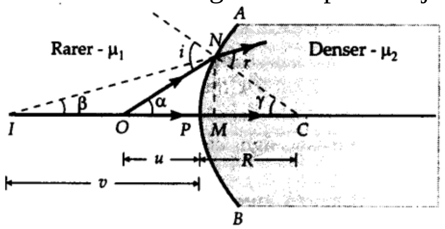
or $\mu_1 \left[\frac{NM}{OP} + \frac{NM}{PC}\right] = \mu_2 \left[\frac{NM}{PC} - \frac{NM}{PI}\right]$ or $\frac{\mu_1}{OP} + \frac{\mu_2}{PI} = \frac{\mu_2 - \mu_1}{PC}$

Using new Cartesian sign convention, we find

Object distance, OP = – u , Image distance, PI = + v , Radius of curvature, PC = + R

$\therefore \quad \frac{\mu_1}{-u} + \frac{\mu_2}{v} = \frac{\mu_2 - \mu_1}{R}$ or $\boxed{\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}}$

(ii) The object lies in the rarer medium and the image formed is virtual. When the object O in the rarer medium lies close to the pole P of the convex refracting surface, the two refracted rays appear to diverge from a point I on the principal axis, as shown in figure. So I is the virtual image of the point object O.



From ΔNOC, $i = \alpha + \gamma$ or $i = \gamma - \alpha$

From ΔNCI, $r = \beta + \gamma$

Suppose all the rays are *paraxial*. Then the angles i, r, α, β and γ will be small

$\therefore \quad \alpha \approx \tan\alpha = \frac{NM}{OM} = \frac{NM}{OP}$ [$\because M$ is close to P]

$\beta \approx \tan\beta = \frac{NM}{MI} = \frac{NM}{PI}$ and $\gamma \approx \tan\gamma = \frac{NM}{CM} = \frac{NM}{CP}$

From Snell's law of refraction, for refraction from rarer to denser medium, we have $\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$

As *i* and *r* are small angles, so $\frac{i}{r} = \frac{\mu_2}{\mu_1}$ or $\mu_1 i = \mu_2 r$ or $\mu_1(\alpha + \gamma) = \mu_2(\beta + \gamma)$

or $\mu_1 \left[\frac{NM}{OP} + \frac{NM}{PC}\right] = \mu_2 \left[\frac{NM}{IP} + \frac{NM}{PC}\right]$ or $\mu_1 \left[\frac{1}{OP} + \frac{1}{PC}\right] = \mu_2 \left[\frac{1}{IP} + \frac{1}{PC}\right]$

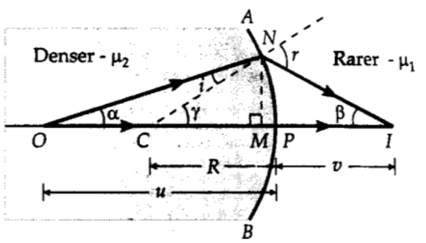
or $\frac{\mu_1}{OP} - \frac{\mu_2}{IP} = \frac{\mu_2 - \mu_1}{PC}$

Using new Cartesin sign convention, we find that

Object distance, *OP* = – *u* , Image distance, *IP* = – *v* , Radius of curvature, *PC* = + *R*

$\therefore \quad \frac{\mu_1}{-u} - \frac{\mu_2}{-v} = \frac{\mu_2 - \mu_1}{R}$ or $\boxed{\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}}$

(iii) The object lies in the denser medium and the image formed in real : As shown in figure a convex refracting surface which is convex towards the rarer medium. The point object *O* lies in the denser medium. The two refracted rays meet at point *I*. So *I* is the real image of the point object *O*.



From ΔNOC, $\gamma = i + \alpha$ or $i = \gamma - \alpha$

From ΔNIC, $r = \beta + \gamma$

Suppose all the rays are paraxial.

Then the angles *i*, *r*, α, β and γ will be small.

$\therefore \quad \alpha \approx \tan\alpha = \frac{NM}{OM} = \frac{NM}{OP}$

$\beta \approx \tan\beta = \frac{NM}{MI} = \frac{NM}{PI}$ and $\gamma \approx \tan\gamma = \frac{NM}{CM} = \frac{NM}{CP}$

From Snell's law of refraction, for refraction from denser to rarer medium, we have $\frac{\sin i}{\sin r} = \frac{\mu_1}{\mu_2}$

As i and r are small angles , so $\frac{i}{r} = \frac{\mu_1}{\mu_2}$ or $\mu_2 i = \mu_1 r$

or $\mu_2(\gamma - \alpha) = \mu_1(\beta + \gamma)$

or $\mu_2\left[\frac{NM}{CP} - \frac{NM}{OP}\right] = \mu_1\left[\frac{NM}{PI} + \frac{NM}{CP}\right]$

or $\mu_2\left[\frac{1}{CP} - \frac{1}{OP}\right] = \mu_1\left[\frac{1}{PI} + \frac{1}{CP}\right]$ or $-\frac{\mu_1}{PI} - \frac{\mu_2}{OP} = \frac{\mu_1 - \mu_2}{CP}$

Using the new Cartesian sign convention, we have

Object distance, OP = – u , Image distance, PI = + v , Radius of curvature, CP = – R

$\therefore \quad -\frac{\mu_1}{v} - \frac{\mu_2}{-u} = \frac{\mu_1 - \mu_2}{-R}$ or $\boxed{\frac{\mu_1}{v} - \frac{\mu_2}{u} = \frac{\mu_1 - \mu_2}{R}}$

(iv) The object lies in the denser medium and the image formed is virtual

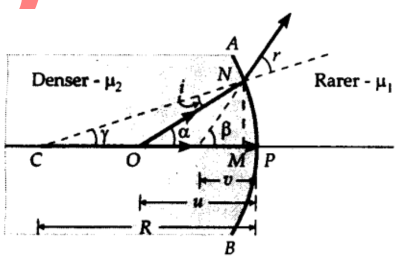
If the point object O placed on the principal axis lies close to the pole of the refracting surface, then the two refracted rays appear to come from the point I, as shown in figure. So I is the virtual image of the point object O.

From ΔNOC, $i + \gamma = \alpha$ or $i = \alpha - \gamma$

From ΔNIC , $r + \gamma = \beta$ or $r = \beta - \gamma$

Suppose all the rays are *paraxial*.

Then the angles i, r, α, β and γ will be small.



$\therefore \quad \alpha \approx \tan\alpha = \frac{NM}{OM} = \frac{NM}{OP}$ [∵ *M is close to P*]

$\beta \approx \tan\beta = \frac{NM}{IM} = \frac{NM}{IP}$ and $\gamma \approx \tan\gamma = \frac{NM}{CM} = \frac{NM}{CP}$

From Snell's law of refraction, for refraction from denser to rarer medium, we have $\frac{\sin i}{\sin r} = \frac{\mu_1}{\mu_2}$

As i and r are small angles, so $\frac{i}{r} = \frac{\mu_1}{\mu_2}$ or $\mu_2 i = \mu_1 r$

or $\mu_2(\alpha - \gamma) = \mu_1(\beta - \gamma)$ or $\mu_2\left[\frac{NM}{OP} - \frac{NM}{CP}\right] = \mu_1\left[\frac{NM}{IP} - \frac{NM}{CP}\right]$

or $\mu_2\left[\frac{1}{OP} - \frac{1}{CP}\right] = \mu_1\left[\frac{1}{IP} - \frac{1}{CP}\right]$ or $-\frac{\mu_1}{IP} + \frac{\mu_2}{OP} = -\frac{\mu_1 - \mu_2}{CP}$

Using the new Cartesian sign convention, we have

Object distance, OP = – u , Image distance, IP = – v , Radius of curvature, CP = – R

$\therefore \quad -\frac{\mu_1}{-v} + \frac{\mu_2}{-u} = -\frac{\mu_1 - \mu_2}{-R}$ or $\boxed{\frac{\mu_1}{v} - \frac{\mu_2}{u} = \frac{\mu_1 - \mu_2}{R}}$

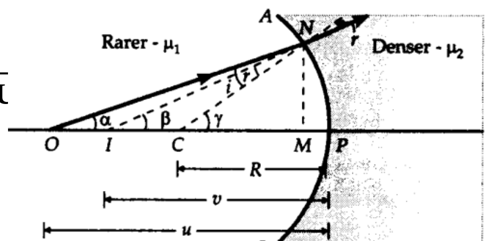
Refraction at a concave spherical surface

(i) The object lies in the rarer medium :

In fig. *APB* is a concave refracting surface separating two media of refractive indices μ_1 and μ_2.

Let *P* = Pole of the concave surface *APB*

C = Centre of curvature of the principal axis.



O = Point object placed on the principal axis.

I = Virtual image of point object O.

In ΔNOC, γ is an exterior angle, therefore

$$\gamma = \alpha + i \qquad \text{or} \qquad i = \gamma - \alpha$$

Similarly, from ΔNIC, we have

$$\gamma = \beta + r \qquad \text{or} \qquad r = \gamma - \beta$$

Suppose all the rays are paraxial. Then the angles i, r, α, β and γ will be small.

$$\therefore \quad \alpha \approx \tan\alpha = \frac{NM}{OM} = \frac{NM}{OP} \qquad [\because M \text{ is close to } P]$$

$$\beta \approx \tan\beta = \frac{NM}{IM} = \frac{NM}{IP} \qquad \text{and} \qquad \gamma \approx \tan\gamma = \frac{NM}{MC} = \frac{NM}{PC}$$

From Snell's law of refraction, $\dfrac{\sin i}{\sin r} = \dfrac{\mu_2}{\mu_1}$.

As i and i are small angles, therefore $\dfrac{i}{r} = \dfrac{\mu_2}{\mu_1}$ or $\mu_1 i = \mu_2 r$

$$\text{or} \quad \mu_1[\gamma - \alpha] = \mu_2[\gamma - \beta] \qquad \text{or} \quad \mu_1\left[\frac{NM}{CP} - \frac{NM}{OP}\right] = \mu_2\left[\frac{NM}{CP} - \frac{NM}{IP}\right]$$

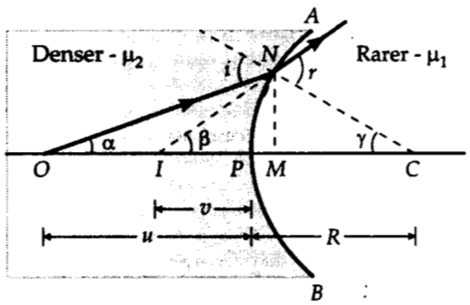
$$\text{or} \quad \mu_1\left[\frac{1}{CP} - \frac{1}{OP}\right] = \mu_2\left[\frac{1}{CP} - \frac{1}{IP}\right] \qquad \text{or} \quad -\frac{\mu_1}{OP} + \frac{\mu_2}{IP} = \frac{\mu_2 - \mu_1}{CP}$$

Using new Cartesian sign convention, we find

Object distance, $OP = -u$, Image distance $IP = -v$, Radius of curvature $CP = -R$

$$\therefore \quad \frac{-\mu_1}{-u} + \frac{\mu_2}{-v} = \frac{\mu_2 - \mu_1}{-R} \qquad \text{or} \qquad \frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$

(ii) The object lies in the denser medium : As shown in the figure, when the point object O is placed in the denser medium, the refracted rays appear to diverge from a point I in the denser medium. So I is the virtual image of the point object O.



From ΔNOC, $i = \alpha + \gamma$

From ΔNIC, $r = \beta + \gamma$

Suppose all the rays are paraxial.

Then the angles i, r, α, β and γ will be small.

$$\therefore \quad \alpha \approx \tan\alpha = \frac{NM}{OM} = \frac{NM}{OP} \qquad [\because M \text{ is close to } P]$$

$$\beta \approx \tan\beta = \frac{NM}{IM} = \frac{NM}{IP}$$

$$\text{and} \quad \gamma \approx \tan\gamma = \frac{NM}{MC} = \frac{NM}{PC}$$

From Snell's law of refraction, fro refraction from denser to rarer medium, we have $\dfrac{\sin i}{\sin r} = \dfrac{\mu_1}{\mu_2}$

As i and r small angles , so $\dfrac{i}{r} = \dfrac{\mu_1}{\mu_2}$ or $\mu_2 i = \mu_2 r$

$$\text{or} \qquad \mu_2[\alpha + \gamma] = \mu_1[\beta + \gamma]$$

or $$\mu_2\left[\frac{NM}{OP}+\frac{NM}{PC}\right]=\mu_1=\left[\frac{NM}{IP}+\frac{NM}{PC}\right]$$

or $$\mu_2\left[\frac{1}{OP}+\frac{1}{PC}\right]=\mu_1\left[\frac{1}{IP}+\frac{1}{PC}\right]$$

or $$-\frac{\mu_1}{IP}+\frac{\mu_2}{OP}=\frac{\mu_1-\mu_2}{PC}$$

Using new Cartesian sign convention, we find

Object distance, $OP=-u$

Image distance, $IP=-v$

Radius of curvature, $PC=+R$

Note :

- For both convex and concave spherical surfaces, the refraction formulae are same, only proper signs of u, v and R are to be used.
- For refraction from rarer to denser medium, the refraction formula is $\frac{\mu_2}{v}-\frac{\mu_1}{u}=\frac{\mu_2-\mu_1}{R}$. ...(1)
- For refraction from denser to rarer medium, we interchange μ_1 and μ_2 and obtain the refraction formula, $\frac{\mu_1}{v}-\frac{\mu_2}{u}=\frac{\mu_1-\mu_2}{R}$. ....(2)
- If the rarer medium is air $(\mu_1=1)$ and the denser medium has refractive index μ (i.e., $\mu_2 = \mu$), then fore refraction from rarer to denser medium, from (1) we get the relation : $\frac{\mu}{v}-\frac{1}{u}=\frac{\mu-1}{R}$ ....(3)

  For refraction from denser to rarer medium, we put $\mu_1/\mu_2=1/\mu$ in (2) and get the relation $\frac{1/\mu}{v}-\frac{1}{u}=\frac{(1/\mu)-1}{R}$
- For an object placed in air the refraction formula (3) is applicable, i.e., $\frac{\mu}{v}-\frac{1}{u}=\frac{\mu-1}{R}$. As R is positive for a convex surface v will be negative if the value of u is less than $R/(\mu-1)$. In that case, the image will be formed in air and will be virtual. As R is negative for a concave e surface, the value of v will also be negative for all negative values of u. Thus image will always be formed in air and will be virtual.
- The factor $\frac{\mu_2-\mu_1}{R}$ is called **power factor** of the spherical refracting surface. It gives a measure of the degree to which refracting surface can converge or diverge the rays of light passing through it.

Subjective Assignment –IV

1. Light from a point source in air falls on a convex spherical glass surface (μ = 1.5 radius of curvature = 20 cm). The distance of light source from the glass surface is 100cm. At what position is the image formed?
2. A glass dumbbell of length 30 cm and refractive index 1.5 has ends of 3 cm radius of curvature. Find the position of the image formed due to refraction at one end only, when the object is situated in air at a distance of 12 cm from the end of the dumbbell along the axis.
3. What curvature must be given to the bounding surface of μ = 1.5 for virtual image of an object in the medium of μ = 1 at 10 cm to be formed at a distance of 40 cm. Also calculate power of the surface and two principal focal lengths of the surface.

4. A small air bubble in a glass sphere of radius 2cm appears to be 1cm from the surface when looked at, along a diameter. If the refractive index of glass is 1.5, find the true position of the air bubble.

5. An empty spherical flask of diameter 15 cm is placed in water of refractive index $\frac{4}{3}$. A parallel beam of light strikes the flask. Where does it get focused, when observed from within the flask?

6. A sunshine recorder globe of 30cm diameter is made of glass of refractive index μ = 1.5. A ray enters the globe parallel to the axis. Find the position from the cnetre of the sphere where the ray crosses the axis.

7. A convex refracting surface of radius of curvature 20 cm separates two media of refractive indices 4/3 and 1.60. An object is placed in the first medium (μ = 4/3) at a distance of 200 cm from the refracting surface. Calculate the position of the image formed.

8. One end of a cylindrical rod is grounded to a hemispherical surface of radius R = 20 mm. It is immersed in water of refractive index 1.33. If the refractive index of the rod is 1.50, find the position of the image of an object placed on the axis of the rod, inside water at 10cm from the pole.

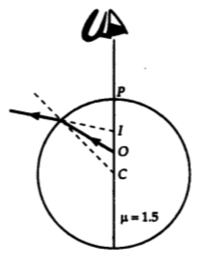
9. A concave spherical surface of refractive index 3/2 is immersed in water of refractive index 4/3. If a point object lies in water at a distance of 10 cm from the pole of the refracting surface, calculate the position of the image. Given that radius of curvature of the spherical surface is 18 cm.

10. A glass sphere of radius 15 cm has a small bubble a diameter of the sphere from the side on which it lies. How far from the surface will it appear to be if the refractive index of glass is 1.5?

11. An object is placed 50 cm from the surface of a glass sphere of radius 10 cm along the diameter. Where will the final image be formed after refraction at both the surfaces? μ of glass = 1.5.

12. A spherical surface of radius 30 cm separates two transparent media A and B with refractive indices 1.33 and 1.48 respectively. The medium A is on the convex side of the surface. Where should a point object be placed in medium A so that the paraxial rays becomes parallel after refraction at the surface?

13. Fig. shows a small air bubble inside a glass sphere (μ = 1.5) of radius 10 cm. The bubble is 4.0 cm below the surface and is viewed normally from the outside. Find the apparent depth of the bubble.



Answers

1.	+ 100 cm	2.	18 cm	3.	6.25 D , – 16 cm , 24 cm
4.	– 1.2 cm	5.	– 22.5 cm	6.	22.5 cm
7.	At 240 cm in denser medium	8.	Virtual image at 31.25 cm from pole and inside water		
9.	Virtual image at 10.52 cm from pole and inside the water				
10.	Virtual image is seen at 7.5 cm from the spherical surface				
11.	At 20 cm from the centre of the sphere.				
12.	At 266 cm from the pole.	13.	3 cm below the surface		

Lens Maker's Formula

This formula relates the focal length of a lens to the refractive index of the lens material and the radii of curvature of its two surfaces. This formula is so called because it is used by manufacturers to design lenses of required focal length from a glass of given refractive index.

New Cartesian sign convention for spherical lenses:

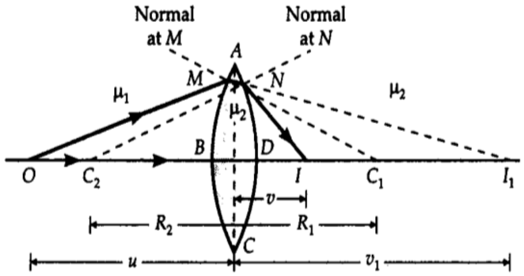
(i) All distances are measured from the optical centre of the lens.

(ii) The distances measured in the direction of incident light are positive.

(iii) The distances measured in the opposite direction of incident light are negative.

Len's maker's formula for a double convex lens

As shown in figure, consider a thin double convex lens of refractive index μ_2 placed in a medium of refractive index μ_1. Here $\mu_1 < \mu_2$. Let B and D be the poles , C_1 and C_2 be the centres of curvature, and R_1 and R_2 be the radii of curvature of the two lens surfaces ABC and ADC , respectively.



Suppose a point object O is placed on the principal axis in the rarer medium of refractive index μ_1. The ray OM is incident on the first surface ABC. It is refracted along MN, bending towards the normal at this surface. If the second surface ADC were absent, the ray MN would have met the principal axis at I_1. So, we can treat I_1 as the real image formed by first surface ABC in the medium of refractive index μ_2.

For refraction of surface ABC, we can write the relation between the object distance u, image distance v_1 and radius of curvature R_1 as

$$\frac{\mu_2}{v_1}-\frac{\mu_1}{u}=\frac{\mu_2-\mu_1}{R_1} \qquad ....(1)$$

But actually the ray MN suffers another refraction at surface ADC, bending away from the normal at point N. The emergent ray meets the principal axis at point I which is the final image of O formed by the lens. For refraction at second surface, I_1 acts as a virtual object placed in the medium of refractive index μ_2 and I is the real image formed in the medium of refractive index μ_1. Therefore, the relation between the object distance v_1, image distance v and radius of curvature R_2 can be written as $\frac{\mu_1}{v}-\frac{\mu_2}{v_2}=\frac{\mu_1-\mu_2}{R_2}$ ....(2)

Adding equations (1) and (2), we get

$$\frac{\mu_1}{v}-\frac{\mu_1}{u}=(\mu_2-\mu_1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$$

$$\frac{1}{v}-\frac{1}{u}=\left[\frac{\mu_2-\mu_1}{\mu_1}\right]\left[\frac{1}{R_1}-\frac{1}{R_2}\right] \qquad ... (3)$$

If the object is placed at infinity ($u = \infty$), the image will be formed at the focus, i.e., $v = f$. Therefore,

$$\frac{1}{f}=\left[\frac{\mu_2-\mu_1}{\mu_1}\right]\left[\frac{1}{R_1}-\frac{1}{R_2}\right] \qquad ... (4)$$

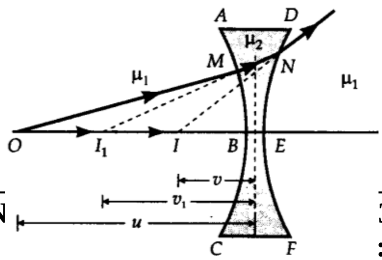
This is *lens marker's formula*. When the lens is placed in air, $\mu_1 = 1$, and $\mu_2 = \mu$. The lens maker's formula takes the form :

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

From equations (3) and (4), we have $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$.

This is the thin lens formula which gives relationship between u, v and f of a lens.

Lens maker's formula for a double concave lens : As shown in the fig. consider a thin double concave lens of refractive index μ_2 placed in a medium of refractive index μ_1. Here $\mu_1 < \mu_2$ B and E be the poles, and R_1 and R_2 be the radii of curvature of the two lens surfaces ABC and DEF, respectively. Suppose a point object O is placed on the principal axis in the rarer medium of refractive index μ_1. First the spherical surface ABC



forms its virtual image I_1. As refraction occurs from rarer to denser medium, so we can write the relation between object distance u, image distance v_1 and radius of curvature R_1 as

$$\frac{\mu_2}{v_1} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R_1} \quad \text{....(1)}$$

But the lens material is not continuous. The ray MN suffers another refraction at N and emerges along IN. So I is the final virtual image of the point object O. The image I_1 acts as an object for refraction at surface DEF from denser to rarer medium. So the relation between object distance v_1, image distance v and radius of curvature R_2 can be written as

$$\frac{\mu_1}{v} - \frac{\mu_2}{v_1} = \frac{\mu_1 - \mu_2}{R_2} \quad \text{....(2)}$$

Adding equations (1) and (2), we get

$$\frac{\mu_1}{v} - \frac{\mu_1}{u} = (\mu_2 - \mu_1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \quad \text{or} \quad \frac{1}{v} - \frac{1}{u} = \left[\frac{\mu_2 - \mu_1}{\mu_1}\right]\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

If an object is placed at infinity, then the image is formed at the focus i.e., $v = f$, so

$$\frac{1}{f} = \left[\frac{\mu_2 - \mu_1}{\mu_1}\right]\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

This is lens marker's formula.

when the lens is placed in air, $\mu_1 = 1$ and $\mu_2 = \mu$. The lens maker's formula takes the form :

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

Subjective Assignment – V

1. The radius of curvature of each face of biconcave lens, made of glass of refractive index 1.5 is 30 cm. Calculate the focal length of the lens in air.
2. The radii of curvature of the faces of a double convex lens are 10 cm and 15 cm. If focal length is 12 cm, what is the refractive index of glass?
3. A biconvex lens has a focal length half the radius of curvature of either surface. What is the refractive index of lens material?
4. The radii of curvature of a double convex lens of glass (μ = 1.5) are in the ratio 1 : 2. This lens renders the rays parallel coming from an illuminated filament at a distance of 6 cm. Calculate the radii of curvature of its surfaces.
5. Find the radius of curvature of the convex surface of a plano–convex lens, whose focal length is 0.3 m and the refractive index of the material of the lens is 1.5.
6. A convex lens of focal length 0.2 m and made of glass (μ = 1.50) is immersed in water (μ = 1.33).Find the change in the focal length of the lens.
7. The radii of curvature of a double convex lens are 10 cm and 20 cm respectively. Calculate its focal length when it is immersed in a liquid of refractive index 1.65. State the nature of the lens in the liquid. The refractive index of glass is 1.5
8. If the refractive index from air to glass is 3/2 and that from air to water is 4/3, find the ratio of focal lengths of a glass lens in water and in air.
9. A double convex lens has a focal length of 25 cm in air. When it is dipped into a liquid of refractive index 4/3, its focal length is increased to 100 cm. Find the refractive index of the lens material.

10. An equiconvex lens of focal length 15 cm is cut into two equal halves as shown in fig. What is the focal length of each half?
11. The focal length of a concavo–convex lens of radii of curvature 5 cm and 10 cm is 20 cm. What will be its focal length in water? Given ${}^{a}\mu_{w} = 4/3$.
12. A convex lens of focal length f and refractive index 1.5 is immersed in a liquid of refractive index (i) 1.6 (ii) 1.3 and (iii) 1.5.What changes happen to the focal length of the lens in the three cases?
13. The focal length of a plano–convex lens is 20 cm in air. Refractive index of glass is 1.5. Calculate (i) the radius of curvature of lens surface and (ii) its focal length when immersed in liquid of refractive index 1.6
14. The focal length of a glass convex lens in air is 15 cm. Calculate its focal length, when it is totally immersed in water. Given ${}^{a}\mu_{w} = 4/3$ and ${}^{a}\mu_{g} = 1.5$.
15. A diverging lens of refractive index 1.5 and of focal length 15 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.

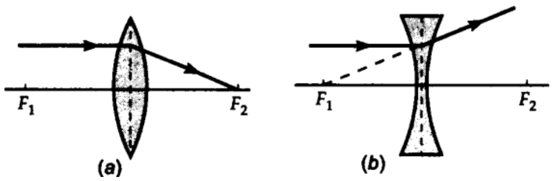
Answers

1.	– 30 cm	2.	$\mu = 1.5$	3.	2	4.	4.5 cm , – 9.0 cm
5.	0.15 m	6.	0.58 m	7.	– 73.33 cm	8.	4 : 1
9.	1.5	10.	30 cm	11.	– 80 cm		
12.	(i) – 8f (ii) + 3.25 f	(iii) ∞		13.	(i) – 10 cm	(ii) – 160 cm	
14.	60 cm	15.	– 63.75 cm				

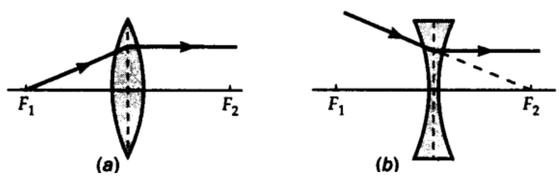
Rules for drawing images formed by spherical Lenses

The position of the image formed by any spherical lens can be found by considering any two of the following rays of light coming from a point on the object.

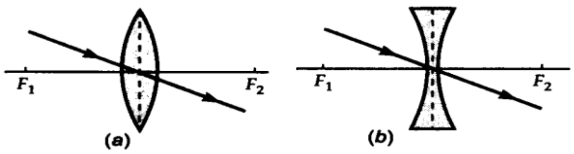
(i) A ray from the object parallel to the principal axis after refraction passes through the second principal focus F_2 [in a convex lens, as shown in fig. (a)] or appears to diverge [in a concave lens, as shown in fig. (b)] from the first principal focus F_1



(ii) A ray of light passing through the first principal focus [in a convex lens, as shown in figure (a) or appearing in meet at it[in a concave lens, as shown in fig. (b)] emerges parallel to the principal axis after refraction.



(iii) A ray of light, passing through the optical centre of the lens, emerges without any deviation after refraction, as shown in fig. (a) and (b).

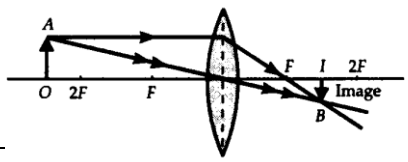


Formation of images by spherical lenses

(a) Object beyond 2F : The image is

(i) between F and 2F (ii) real

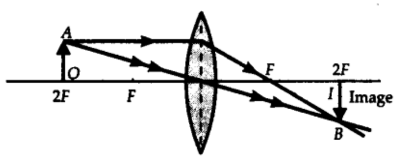
(iii) inverted (d) smaller



(b) Object at $2F$: The image is

(i) at $2F$ (ii) real

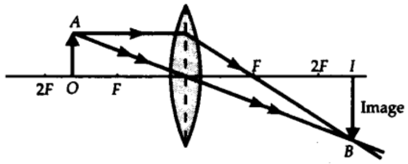
(iii) inverted (iv) same size



(c) Object between $2F$ and F : The image is

(i) beyond $2F$ (ii) real

(iii) inverted (iv) larger



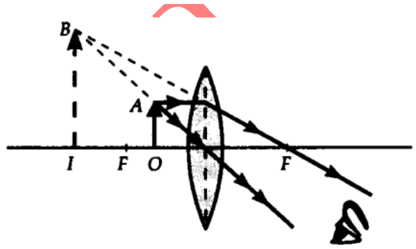
(d) Object between F and O : the image is

(i) behind object

(ii) virtual

(iii) erect

(iv) larger



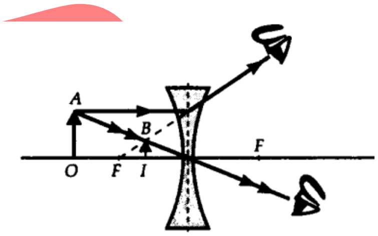
(e) Object in any position : The image is

(i) in front of object

(ii) virtual

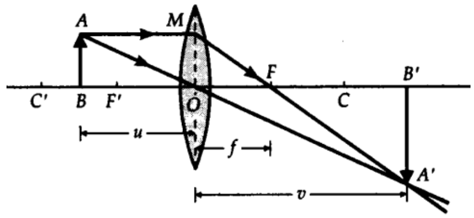
(iii) erect

(iv) smaller



Derivation of thin lens formula for a convex lens when it forms a real image

As shown in figure, consider an object AB placed perpendicular to the principal axis of a thin convex lens between its F' and C'. A real, inverted and magnified image $A'B'$ is formed beyond C on the other side of the lens.



$\Delta A'B'O$ and ΔABO are similar,

$\therefore \quad \dfrac{A'B'}{AB} = \dfrac{OB'}{BO}$ ....(1)

Also $\Delta A'B'F$ and ΔMOF are similar,

$\therefore \quad \dfrac{A'B'}{MO} = \dfrac{FB'}{OF}$

But $MO = AB$,

$\therefore \quad \dfrac{A'B'}{AB} = \dfrac{FB'}{OF}$ ....(2)

From (1) and (2), we get $\dfrac{OB'}{BO} = \dfrac{FB'}{OF} = \dfrac{OB' - OF}{OF}$

Using new Cartesian sign convention, we get

Object distance, $BO = -u$, Image distance, $OB' = +v$, Focal length, $OF = +f$

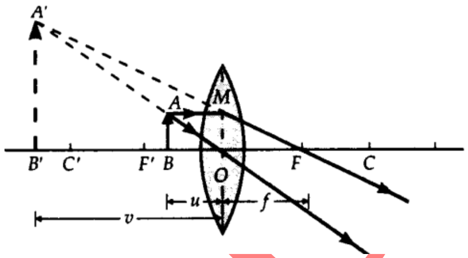
$\therefore \quad \dfrac{v}{-u} = \dfrac{v-f}{f}$ or $vf = -uv + uf$ or $uv = uf - vf$

Dividing both sides by *uvf*, we get $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$

This proves the lens formula for a convex lens when it forms a real image.

Derivation of thin lens formula for a convex lens when it forms a virtual image

As shown in the figure, when an object *AB* is placed between the optical centre *O* and the focus *F* of a convex lens, the image *A′B′* formed by the convex lens is virtual, erect and magnified.



Triangles *A′B′O* and *ABO* are similar.

$$\frac{A'B'}{AB}=\frac{B'O}{BO} \quad ....(1)$$

Also, triangles $A'B'F$ and MOF are similar.

$$\therefore \quad \frac{A'B'}{AB}=\frac{B'F}{OF}$$

But *MO* = *AB*, therefore $\frac{A'B'}{AB}=\frac{B'F}{OF} \quad ....(2)$

From (1) and (2), we get $\frac{B'O}{BO}=\frac{B'F}{OF}=\frac{B'O+OF}{OF}$

Using new Cartesian sign convention, $BO=-u,\ B'O=-v,\ OF=+f$

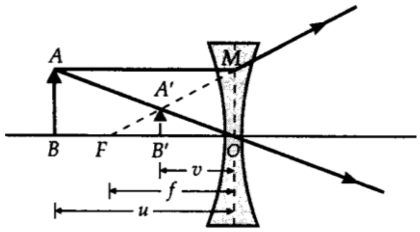
$$\therefore \quad \frac{-v}{-u}=\frac{-v+f}{f} \quad \text{or} \quad -vf=uv-uf \quad \text{or} \quad uv=uf-vf$$

Dividing both sides by *uvf*, we get $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$

This proves the thin lens formula for a convex lens when it forms a virtual image.

Derivation of thin lens formula for a concave lens

As shown in figure, suppose *O* be the optical centre and *F* be the principal focus of concave lens of focal length *f*. *AB* is an object placed perpendicular to its principal axis. A virtual, erect and diminished image *A′B′* is formed due to refraction through the lens.



As $\quad \Delta A'B'O \sim \Delta ABO$

$$\therefore \quad \frac{A'B'}{AB}=\frac{B'O}{BO} \quad ....(1)$$

Also, $\quad \Delta A'B'F \sim \Delta MOF$

$$\therefore \quad \frac{A'B'}{MO}=\frac{FB'}{FO}$$

But *MO* = *AB*, therefore $\frac{A'B'}{AB}=\frac{FB'}{FO} \quad ....(2)$

From (1) and (2), we get $\frac{B'O}{BO}=\frac{FB'}{FO}=\frac{FO-B'O}{FO}$

Using new Cartesian sign convention, we get

$$BO=-u,\ B'O=-v,\ FO=-f$$

$$\therefore \qquad \frac{-v}{-u}=\frac{-f+v}{-f} \quad \text{or} \quad uf=uf-uv \quad \text{or} \quad uv=uf-vf$$

Dividing both sides by *uvf*, we get $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$.

This proves the thin lens formula for a concave lens.

Linear Magnification

The linear magnification produced by a lens is defined as the ratio of the size of the image formed by the lens to the size of the object. It is denoted by *m*. Thus

$$m=\frac{\text{Size of image}}{\text{Size of object}}=\frac{h_2}{h_1}$$

$\therefore$ Magnification, $m=\frac{h_2}{h_1}=\frac{v}{u}$.

Linear magnification in terms of *u* and *f* : The thin lens formula is $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$.

Multiplying both sides by *u*, we get $\frac{u}{v}-1=\frac{u}{f}$ or $\frac{u}{v}=1+\frac{u}{f}=\frac{f+u}{f}$

$$\therefore \qquad m=\frac{v}{u}=\frac{f}{f+u}$$

Linear magnification in terms of *v* and *f* : The thin lens formula is $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$.

Multiplying both sides by *v*, we get $1-\frac{v}{u}=\frac{v}{f}$ $\quad\therefore\quad$ $m=\frac{v}{u}=1-\frac{v}{f}=\frac{f-v}{f}$

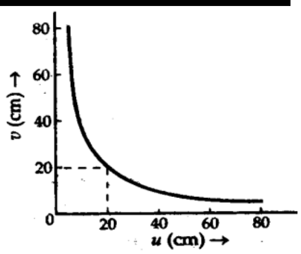
Hence $m=\frac{v}{u}=\frac{f}{f+u}=\frac{f-v}{f}$.

Note :

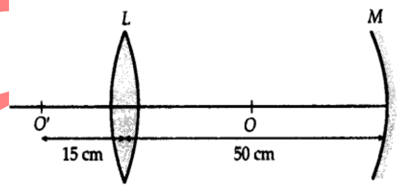
- The same thin lens formula is valid for both convex and concave lenses and for both real and virtual images.
- When $|m|>1$, the image is magnified.
- When $|m|<1$, the image is diminished.
- When $|m|=1$, the image is of the same size as the object.
- When *m* is positive (or *v* is negative), the image is virtual and erect.
- When *m* is negative (or *v* is positive), the image is real and inverted.

Subjective Assignment – VI

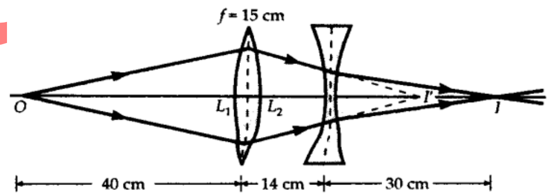
1. A lens forms a real image of an object. The distance of the object to the lens is *u* cm and the distance of the image from the lens is *v* cm. The given graph shows the variation of *v* and *u*. (i) What is the nature of the lens? (ii) Using this graph, find the focal length of this lens.



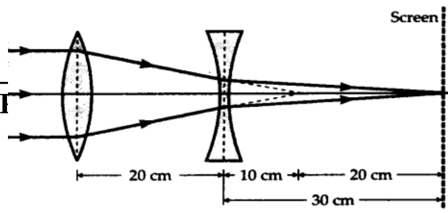
2. A needle placed 45cm from a lens forms an image on a screen placed 90 cm on the other side of the lens. Identify the type of the lens and determine its focal length. What is the size of image if the size of the needle is 5.0 cm?
3. A convergent beam of light passes through a diverging lens of focal length 0.2m and comes to focus at distance 0.3m behind the lens. Find the position of the point at which the beam would converge in the absence of the lens.
4. A needle 10cm long is placed along the axis of a convex lens of focal length 10cm such that the middle point of the needle is a distance of 20cm from the lens. Find the length of the image of the needle.
5. A double convex lens has 10cm and 15 cm as its two radii of curvatures. The image of an object placed 30 cm from the lens, is formed at 20cm from the lens on the other side. Find the refractive index of the material of the lens. What will be the focal length of the lens, if it is immersed in water of refractive index 1.33 cm?
6. An illuminated object and a screen are placed 90 cm apart. What is the focal length and nature of the lens required to produce a clear image on the screen, twice the size of the object?
7. The image obtained with a convex lens is erect and its length is four times the length of the object. If the focal length of the lens is 20cm , calculate the object and image distances.
8. An illuminated object and a screen are placed on an optical bench and a converging lens is placed between them to throw a sharp image of the object on the screen, the linear magnification of the image is found to be 2.5. The lens is now moved 30cm nearer the screen and a sharp image is again formed. Calculate the focal length of the lens.
9. In the accompanying diagram, the direct image formed by the lens (f = 10 cm) of an object placed at O and that formed after reflection from the spherical mirror are formed at the same point O'. What is the radius of curvature of the mirror?



10. In the following ray diagram are given the positions of an object O, image I and two lenses L_1 and L_2. The focal length of L_1 is also given. Find the focal length of L_2.

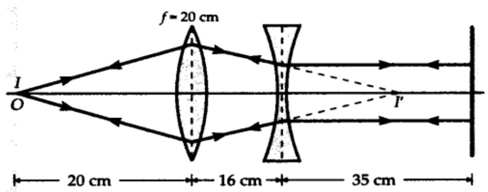


11. A convex lens of focal length 10 cm is placed coaxially 5cm away from a concave lens of focal length 10cm. If an object is placed 30 cm in front of the convex lens, find the position of the final image formed by the combined system.
12. A convex lens is placed on an optical bench and is moved till it gives a real image of an object at a minimum distance of 80 cm from the latter. Find the focal length of the lens. If the object is placed at a distance of 15 cm from the lens, find the position of the image.
13. A convex lens of focal length 30 cm is placed between a screen and a square plate of area 4 cm^2. The image of the plate formed on the screen is 16 cm^2. Calculate the distance between the plate and the screen.
14. The image of a needle placed 45 cm from a lens is formed on a screen placed 90 cm on the other side of the lens. Find the displacement of the image, if the object is moved by 5.0 cm away from the lens.
15. A screen is placed 80 cm from an object. The image of the object on the screen is formed by a convex lens at two different locations, separated by 10 cm. Calculate the focal length of the lens used.



16. In the figure as shown , rays are coming from infinity and after passing through both the lenses meet on a screen placed at a distance of 30 cm from the concave lens. Calculate the focal length of the concave lens.

17. In the following ray-diagram are shown the positions of the object O, image I, two lenses and a plane mirror. The focal length of one of the lenses is also given. Calculate the focal length of the other lens.

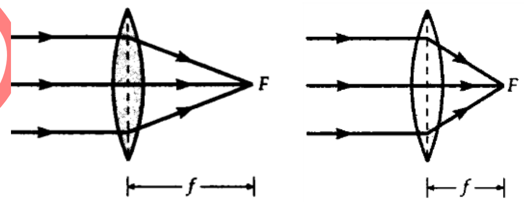


Answers

1.	+ 10 cm	2.	+ 30cm , – 10 cm	3.	+ 0.12 m
4.	13.33 cm	5.	1.5, 46.94 cm	6.	20 cm
7.	– 15 cm , – 60 cm	8.	14.3 cm	9.	20 cm
10.	– 15 cm	11.	∞		
12.	f = 20cm, virtual and erect image at 60 cm from the lens on the same side as the object				
13.	135 cm	14.	15, towards the lens	15.	19.7 cm
16.	15 cm	17.	20 cm		

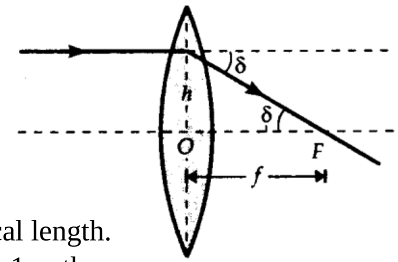
Power of a lens

The power of a lens is a measure of the degree of convergence or divergence of the light rays falling on it. Smaller the focal length of a lens, more is ability to bend light rays and greater is its power.



The power of a lens is defined as the tangent of the angle by which it converges or diverges a beam of light falling at unit distance from the optical centre.

A beam of light is incident at distance h from the optical centre O of a convex lens of focal length f. It converges the beam by angle is δ.



Clearly , $\tan\delta = \dfrac{h}{f}$

If h = 1, then $\tan\delta = \dfrac{h}{f}$ or $\boxed{P = \dfrac{1}{f}}$

Thus the power of a lens may also be defined as the reciprocal of its focal length.

SI unit of power : The SI unit of power is **dioptre**, denoted by D. If f = 1m, then

$$P = \frac{1}{1m} = 1m^{-1} = 1\text{dioptre}(\text{D})$$

One **dioptre** is the power of a lens whose principal focal length is 1 metre.

The focal length of a converging lens is positive and that of a diverging lens is negative. Thus, the power of a converging lens is positive and that of a diverging lens is negative. The power of a lens is measured by **dioptremeter**.

By using lens maker' formula, the power of a lens can be expressed in terms of its refractive index μ and radii of curvature R_1 and R_2 as follows :

$$\boxed{P=\frac{1}{f}(\mu-1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]}.$$

As the power of a lens is reciprocal of its focal length, so it characterizes the focal properties of the lens, such as nature, size and position of image, etc.

Combination of thin lenses

In many optical instruments, two or more lenses are used either in contact or with a gap between them. The purpose of using a lens combination is

(i) To magnify an image.

(ii) To increase the sharpness of the final image by minimizing certain defects or aberrations in it.

(iii) To erect the final image.

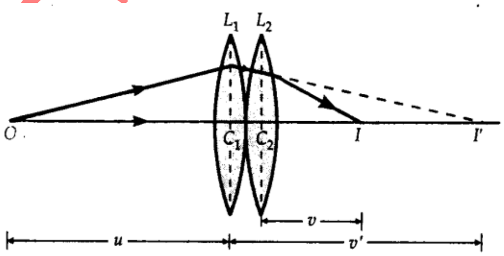
(iv) To increase the field of view.

Total magnification : When lenses are used in combination, each lens magnifies the image formed by the preceding lens. Hence the total magnification m is equal to the product of the magnifications m_1, m_2 and m_3...., produced by the individual lenses.

$$\boxed{m=m_1\times m_2\times m_3\times.......}$$

Equivalent lens : A single lens which forms the image of an object at the same position as is formed by a combination of lenses is called an equivalent lens.

Equivalent focal length and power of two thin lenses in contact : As shown in the fig., let L_1 and L_2 be two thin lenses of focal length f_1 and f_2 respectively, placed coaxially in contact with one another. Let O be a point object on the principal axis of the lens system.



Let $OC_1=u$. In the absence of second lens L_2, the first lens L_1 will form a real image I' of O at distance $C_1I'=v'$.

Using thin lens formula, $$\frac{1}{f_1}=\frac{1}{v'}-\frac{1}{u} \qquad ....(1)$$

The image I' acts as a virtual object $(u=v')$ for the second lens L_2 which finally forms its real image I at distance v. Thus, $$\frac{1}{f_2}=\frac{1}{v}-\frac{1}{v'} \qquad ....(2)$$

Adding equations (1) and (2), we get $$\frac{1}{f_1}+\frac{1}{f_2}=\frac{1}{v}-\frac{1}{u}. \qquad ....(3)$$

For the combination of thin lenses in contact, if f is the equivalent focal length, then

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f} \qquad ....(4)$$

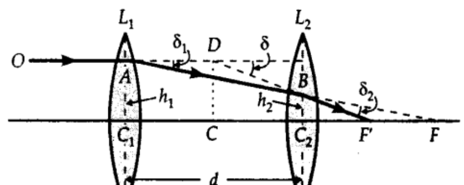
From equations (3) and (4), we find that

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

$\therefore$ Equivalent power, $$\boxed{p=p_1+p_2}$$

Fro n thin lenses in contact, we have $$\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}+\frac{1}{f_3}+......\frac{1}{f_n}$$

$\therefore$ Equivalent power, $$P=P_1+P_2+P_3+......+P_n$$



Thin lenses separated by a small distance : As shown in figure, consider two thin lenses L_1 and L_2 of focal lengths f_1 and f_2, respectively. The two lenses are placed coaxially, distance '*d*' apart. Suppose a ray *OA* traversing parallel to the principal axis is incident on lens L_1. It is refracted along *AF*, *F* being the second principal focus of L_1. The deviation produced by L_1 is

$$\delta_1 \approx \tan\delta_1 = \frac{h_1}{f_1}$$

The emergent ray is further refracted by second lens L_2 along BF'. Since the incident ray *OA* is parallel to the principal axis, F' should be second principal focus of the combination. The deviation produced by the second lens L_2 is

$$\delta_2 \approx \tan\delta_2 = \frac{h_2}{f_2}$$

The final emergent ray BF', when produced backwards, meets the incident ray at point *D*. Obviously, δ is the final deviation produced. A single thin lens placed at *C* will produce the same deviation as by the combination of two lenses. Thus distance CF' is the second focal length of the combination. If f is the focal length of the combination, then $\delta = \frac{h_1}{f}$

It is obvious from fig. that $\delta = \delta_1 + \delta_2$

$$\therefore \quad \frac{h_1}{f} = \frac{h_1}{f_1} + \frac{h_2}{f_2} \quad \text{... (1)}$$

As $\Delta AC_1F \sim \Delta BC_2F$, therefore, we have

$$\frac{AC_1}{C_1F} = \frac{BC_2}{C_2F} \quad \text{or} \quad \frac{h_1}{f_1} = \frac{h_2}{f_1 - d} \quad \text{or} \quad h_2 = \frac{f_1 - d}{f_1} \cdot h_1 \quad \text{.... (2)}$$

Using equation (2) in equation (1), we get $\frac{h_1}{f} = \frac{h_1}{f_1} + \frac{f_1 - d}{f_1 f_2} \cdot h_1$ or $\boxed{\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}}$

In terms of powers of the lenses $\boxed{P = P_1 + P_2 - d \cdot P_1 \cdot P_2}$.

Subjective Assignment – VII

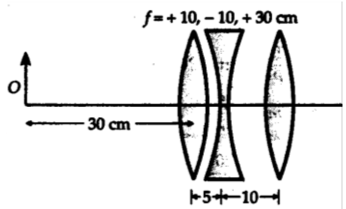
1. If the power of a lens is +5 dioptre, what is the focal length and nature of the lens?
2. The radius of curvature of each surface of a convex lens of refractive index 1.5 is 40cm. Calculate its power.
3. A convex lens is made of glass of refractive index 1.5. If the radius of curvature of the each of the two surfaces is 20 cm, find the ratio of the powers of the lens, when placed in air to its power, when immersed in a liquid of refractive index 1.25
4. (i) If f = + 0.5m, what is the power of the lens? (ii) The radii of curvature of the faces of a double convex lens are 10 cm and 15 cm. Its focal length is 12cm. What is the refractive index of glass? (iii) A convex lens has 20 cm focal length in air. What is focal length in water? (Refractive index of air–water = 1.33, refractive index for air-glass = 1.5).
5. Two thin lenses of focal lengths + 10cm and – 5 cm are kept in contact. What is the (i) focal length and (ii) power of the combination?
6. Two lenses of powers +15 D and – 5D are in contact with each other forming a combination lens.
   (a) What is the focal length of this combination?
   (b) An object of size 3 cm is placed at 30 cm from this combination of lenses. Calculate the position and size of the image formed.

7. A glass convex lens has a power of +10D. When this lens is totally immersed in a liquid, it acts as a concave lens of focal length 50cm. Calculate the refractive index of the liquid. Given ${}^{a}\mu_g = 1.5$.

8. A real image is formed by the lens at a distance of 20cm from the lens. The image shifts towards the combination by 10cm when a second lens is brought in contact with the first lens. Determine the power of the second lens.

9. An object is situated at 20 cm on the left of a convex lens of focal length 10cm. Another convex lens of focal length 12.5 cm is placed at a distance of 30 cm on the right of the first lens. Find the position and magnification of the final image. State also the nature of the image.

10. Find the position of the image formed by the lens combination given in figure.



11. Two lenses of powers 10 D and – 5 D are placed in contact.
(i) Calculate the power of the new lens.
(ii) Where should an object be held from the lens, so as to obtain a virtual image of magnification 2?

12. The power of a thin convex lens of glass is 5 D. When it is immersed in a liquid of refractive index μ, it behaves like a divergent lens of focal length 1 m. Calculate μ of liquid, if μ of glass =3/2.

13. A compound lens is made of two lenses having powers + 15.5D and — 5.5D. An object of 3 cm height is placed at a distance of 30 cm from this compound lens. Find the size of the image.

14. Rays coming from an object situated at infinity, fall on a convex lens and an image is formed at a distance of 16 cm from the lens. When a concave lens is kept in contact with the convex lens, the image is formed at a distance of 20 cm from the lens combination. Calculate the focal length of the concave lens.

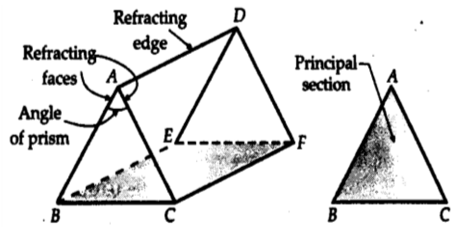
15. An equiconvex lens, with radii of curvature of magnitude 20 cm each, is put over a liquid layer poured on top of a plane mirror. A small needle, with its tip on the principal axis of the lens, is moved along the axis until its inverted real image coincides with the needle itself. The distance of the needle, from the lens, is measured to be 30 cm. On removing the liquid layer, and repeating the experiment, the distance is measured to be 20 cm. Given that the two values of the distance measured represent the focal length values in the two cases, calculate the refractive index of the liquid.

Answers

1.	+ 20 cm	2.	2.5 D	3.	5D , 2D , 5 : 2		
4.	(i) + 2D , (ii) 1.5 (iii) 78.2 cm	5.	– 10 cm, – 10 D				
6.	(a) 10 cm , – 1.5 cm , 15 cm (real)	7.	1.67	8.	0.5 D		
9.	50 cm, virtual, 5	10.	30 cm	11.	(i) 5D (ii) – 10 cm		
12.	5/3	13.	– 1.5 cm	14.	– 80 cm	15.	1.33

Prism

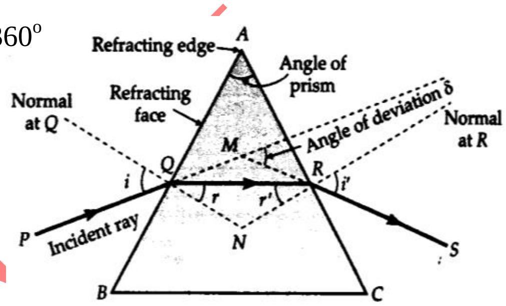
A prism is a wedge shaped portion of a transparent refracting medium bounded by two plane faces inclined to each other at a certain angle. The two plane faces (*ABCD* and *ACFD*) inclined to each other are called **refracting faces** of the prism.



The line (*AD*) along with the two refracting faces meet is called the **refracting edge** of the prism. The third face (*BCFE*) of the prism opposite to the refracting edge is called the **base** of the prism. The angle A included between the two refracting faces is called **angle of the prism.**

Refraction though a Prism

Deviation produced by a prism : In the fig. let *ABC* represent the principal section of prism. A ray *PQ* is incident on face *AB*. As it enters the denser medium (glass), it bends towards the normal along path *QR*. The ray *QR* suffers another refraction at face *AC*; bending away from the normal, it emerges along *RS*. The angle of deviation δ is the angle between the incident ray and the emergent ray. Let *i* and *r* be the angles of incidence and refraction at the face *AB*, and *r′* and *i′* be angles of incidence and emergence at the face *AC*. Let A be the angle of the prism.



From the quadrilateral *AQNR*, $A + \angle AQN + \angle QNR + \angle NRA = 360^o$

$$A + 90^o + \angle QNR + 90^o = 360^o$$

Since $\angle AQN = \angle LNRA = 90^o$

$\therefore \quad A + \angle QNR = 180°$

From the triangle, *QNR*, $r + r' + \angle QNR = 180°$

$\therefore \quad A = r + r'$

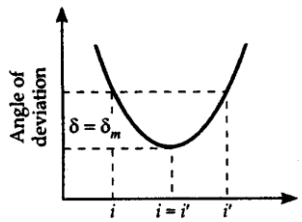
Now, from the triangle *MQR*, the deviation produced by the prism is

$$\delta = \angle MQR + \angle MRQ = (i - r) + (i' - r')$$

or $\delta =$ deviation at the first face + deviation at the second face

$$= (i + i') - (r + r')$$

or $\boxed{\delta = i + i' - A}$ or $\boxed{i + i' = A + \delta}$



Factors on which the angle of deviation depends :

(i) The angle of incidence. (ii) The material of the prism.

(iii) The wavelength of light used. (iv) The angle of the prism.

The minimum value of the angle of deviation suffered by a ray on passing through a prism is called The angle of minimum deviation and is denoted by δ_m.

Relation between refractive index and angle of minimum deviation : When a prism is in the position of minimum deviation, a ray of light passes symmetrically (parallel to the base) through the prism so that

$$i = i', \ r = r', \ \delta = \delta_m$$

As $A + \delta = i + i'$

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

Also, $A = r + r' = r + r = 2r$, so $r = \dfrac{A}{2}$

From Snell's law, the refractive index of the material of the prism will be

$$\mu = \frac{\sin i}{\sin r} \quad \text{or} \quad \boxed{\mu = \frac{\sin \frac{A + \delta_m}{2}}{\sin \frac{A}{2}}}$$

Deviation Through a prism of small angle :

As shown in figure. For refraction at face *AB*, we have, $\mu = \dfrac{\sin i}{\sin r}$

Suppose the light is incident at a small angle *i* on the prism, then *r* will also be small.

$$\sin i = i \qquad \text{and} \qquad \sin r \approx r$$

$$\therefore \qquad \mu = \frac{i}{r} \qquad \text{or} \qquad i = \mu r$$

If the angle of the prism is small, then angles r' and i' for the refraction at face AC will also be small. We can write

$$\mu = \frac{\sin i'}{\sin r'} = \frac{i'}{r'} \qquad \text{or} \qquad i' = \mu r'$$

Hence deviation produced by the prism is

$$\delta = i + i' - A = \mu r + \mu r' - A$$

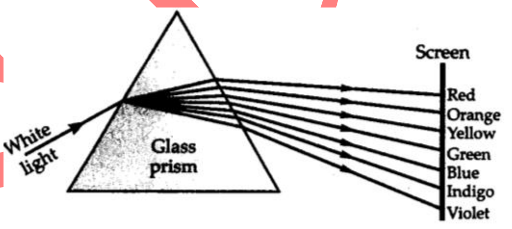
$$= \mu(r + r') - A = \mu A - A \qquad [\because r + r' = A]$$

or $$\boxed{\delta = (\mu - 1)A}$$

Clearly, the deviation produced by a small angled prism does not depend on the angle of incidence. It depends on the angle of the prism and the refractive index of its material.

Dispersion of white light

When a narrow beam of sunlight is incident on a glass prism, the emergent light when made to fall on a screen shows several coloured bands. Broadly, the component colours are in the sequence: violet , indigo, blue, green, yellow, orange and red (given by the acronym **Vibgyor**). The red colour bends the least and the violet colour bends the most, as shown in figure.



The phenomenon of splitting of white light into its component colours on passing through a refracting medium is called **dispersion of light.** The pattern of the coloured bonds obtained on the screen is called **spectrum.**

Cause of dispersion : Each colour of light is associated with a definite wavelength. In the visible spectrum, red light is at the long wavelength end (~ 400 nm). Dispersion takes place because the refractive index of the refracting medium is different for different wavelengths. The refractive index μ of a material for wavelength λ is given by the Cauchy's relation.

$$\mu = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4}$$

where a, b and c are constants, the values of which depend on the nature of the material. Also, for a small-angled prism, the angle of deviation of given by $\delta = A(\mu - 1)$.

Now, $\lambda_{red} > \lambda_{violet}$

$\therefore$ $\mu_{red} < \mu_{violet}$, and hence $\delta_{red} < \delta_{violet}$

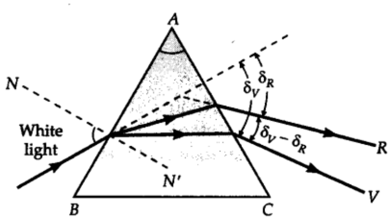
Thus the red colour is deviated the least and the violet is deviated the most. Other colours are deviated by angles between $\delta_{red} < \delta_{violet}$.

Dispersive media : In some refracting media, different colours of light travel with different speeds. The variation of refractive index with wavelength is highly pronounced for such media. These media which bring about a good dispersion of white light are called dispersive media. For example, glass, quartz, etc.

Non-dispersive media. In vacuum, all colours of light travel with the same speed. So the refractive index of vacuum is independent of wavelength. White light does not undergo dispersion in vacuum. Such a medium is called a non-dispersive medium.

Angular Dispersion and dispersive power

When a beam of white light passes through a prism, it gets dispersed into its constituent



colours. Let δ_V, δ_R and δ be the angles of deviation for violet, red and yellow (mean) colours respectively, as shown in figure.

Then $\delta_V = (\mu_V - 1)\, A, \quad \delta_R = (\mu_R - 1)\, A$

$\delta = (\mu - 1)\, A$ where μ_V, μ_R and μ are the refractive indices of the prism material for violet, red and yellow means colours, respectively.

The angular separation between the two extreme colours (violet and red) in the spectrum is called the angular dispersion.

$\therefore$ Angular dispersion $= \delta_V - \delta_R = (\mu_V - 1)\, A - (\mu_R - 1)\, A = (\mu_V - \mu_R)\, A$

Clearly, the angular dispersion produced by a prism depends upon (i) angle of the prism and (ii) nature of the material of the prism.

Dispersive power is the ability of the prism material to cause dispersion. It is defined as the ratio of the angular dispersion to the mean deviation.

$\therefore$ Dispersive power, $$\omega = \frac{\text{Angular dispersion}}{\text{Mean deviation}} = \frac{\delta_V - \delta_R}{\delta} = \frac{(\mu_V - 1)\, A - (\mu_R - 1)\, A}{(\mu - 1)\, A}$$

or $$\omega = \frac{\mu_V - \mu_R}{\mu - 1}.$$

NOTE

- The refractive index (μ) of any material for yellow light is equal to the mean of the refractive indices for the violet and red lights, i.e.,]

$$\mu = \frac{\mu_V + \mu_R}{2}$$

That is why yellow light is called ***mean light*** and its deviation is called ***mean deviation,*** which is given by

$$\delta = \frac{\delta_V + \delta_R}{1}$$

- Due to its small wavelength, violet light is harmful to our eyes. So in experiments, angular dispersion and dispersive power of a material are measured for *blue* and *red* lights. Thus

$$\omega = \frac{\mu_B - \mu_R}{\mu - 1}$$

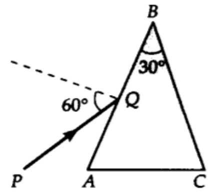
- The dispersive power depends on the nature of the material of the prism and not on its refracting angle, A. However, both angular dispersion and mean derivation also depend on the angle of the prism.
- Greater the dispersive power of a material, larger is the spread of a spectrum produced by the prism of the material.
- Dispersive power of flint glass is more than that of crown glass.

Subjective Assignment – VIII

1. Calculate the refractive index of the material of an equilateral prism for which the angle of minimum deviation is 60^o.
2. A ray of light passes through an equilateral glass prism, such that the angle of incidence is equal to the angle of emergence. If the angle of emergence is 3/4 times the angle of the prism, calculate the refractive index of the glass prism.

3. A ray of light suffers minimum deviation, while passing through a prism of refractive index 1.5 and refracting angle 60^o. Calculate the angle of deviation and angle of incidence.

4. A ray of light *PQ* is incident at angle of 60^o on the face *AB* of a prism of angle 30^o, as shown in fig. (a). The ray emerging out of the prism makes an angle of 30^o with the incident ray. Show that the emergent ray is perpendicular to the face *BC* through which it emerges. Also calculate the refractive index of the prism material.



5. A glass prism of refracting angle 60^o and refractive index 1.5, is completely immersed in water of refractive index 1.33. Calculate the angle of minimum deviation of the prism in this situation. $(\sin^{-1} 0.56 = 34.3°)$.

6. One face of a prism of refracting angle 30^o and refractive index 1.414 is silvered. At what angle must a ray of light fall on the unsilvered face so that after refraction into the prism and reflection at the silvered surface it retrace its path?

7. Find the angle of dispersion between red and violet colours produced by a flint glass prism of refracting angle 60^o. Refractive indices of prism for red and violet colours are 1.622 and 1.663, respectively.

8. A thin prism of refracting angle 2^o deviates an incident ray through an angle of 1^o. find the value of refractive index of the material of the prism.

9. A prism with refracting angle of 60^o, gives angle of minimum deviation, 53^o, 51^o and 52^o for blue, red and yellow light respectively. What is the dispersive power of the material of the prism?

10. Refractive indices of flint glass for blue & red colours are 1.664 and 1.644. Calculate its dispersive power

11. A glass prism deviates the red and the blue rays through 10^o and 12^o, respectively. A second prism of equal angle deviates them through 8^o and 10^o respectively. Find the ratio of their dispersive powers.

12. Using a spectrometer, the following data are obtained for a crown glass prism and a flint glass prism:
    Crown glass prism : $A = 72.0°$
    Minimum deviation angle : $\delta_B = 54.6°$, $\delta_R = 53.0°$, $\delta_Y = 54.0°$
    Flint glass prism : $A = 60.0°$, $\delta_B = 52.8°$, $\delta_R = 50.6°$, $\delta_Y = 51.9°$
    Compare the dispersive powers of the two varieties of glass prisms.

13. A ray of light strikes one face of the prism at an angle of incidence 60^o and angle of refraction is 30^o. If the angle of prism is 60^o, find the angle of emergence.

14. A ray of light falls normally on the face of a glass prism having refractive index of 1.5. Find the angle of prism, if the ray just fails to emerge from the second face.

15. A thin prism of 6^o angle gives a deviation of 3^o. What is the refractive index of the material of the prism?

16. Once face of a prism with a refracting angle of 30^o is coated with silver. A ray incident an another face at an angle of 45^o is refracted and reflected from the silver coated face and retraces its path. Find the refractive index of the material of the prism.

17. Find the angle of flint glass prism which produces the same angular dispersion for *C* and *F* wavelengths in 10^o crown glass prism.
    For crown glass : $\mu_F = 1.5230$, $\mu_C = 1.5145$
    For flint glass : $\mu_f = 1.6637$, $\mu_C = 1.6444$

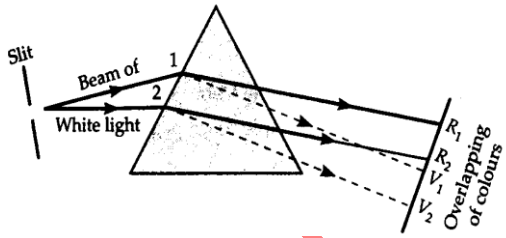
Answers

1.	$\sqrt{3}$	2.	1.414	3.	48.6^o, 37.2^o
4.	$\sqrt{3}$	5.	8.6^o	6.	45^o
7.	2.46^o	8.	1.5	9.	0.038

10.	0.0305	11.	9 : 11	12.	0.0213, 0.0335, 1.57
13.	60^o	14.	41.8^o	15.	1.5
16.	1.414	17.	4.4^o		

Pure and Impure Spectra

Monochromatic and polychromatic lights : A light of single wavelength is called monochromatic light. The commonly used source of monochromatic light is sodium lamp which emits yellow light of two wavelengths 5890 Å and 5896 Å As the two wavelengths are very close, so sodium lamp can be regarded as a source of monochromatic light of mean wavelength 5893 Å.



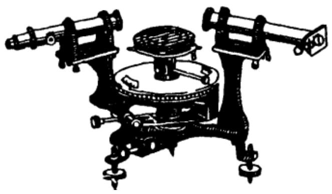
Generally, the sources of light are ***polychromatic*** *which give light of several wavelengths.*

Pure and impure spectra : A spectrum in which the component colours of the spectra of different rays overlap each other and the various colours are not distinctly seen is called **impure spectrum**. On the other hand, a spectrum in which three in no overlapping of different colours and different colours are distinctly seen is called the ***pure spectrum.***

Spectrometer

It is an optical device used for producing and studying the spectra of different light sources.

Construction : A spectrometer has three main parts.



1. Collimator : It produces a parallel beam of light. It consists of two co–axial metal tubes. The outer tube is mounted horizontally and carries a convex lens L_1 at its free end. The inner tube has an adjustable vertical slits at the free end and can be slided inside the outer tube by a rack and pinion arrangement. The slit is adjusted in the focal plane of lens L_1. When a light source is kept in front of the slit, a parallel beam of light emerges from the collimator.

2. Prism table : It is a circular horizontal plate on which the prism is placed. It can be adjusted at a desired height with the help of a clamping screw. It can be rotated about a vertical axis. Its position can be noted with the help of the venires V_1 and V_2 attached to it and moving over a graduated circular scale carried by the telescope.

3. Telescope : It is used for observing the spectrum. It is mounted horizontally on a vertical arm attached to the main circular scale. It can be rotated about the same vertical axis about which the prism table rotates. Its position can be noted on the circular scale by the vernier's V_1 and V_2. A cross-wire is fixed at the focus of the eyepiece.

Working: For getting a pure spectrum, the following adjustments are made in a spectrometer:

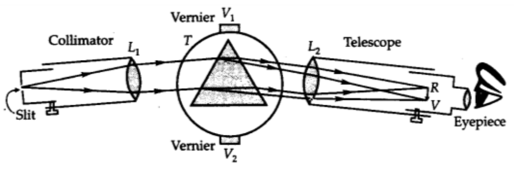
1. Focussing the eyepiece: The eyepiece of the telescope is moved in and out so that the cross-wires are clearly visible.

2. Focussing the telescope for parallel rays : The telescope is turned towards a distant object. The distance between the eyepiece and the object is so adjusted that object becomes clearly visible. This sets the telescope for receiving the parallel rays.

3. Focussing the collimator for parallel rays : Illuminate the slit with a bright source and view it through the telescope. Adjust the distance between the slit and the collimator lens till a clear image of the slit is seen. This sets the collimator to provide a parallel beam of light.

4. Setting the prism : The prism is placed at the centre of the prism table. The prism table is rotated so that light from the collimator falls on refracting face *AB* and after refraction emerges from the other face *AC*. The prism causes dispersion. They rays of a given colour emerge parallel to each other. They are received by the telescope.

All red rays are focused at *R*, all violet rays at *V* and rays of other colours in between and a spectrum *RV* is formed in the focal plane of the objective, as shown in fig. A magnified spectrum is viewed through the eyepiece.



5. **To get rid of overlapping of colours :** The prism is set in the minimum deviation position for some mean (yellow) colour. This gives a pure spectrum.

Uses of a spectrometer :

1. To measure the angle of the prism.
2. To determine the refractive index of the prism material.
3. To determine the wavelength of the light.
4. To measure the dispersive power of a prism.

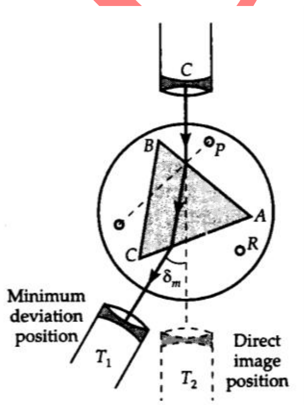
Measurement of refractive index (μ) ; The refractive index μ of the material of a prism is given by

$$\mu = \frac{\sin\frac{A+\delta_m}{2}}{\sin\frac{A}{2}}$$

To determine μ, we need to measure :

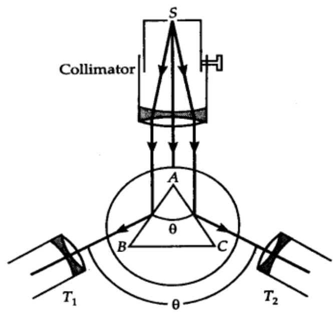
(i) angle of minimum deviation (δ_m) and

(ii) the refracting angle of the prim (A) .



Measurement of δ_m : Set the prism in the minimum deviation position, as shown in figure. Turn the telescope so that its cross–wire coincides with mean (yellow) colour of the spectrum. Let this position be T_1. Remove the prism. Turn the telescope to position T_2 so that direct image of slit is seen. The difference between the two positions gives δ_m.

Measurement of A. Place the prism *ABC* on the prism table so that light falls directly on faces *AB* and *AC* of the prism, as shown in fig. Look for the brightest image of the slit formed by reflection of light from faces *AB* and *AC*. Set the telescope in position T_1 so that cross–wire coinc ides with the image of the slit from face *AB*. Turn the telescope to the position T_2 so as to focus the image of the slit from face *AC*. Let θ be the angle through which telescope turns. Then, $A = \frac{\theta}{2}$.



Scattering of light

This is the phenomenon in which light is deflected from its path due its interaction with the particles of the medium through which it passes. Basically, the scattering process involves the absorption of light by the molecules followed by its re-radiation in different directions.

Two types of Scatterings :

(i) Elastic or Rayleigh scattering : When the size '*a*' of the scattering particles is much smaller than the wavelength 'λ' of incident light, there is no exchange of energy between the incident light and the scattering particles. Consequently, there is no change in the frequency or wavelength of the scattered light. This type of scattering is called elastic or Rayleigh scattering. It obeys Rayleigh's law of scattering.

(ii) Inelastic scattering : When the size of the scattering particles is much greater than the wavelength of incident light i.e., $a >> \lambda$, there is interchange of energy between incident light and the scattering particles. Consequently, the scattered light has a frequency or wavelength different from that of incident light. This type of scattering is called **inelastic scattering**. For example, the Raman effect and Compton effect.

Rayleight's law of scattering. *According to Rayleigh's law of scattering, the intensity of light of wavelength λ present in the scattered light is inversely proportional to the fourth power of λ, provided the size of the scattering particles are much smaller than λ.* Mathematically,

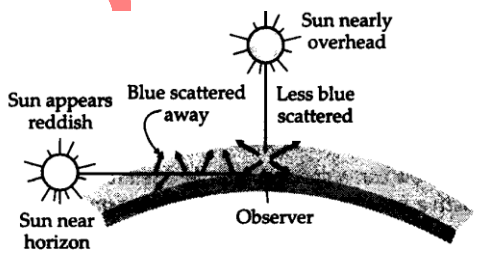
$$I \propto \frac{1}{\lambda^4} \qquad [\text{For } a << \lambda]$$

Thus the scattered intensity is maximum for shorter wavelengths.

(1) Blue colour of the sky : The blue colour of the sky is due to the scattering of sunlight by the molecules of the atmosphere. As sunlight passes through atmosphere, the nitrogen and oxygen molecules of air absorb some amount of sunlight and re-emit it. The free gas molecules scatter light in all directions. According to **Rayleigh's law of scattering**, intensity of scattered light. $I \propto \frac{1}{\lambda^4}$.

So, the light at the short wavelength (blue) end of the visible spectrum is scattered about ten times more than the light at the long wavelength (red end). When we look at the sky, the scattered light enters our eyes and this light contains blue colour in a larger proportion. That is why the sky appears blue.

(2) Reddishness at sunset and sunrise : When the sun is near the horizon at sunset or sunrise, the light rays have to traverse a larger thickness of the atmosphere than when the sun is overhead at noon. In accordance with Rayleigh's scattering law, the lower wavelengths in the blue region are almost completely scattered away by the air molecules. The higher wavelengths in the red region are least scattered and reach our eyes. Hence the sun appears almost reddish at sunset and sunrise.



(3) Clouds appear white : Large particles like raindrops, dust and ice particles do not scatter light in accordance with Rayleigh's law, i.e., their scattering power is not selective. They scatter light of all colours almost equally. Hence the clouds which have dropes of water with $a >> \lambda$ are generally white.

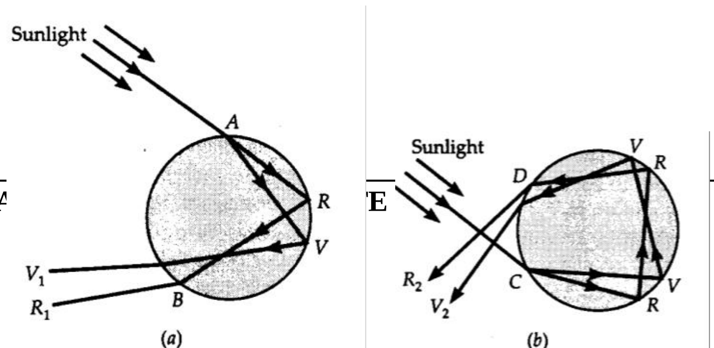
(4) Danger signals are red : According to Rayleigh's law, the intensity of scattered light is inversely proportional to the fourth power of wavelength. In the visible spectrum, red colour has the largest wave–length, it is scattered the least. Even in foggy conditions, such a signal covers large distances without any appreciable loss of intensity due to scattering. Therefore, red coloured signals are preferred.

NOTE

♦ If the earth had no atmosphere, there would be no scattering of light, the sky would appear black and stars could be seen during day hours. This is what astronauts actually observe at heights 20km above the earth where the atmosphere becomes quite thin or on the moon which has no atmosphere.

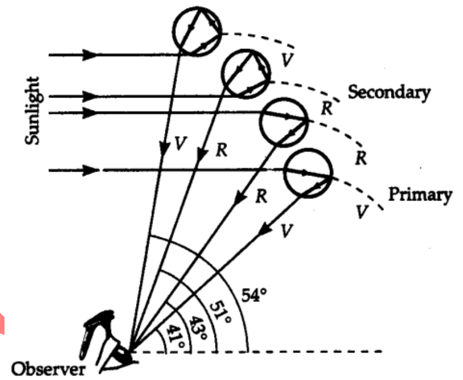
Rainbow

The rainbow is nature's most spectacular display of the spectrum of light, produced by refraction, dispersion and internal reflection of sunlight by spherical rain drops. It is observed when the sun shines on rain drops, during or



after a shower. An observer standing with his back towards the sun observes it in the form of concentric circular arcs (bows) of different colours in the horizon. The inner brighter rainbow is called the primary rainbow and the outer fainter rainbow is called the secondary rainbow.

The ***primary rainbow*** is formed by rays which undergo one internal reflection and two refractions and finally emerge from the raindrops at minimum deviation. The red rays emerge from the water drops at one angle of 43° and the violet rays emerge at another angle of 41°. The parallel beam of sunlight getting dispersed at these angles produces a cone of rays at the observer's eye, as shown in Figure. Thus the rainbow is seen as a colourful arc, with its inner edge violet and outer edge red in colour. The secondary rainbow is formed by the rays which undergo two internal reflections and two refractions before emerging from the water drops at minimum deviation.



Due to two internal reflections, the sequence of colour in secondary rainbow is opposite to that in the primary rainbow. Here the inner red rays emerge from the water drops at angle of 51^o and the outer violet rays emerge at angle of 54^o

Optical instruments

Optical instruments are the devices which make use of mirrors, lenses and prisms and are primarily used to extend the range of vision of human eye.

Essential features of an optical instrument : The design of an optical instrument must meet the following two requirements :

1. High magnification : Magnification is the ratio of the size of the final image to the size of the object. An optical instrument with high magnification makes viewing more clear and comfortable, by increasing the size of the image.

2. Adequate resolution : The resolution of an optical instrument is its ability to resolve the images of two closely spaced objects so that they can be seen separately. An optical instrument with high resolution reveals the finer details of the objects.

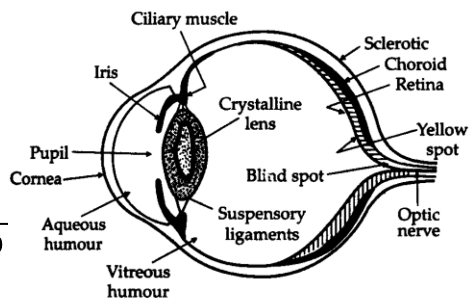
The Human Eye

It is the most valuable and sensitive sense organ. It is a remarkable optical instrument.

Structure of the eye. As shown in figure, the main parts of the human eye are as follows :

1. Sclerotic : It has a tough and opaque white covering, called sclerotic which protects and holds the eyeball.

2. Cornea : It is the transparent membrane on the front portion of the eyeball through which light enters eye.



3. Choroid : It is a black membrane below the sclerotic. It absorbs stray light and avoids any blurring of image due to multiple reflections in the eyeball.

4. Iris and pupil : Iris is an opaque circular diaphragm having a small central hole called the pupil. Under the muscular action of the iris, the size of the pupil becomes smaller in bright light and larger in dim light.

5. Eyelens : It is a double convex lens situated behind the iris. It is composed of a fibrous, jelly like material. The lens is held in position by suspensory ligaments and connected to the sclerotic by the ciliary muscles. By contracting or relaxing, the ciliary muscles can change the shape or curvature of the eyelens and hence change its focal length. This ability of the eyelens to change its focal length is called accommodation. This enables the eyelens to focus the images of objects at different distances on the retina of the eye.

6. Retina : It is a delicate membrane of nerve fibres on the inner side of the backwall of the eye. It contains light sensitive cells called rods and cones. Rods are sensitive to intensity of light while cones are sensitive to colours. These cells change light energy into electrical signals which send message to the brain via the optic nerves.

7. Blind spot and yellow spot : In the region where the optic nerve enters the eyeball, there are no rods and cones. This region is totally insensitive to light and is called blind spot. Yellow spot has maximum concentration of light sensitive cells. It is situated in the centre of the retina.

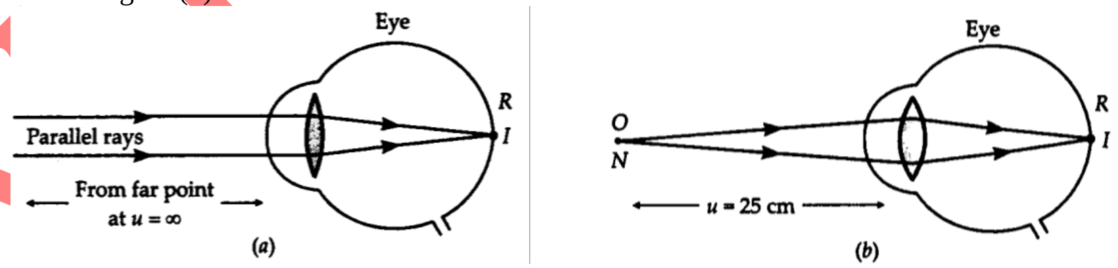
8. Aqueous humour and vitreous humour : Aqueous humour is a salty fluid ($\mu = 1.337$) that fills the space between the cornea and the eye lens. Vitreous humour is a jelly like fluid ($\mu = 1.437$) that fills the space between the retina and the eye lens.

Action of Eye: As the rays from an object enter the eye, they suffer refractions on passing successively through these structures and get converged. A real and inverted image is formed on the retina. The light sensitive cells of retina get activated and generate electrical signals that are sent to the brain through the optic nerves. Our brain translates the inverted image into an erect image.

Accommodation : Accommodation is the ability or property of the eyelens due to which it can change its curvature or focal length so that images of objects at various distances can be formed on the same retina. The focal length of the eyelens is automatically changed with the help of ciliary muscles as follows :

(a) Viewing far off objects : When the ciliary muscles are completely relaxed, the eyelens is thin and its focal length is maximum (equal to distance between eyelens and retina). The rays coming from the distant object are parallel to each other and they are focused at the retina as shown in figure (a) below.

(b) Viewing nearby objects : When we look at a nearby object, the ciliary muscles contract, the eyelens bulges out and becomes thick and its focal length is reduced. This focuses the light from the nearby object on the retina, as shown in figure (b) below.



(i) Range of normal vision : Due to accommodation property of the lens, a normal eye can clearly see the object situated and where between infinity and 25 cm from it. The distance between infinity and 25cm point is called the range of normal vision.

(ii) Least distance of distinct vision : The minimum distance from the eye, at which the eye can see the object clearly and distinctly without any strain is called the least distance of distinct vision. It is denoted by the letter *D*. **For a normal eye, its value is 25 cm.**

(iii) Near point : The nearest point from the eye, at which an object can be seen clearly by the eye is called its near point. The near point of a normal eye is at a distance of 25 cm.

(iv) **Far point :** The farthest point from the eye, at which an object can be seen clearly by the eye is called the far point of the eye. For a normal eye, the far point is at infinity.

(v) **Power of accommodation :** The power of accommodation of the eye is the maximum variation of its power for focusing on near and far (distant) objects. For a normal eye, the power of accommodation is about 4 dioptres.

Persistence of vision : The impression or sensation of an image on the retina remains (or persists) for about (1/16)th of a second even after the removal of the object. ***The phenomenon of the continuation of the impression of an image on the retina for some time even after the light from the object is cut off is called persistence of vision.*** For example, if there be a picture of a bird on one side of a piece of card–board and a picture of a cage just on the opposite side, then on rapidly revolving the card–board, the two impressions merge and the bird will appear to be inside the cage due to persistence of vision.

Rods : These are rod–shaped light sensitive cells of the retina which are responsible for twilight (black and white) vision. These cells are very sensitive to intensity of incident light, that is, the degree of brightness and darkness. The rods cannot distinguish between various colours.

Cones : These are cone shaped light sensitive cells of the retina which are responsible for colour vision. Different cones respond selectively to different colours. Three types of cones viz. R–cones, G–cones are B–cones are respectively sensitive to red, green and blue light.

Note :

♦ **Cinematography :** Cinematography works on the principle of persistence of vision. If photographs of a moving object are taken at intervals of about (1/24)th of a second and then projected on the screen at the same rate, the discontinuous pictures merge or blend together to produce the impression of the moving object on the eyes.

♦ **Colour blindness :** A person who cannot distinguish between various colours but can see well otherwise, is said to be colour blindness. Colour blindness is due to the lack of either one type, two types or all the three types of cones in the retina of the eyes. Colour blindness is a genetic disorder which cannot be cured even today.

♦ **Cataract :** In old age, the crystalline lens of some people becomes hazy or even opaque due to the development of membrane over it. This results in the development of cataract, which causes a decrease or loss of vision of the eye. The vision can be restored after getting cataract surgery.

Defects of vision and their correction

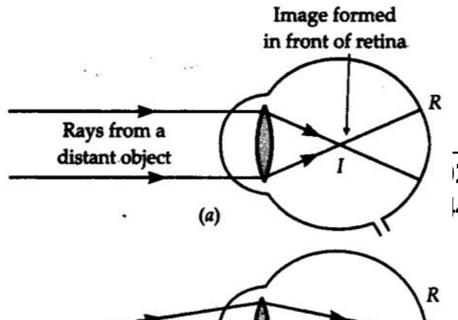
Defects of vision : A normal eye can see objects clearly at any distance between 25 cm and infinity from the eye. Sometimes, a human eye gradually loses its power of accommodation. Then we cannot see the objects clearly. Our vision becomes defective. There are mainly four common defects of vision which can be corrected by the use of suitable eye glasses. These defects are :

(1) Myopia or near–sightedness.

(2) Hypermetropia or far–sightedness

(3) Astigmatism

Myopia or short-sightedness : It is a vision defect in which a person can see nearby objects clearly but cannot see the distant



objects clearly beyond a certain point. This defect is common among children.

(i) The eyeball gets elongated along its axis so that the distance between the eyelens and the retina becomes larger.

(ii) The focal length of the eyelens becomes too short due to the excessive curvature of cornea.

As a result of the above causes, the parallel rays coming from a distant object do not meet at the retina but at a point in front of the retina, as shown in fig. (a) and the distant object is not seen clearly. The object has to moved closer to the eye to a point F to focus it on the retina, as shown in fig. (b). Thus the far point of a myopic eye is not at infinity but only a few metres from the eye.

Correction of myopia : A myopic eye is corrected by using a concave lens of focal length equal to the distance of the far point F from the eye. This lens diverges the parallel rays from distant object as if they are coming from the far point F. Finally, the eyelens forms a clear image at the retina.

Calculation of focal length and power of correcting lens of myopia. Let x be the distance of the actual far point from the eye and hence from the concave lens placed close to the eye. The rays coming from infinity, after refraction through the concave lens, appear to come from the far point F.

$\therefore$ $u = -\infty,\ v = -x,\ f = ?$

By lens formula, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-x} - \frac{1}{-\infty} = -\frac{1}{x} + 0 = -\frac{1}{x}$

$\therefore$ Required focal length, $f = -x$

Required power, $p = \frac{1}{f} = -\frac{1}{x}$

The negative sign shows that the correcting lens is a concave lens.

Hypermetropia or long-sightedness : It is a vision defect in which a person can see the distant objects clearly but cannot see the nearby objects clearly.

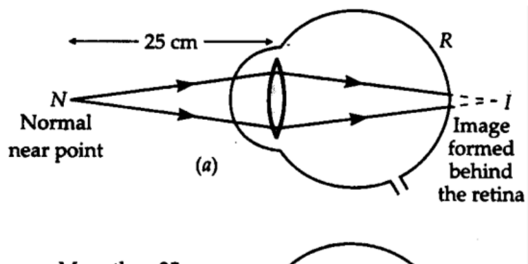
Cause of hypermetropia. This defect arises due to either of the following two reasons

(i) The eyeball becomes too small along its axis so that the distance between the eyelens and the retina is reduced.

(ii) The focal length of the eyelens becomes too large resulting in the low converging power of the eyelens.

As a result of the above causes, the rays coming from an object placed at 25 cm (normal near point) from the eye meet at a point behind the retina, as shown in figure (a). So the object is not seen clearly.

To focus the rays again on the retina, the object has to be moved away from the eyes to a distance greater than 25 cm, as shown in figure (b). Thus, ***the near point of the eye is not at 25 cm but it has shifted to N′ at a distance greater than 25 cm from the eyes***.



Correction of hypermetropia : A hypermetropic eye is corrected by using a convex lens of suitable focal length.

This lens converges the rays such that the rays coming from normal near point N appear to come after refraction, from near point N' of the defected eye. That is a virtual image of the object placed at N is formed at N'. Then the eyelens forms a clear image at the retina, as shown in figure (c).

Calculation of focal length and power of correcting lens in hypermetropia : As shown in figure (c). Let y = distance of the near point N' from the defective eye. Now the near point N of the normal eye is at distance D = 25 cm. the object placed at N forms its virtual image at N' due to the convex lens.

$\therefore$ $$u = -D,\ v = -y,\ f = ?$$

By lens formula, $$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-y} - \frac{1}{-D} = \frac{y-D}{yD}$$

$\therefore$ Required focal length, $$f = \frac{yD}{y-D}$$

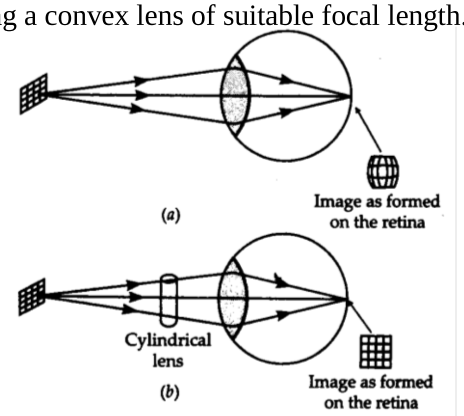
Required power, $$P = \frac{1}{f} = \frac{y-D}{yD}$$

As $y > D$, so both f and D are positive. That is the correcting lens must be a convex lens.

Presbyopia : This defect is similar to hypermetropia i.e., a person having this defect cannot see nearby objects distinctly, but can see distant objects without any difficulty. this defect differs from hypermetropia in the cause by which it is produced. It usually occurs in elderly persons. Due to the stiffening of the ciliary muscles, the eyelens loses flexibiligty and hence the accommodating power of the eyelens decreases. Like hypermetropia, this defect can be corrected by using a convex lens of suitable focal length.

Astigmatism : It is a defect of vision in which a person cannot simultaneously see both the horizontal and vertical views of an object with the same clarity. This defect can occur alongwith myopia or hypermetropia.

Cause of astigmatism : This defect occurs when the cornea is not perfectly spherical in shape. It may have a large curvature in the vertical plane than in the horizontal plane or vice versa. If one looks at a wire mesh with such a defect in the eyelens, focusing in the vertical plane may not be as sharp as in the horizontal plane or vice versa.



Astigmatism results in lines in one direction well focussed while those in perpendicular direction will be distorted or curved, as shown in figure (a).

Correction of Astigmatism : Astigmatism can be corrected by a lens whose one surface is cylindrical. Such a surface focusses rays in one plane but in the perpendicular plane. By suitably choosing the radius of curvature and axis direction of the cylindrical surface, astigmatism can be corrected.

Subjective Assignment – IX

1. What focal length should the reading spectacles have for a person for whom the least distance of distinct vision is 50 cm?
2. A person wears glasses of power – 2.5 D. Is the person far–sighted or near–sighted? What is the far point of the person without glasses?
3. (a) The far point of a myopic person is 80 cm in front of the eye. What is the power of the lens required to enable him to see very distant objects clearly?
   (b) In what way does the corrective lens help the person above? Does the lens magnify very distant objects? Explain carefully.
   (c) The person above prefers to remove his spectacles while reading a book. Explain why?
4. (a) The near point of a hypermetropic person is 75cm from the eye. What is the power of the lens required to enable him to read clearly a book held at 25 cm from the eye?
   (b) In what way does the corrective lens help the person above? Does the lens magnify objects held near the eye?
   (c) The person above prefer to remove his spectacles while looking at the sky. Explain why?
5. A 52 year old near–sighted person wears eye–glass with a power of – 5.5 dioptres for distance viewing. His doctor prescribes a correction of + 1.5 dioptres in the near vision section of his bi–focals. This is measured relative to the main part of the lens. (a) What is the focal length of his distance–viewing part of the lens? (b) What is the focal length of the near–vision section of the lens?
6. The far point of a myopic person is 150 cm in front of the eye. Calculate the focal length and the power of the lens required to enable him to see distant objects clearly.
7. A person can see clearly up to 3 metre only. Prescribe a lens for him so that he can see clearly up to 12 metre.
8. The near point of hypermetropic person is 50 cm from the eye. What is the power of the lens required to enable the person to read clearly a book held at 25 cm from the eye?
9. A short–sighted person can see most clearly at a distance of 15 cm acquires spectacles enabling him to see clearly objects at a distance of 60cm. Calculate the focal length of the lens and power of the lens.

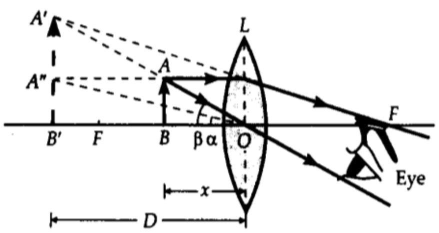
Answers

1.	+ 50 cm	2.	– 40 cm, near sighted	3.	(a) – 1.25 D
4.	(a) + 2.67 D	5.	(a) – 18.73 cm , (b) + 15.4 cm	6.	– 150 cm, – 0.67 D
7.	Concave lens, $f = -4m$	8.	+ 2D	9.	– 20cm, – 5D

Simple Microscope

A simple microscope or a magnifying glass is just a convex lens of short focal length, held close to the eye.

Working Principle : When the final image is formed at the least distance of distinct vision : When an object AB is placed between the focus F and optical centre O of a convex lens ; a virtual, erect and magnified image $A'B'$ is formed on the same side of the lens as the object. Since a normal eye can see an object clearly at the least distance of distinct vision D (= 25 cm), the position of the lens is so adjusted that the final image is formed at the distance D from the lens, as shown in figure.



Magnifying power : The magnifying power of a simple microscope is defined as the ratio of the angles subtended by the image and the object at the eye, when both are at the least distance of distinct vision from the eye. Thus,

$$\text{Magnifying power} = \frac{\text{Angle sobended by the image at the least distance of distinct vision}}{\text{Angle substneded by the object at the least distance of distinct vision}}$$

As the eye is held close to the lens, the anglessubtended at the eye. The image $A'B'$ is formed at the least distance of distinct vision 'D''. Let $\angle A'OB' = \beta$. Imagine the object AB to be displaced to position $A'B'$ at distance D from the lens. Let $\angle A''OB' = \alpha$. Then magnifying power,

$$m = \frac{\beta}{\alpha} = \frac{\tan\beta}{\tan\alpha} \qquad [\because \alpha, \beta \text{ are small angles}]$$

$$= \frac{AB/OB}{A''B'/OB'} = \frac{AB/OB}{AB/OB'} \qquad [\because A''B' = AB]$$

$$= \frac{OB'}{OB} = \frac{-D}{-x} \qquad \text{or} \qquad m = \frac{D}{x}$$

Let f be the focal length of the lens. As the image is formed at the least distance of distinct vision form the lens, so $v = -D$

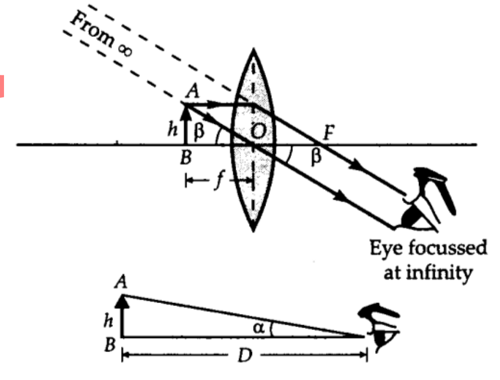
Using thin lens formula, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

we get, $\frac{1}{-D} - \frac{1}{-x} = \frac{1}{f}$ or $\frac{1}{x} = \frac{1}{D} + \frac{1}{f}$ or $\frac{D}{x} = 1 + \frac{D}{f}$

$\therefore$ $\boxed{m = 1 + \frac{D}{f}}$

Thus shorter the focal length of the convex lens, the greater is its magnifying power.

Working principle : When the final image is formed at infinity : When the final image is formed at infinity. When we see an image at the near point, it causes some strain in the eye. Often the object is placed at the focus of the convex lens, so that parallel rays enter the eye, as shown in figure (a). The image is formed at infinity, which is more suitable and comfortable for viewing by the relaxed eye.



Magnifying power : It is define as the ratio of the angle formed by gthe image (when situated at infinity) at the eye to the angle formed by the object at the eye, when situated at the least distance of distinct vision.

$$m = \frac{\beta}{\alpha} = \frac{\tan\beta}{\tan\alpha} \qquad [\alpha, \beta \text{ are small}]$$

$$\tan\beta = \frac{h}{f} \qquad \text{[As soon as above figure]}$$

$$\tan\alpha = \frac{h}{D} \qquad \text{[As soon as above figure]}$$

$$\therefore \quad m = \frac{h/f}{h/D} \qquad \text{or} \qquad \boxed{m = \frac{D}{f}}$$

This magnification is one les than the magnification when the image is formed at the near point. But viewing is more comfortable when the eye is focused at infinity.

Uses of simple microscopes :

1. Watch makers and jewellers use a magnifying glass for having a magnified view of the small parts of watches and the fine jewellery work.
2. In magnifying the printed letters in a book, textures of fibres or threads of a cloth, engravings, details of stamp, etc.
3. Magnifying glass is used in science laboratories for reading vernier scales, etc.

Note :

- ♦ distance of distinct vision (D). The minimum distance from the eye, at which the eye can see the objects clearly and distinctly without any strain is called the least distance of distinct vision. For a normal eye, its value is 25 cm.
- ♦ Near point. The nearest point from the eye, at which an object can be clearly seen by the eye is called its near point. The near point of a normal eye is at a distance of 25 cm.
- ♦ Far point. The farthest point from the eye, at which an object can be seen clearly by the eye, is called the far point of the eye. For a normal eye, the far point is at infinity.
- ♦ Accommodation. It is the ability of the eyelens due to which it can change its focal length so that images of objects at various distances can be formed on the same retina.
- ♦ Power of accommodation. The power of accommodation of the eye is the maximum variation of its power for focussing on near and far objects. For a normal eye, the power of accommodation is about 4 dioptres.
- ♦ The magnifying power is expressed with a unit X. So if a magnifying glass produces an angular magnification of 10, it is called a 10 X magnifier.
- ♦ A simple microscope has a limited maximum magnification of about 10, for realistic focal lengths. For much larger magnifications, we use two convex lenses, one enhancing (compounding) the effect of the other. This is known as the compound microscope.

Subjective Assignment – X

1. A thin convex lens of focal length 5cm is used as a simple microscope by a person with normal near point (25 cm). What is the magnifying power of the microscope?
2. A simple microscope is a combination of two lenses, in contact, of powers +15D and +5D. Calculate the magnifying power of the microscope, if the final image is formed at 25cm from the eye.
3. An object is to be seen through a simple microscope of power 10D. Where should the object be placed so as to produce maximum angular magnification? The least distance for distinct vision is 25cm.
4. A simple microscope is rated 5X for a normal relaxed eye. What will be its magnifying power for a relaxed farsighted eye whose near point is 40 cm?
5. A converging lerns of focal length 6.25 cm is used as a magnifying glass. If the near point of the observer is 25cm from the eye and the lens is held close to the eye, calculate (i) the distance of the object from the lens and (ii) the angular magnifications. Find the angular magnification, when the final image is formed at infinity.
6. A man with normal near point (25 cm) reads a book with small print using a magnifying glass : a thin convex lens of focal length 5 cm.
   (i) What is the closest and the farthest distance at which he can read the book when viewing through the magnifying glass?
   (ii) What is the maximum and the minimum angular magnification (Magnifying power) possible using the above simple microscope?
7. A figure divided into squares each of size 1mm^2 is being viewed at a distance of 9cm through a magnifying glass (a converging lens of focal length 10 cm) held close to the eye.

(i) What is the magnification (image size/object size) produced by the lens? How much is the area of each square in the virtual image? \

(ii) What is the angular magnification (magnifying power) of the lens?

(iii) Is the magnification in (i) equal to the magnifying power in (ii)? Explain.

8. (i) At what distance should the lens be held from the figure in Q. No. 7 in order to view the squares distinctly with the maximum possible magnifying power?

(ii) What is the magnification (image size/object size) in this case?

(iii) Is the magnification equal to magnifying power in this case? Explain.

9. What should be the distance between the object in Q.No. 7 and the magnifying glass if the virtual image of each square in the figure is to have an area 6.25 mm^2? Would you be able to see the squares distinctly with your eyes very close to the magnifier?

10. A magnifying glass is a combination of a convex lens of focal length 5cm and a concave lens of power – 5*D*. If the distance of distinct vision is 20 cm, calculate the magnifying power of the magnifying glass.

11. Magnifying power of a simple microscope *A* is 1.25 less than that of a simple microscope *B*. If the power of the lens used in *B* is 25 *D*, find the power of lens used in A. Given that distance of distinct vision is 25 cm.

12. A child has a near point at 10 cm. What is the maximum angular magnification the child can have with a convex lens of focal length 10 cm?

Answers

1.	6	2.	6	3.	– 7.1 cm
4.	8X	5.	(i) – 5 cm (ii) 5, 4	6.	(i) – 4.2 cm , – 5 cm, (ii) 6, 5
7.	(i) 10, 1 cm^2, (ii) 2.8, (iii) No				
8.	(i) – 7.414 cm (ii) 3.5 (iii) 3.5, yes			9.	– 6cm, – 15 cm, No
10.	4	11.	20 D	12.	2

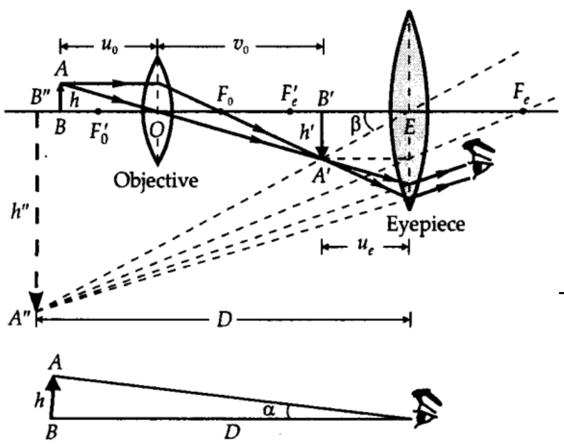
Compound Microscope

A compound microscope is an optical device used to see magnified images of tiny objects. A good quality compound microscope can produce magnification of the order of 1000.

Construction : It consists of two convex lenses of short focal length, arranged co–axially at the ends of two sliding metal tubes.

1. Objective : It is a convex lens of very short focal length f_0 and small aperture. It is positioned near the object to be magnified.

2. Eyepiece or ocular : It is a convex lens of comparatively larger focal length f_e and larger aperture than the objective $(f_c > f_0)$. It is positioned near the eye for viewing the final image. the distance between the two lenses can be varied by using rack and pinion arrangement.



Working (a) When the final image is formed at the least distance of distinct vision : The object *AB* to be viewed is placed at distance u_0, slightly larger than the focal length f_0 of the objective *O*. The objective form real, inverted and magnified image $A'B'$, of the object *AB* on the other side of the lens *O*, as shown in figure. The separation between the objective O and the eyepiece E, is so adjusted that the image $A'B'$ acts as an object for the eyepiece which essentially acts like a simple microscope. The eyepiece E forms a virtual and magnified final image $A''B'$ of the object AB. Clearly, the final image $A''B'$ of the object AB. Clearly, the final image $A''B'$ is inverted with respect to the object AB.

Magnifying power : the magnifying power of a compound microscope is defined as the ratio of the a angle subtended at the eye by the final virtual image tot eh angle subtended at the eye by the object, when both are at the least distance of distinct vision from the eye.

$$m = \frac{\beta}{\alpha} = \frac{\tan\beta}{\tan\alpha} = \frac{h'/u_e}{h/D} = \frac{h'}{h}\frac{D}{u_e} = m_0 m_e$$

Here, $$m_0 = \frac{h'}{h} = \frac{v_0}{u_0}$$

As the eyepiece acts as a simple microscope, so

$$m_e = \frac{D}{u_e} = 1 + \frac{D}{f_e} \quad \therefore \quad m = \frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right).$$

As the object AB is placed close to the focus F_0 of the objective, therefore, $u_0 \approx -f_0$.

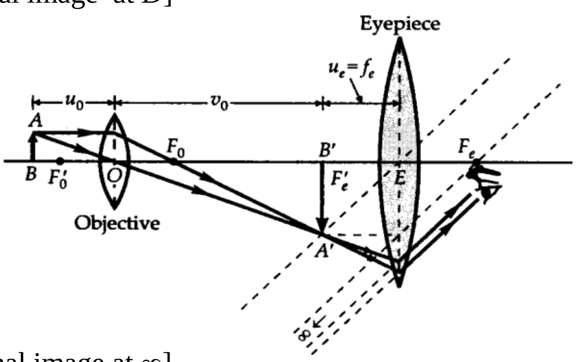
Also image $A'B'$ is formed close to the eyelens whose focal length is short, therefore $v_0 \approx L =$ the length of the microscope tube or the distance between the two lenses.

$$\therefore \qquad m_0 = \frac{v_0}{u_0} = \frac{L}{-f_0}$$

$$\therefore \qquad m = -\frac{L}{f_0}\left(1 + \frac{D}{f_e}\right) \qquad \text{[for final image at } D\text{]}$$

(b) When the final image is formed at infinity :

When the image $A'B'$ lies at the focus F_e' of the eyepiece i.e., $u_e = f_e$, the image $A''B''$ is formed at infinity, as shown in fig.



When the final is formed at infinity,

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

$$\therefore \qquad m = -\frac{L}{f_0} \times \frac{D}{f_e} \qquad \text{[For final image at } \infty\text{]}$$

Obviously, magnifying power of the compound microscope is large when both f_0 and f_e are small.

Note :

♦ In a compound microscope, the objective is a convex lens of short focal length and small aperture, while the eyepiece is a convex lens of short focal length and large aperture.

♦ In actual practice, each of the objective and the eyepiece consists of combination of lenses. To eliminate chromatic aberration, an objective consists of two lenses in contact. To minimize chromatic and spherical aberrations, an eyeplace consists of two lenses separated by a certain distance.

- In a compound microscope, the objective and the eyepiece are placed *a* fixed distance apart. For focusing on an object, the distance of the objective from that object is changed with the help of a rack and pinion arrangement.
- For large magnifying power, both f_0 and f_e have to be small. Also, f_e is taken larger than f_0 as to increase the field of view of the microscope.
- The visibility and quality of the image can be improved by illuminating the object and by using oil immersion objective.
- When the final image is formed at the least distance *D* of distinct vision, the length of the compound microscope $L = v_0 + u_e$.
- When the final image is formed at infinity, the length of the compound microscope, $L = v_0 + f_0$.

Subjective Assignment – XI

1. A compound microscope has a magnification of 30. The focal length of its eyepiece is 5cm. Assuming the final image to be formed at least distance of distinct vision (25 cm), calculate the magnification produced by the objective.
2. A compound microscope with an objective of 1.0 cm focal length and an eyepiece of 2.0 cm focal length has a tube length of 20 cm. Calculate the magnifying power of the microscope, if the final image is formed at the near point of the eye.
3. The focal lengths of the eyepiece and the objective of a compound microscope are 5 cm and 1 cm respectively and the length of the tube is 20 cm. Calculate the magnifying power of the microscope, when the final image is formed at infinity. The value of least distance of distinct vision is 25cm.
4. (i) Draw a labeled ray diagram of a compound microscope, showing the formation of image at the near pint of the eye. (ii) A compound microscope uses an objective lens of focal length 4 cm and eye lens of focal length 10 cm. An object is placed at 6 cm from the objective lens.

   (a) Calculate magnifying power of the compound microscope, if the final image is formed at the near point.

   (b) Calculate the length of the compound microscope also.
5. The total magnification produced by a compound microscope is 20, while that produced by the eyepiece alone is 5. When the microscope is focused on a certain object, the distance between objective and eyepiece is 14 cm. Find the focal length of objective and eyepiece, if distance of distinct vision is 20 cm.
6. The magnification produced by the objective of a compound microscope is 8. If the magnifying power of the microscope be 32, then calculate the magnification produced by the eyepiece.
7. A convex lens of focal length 5 cm is used as a simple microscope. What is its magnifying power if final image is formed at the distance of distinct vision i.e., 25 cm? If it is used as an eyepiece in a compound microscope with objective of magnifying power 40, what is the magnifying power of the compound microscope?
8. The focal lengths of the objective and eye–piece of a compound microscope are 4 cm and 6 cm respectively. If any object is placed at a distance of 6 cm from the objective, what is the magnification produced by the microscope? Distance of the distinct vision = 25 cm.
9. The focal lengths of the objective and the eyepiece of a compound microscope are 11cm and 2cm, respectively and the separation between them is 15 cm. At what distance should an object be placed so that the final image is formed at a distance of 25 cm from the eyepiece?
10. The focal lengths of the objective and the eyepiece of a microscope are 2 cm and 5cm respectively and the distance between them is 20 cm. Find the distance of the object from the objective when the final image seen by the eye is 25 cm from the eyepiece. Also find the magnifying power.
11. A compound microscope is made using a lens of focal length 10 mm as objective and another lens of focal length 115 mm as eyepiece. An object is held at 1.1 cm from the objective and final image is formed at infinity. Calculate distance between objective and eyepiece.

Answers

1.	5	2.	270	3.	70
4.	(a) 7, (b) 19.14 cm	5.	F_0 = 1.8 cm , F_e = 5 cm	6.	4
7.	6, 240	8.	10.33	9.	– 1.08 cm
10.	u_0 = – 2.3 cm, m = 41.5			11.	12.5 cm

Telescope

A telescope is an optical device which enables us to see distant objects clearly. It provides angular magnification of the distant objects.
Different types of telescope. Broadly, the telescopes can be divided into two categories:

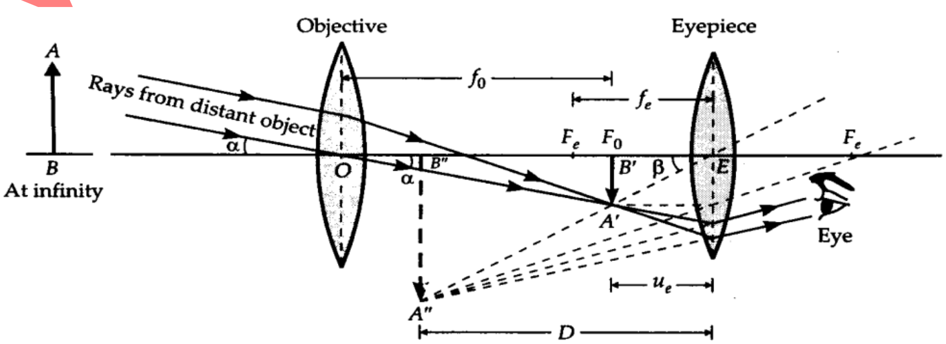
1. **Refracting telescopes :** These make use of lenses to view distant objects. These are of two types:
   (a) **Astronomical telescope :** It is used to see heavenly objects like the sun, stars, planets, etc. The final image formed is inverted one which is immaterial in the case of heavenly bodies because of their round shape.
   (b) **Terrestrial telescope :** It is used to see distant objects on the surface of the earth. The final image formed is erect one. This is an essential condition of viewing the objects on earth's surface correctly.
2. **Reflecting telescopes :** These make use of converging mirrors to view the distant objects. For example, Newtonian and Cassegrain telescopes.

Astronomical Telescope

Astronomical telescope : It is a refracting type telescope used to see heavenly bodies like stars, planets, satellites, etc.
Construction. It consists of two converging lenses mounted co-axially at the outer ends of two sliding tubes.

1. **Objective.** It is a convex lens of large focal length and a much larger aperture. It faces the distant object. In order to form bright image of the distant objects, the aperture of the objective is taken large so that it can gather sufficient light from the distant objects.
2. **Eyepiece.** It is a convex lens of small focal length and small aperture. It faces the eye. The aperture of the eyepiece is taken small so that whole light of the telescope may enter the eye for distinct vision.

   Working. (a) When the final image is formed at the least distance of distinct vision. As shown in Fig., the parallel beam of light coming from the distant object falls on the objective at some angle α. The objective focuses the beam in its focal plane and forms a real, inverted and diminished image A' B'. This image $A'\ B'$ acts as an object for the eyepiece. The distance of the eyepiece is so adjusted that the image $A'\ B'$ lies within its focal length. The eyepiece magnifies this image so that final image $A''\ B''$ is magnified and inverted with respect to the object. The final image is seen distinctly by the eye at the least distance of distinct vision.



Magnifying power : The magnifying power of a telescope is defined as the ratio of the angle subtended at the eye by the final image formed at the least distance of distinct vision to the angle subtended at the eye by the object at infinity, when seen directly.

As the object is very far off, the angle subtended by it at the eye is practically equal to the angle a subtended by it at the objective. Thus $\angle A'OB' = \alpha$.

Also, let $\angle A''EB'' = \beta$

$\therefore$ Magnifying power, $m = \frac{\beta}{\alpha} = \frac{\tan\beta}{\tan\alpha}$ $[\because \alpha, \beta \text{ are small}]$

$$= \frac{A'B'/B'E}{A'B'/OB'} = \frac{OB'}{B'E}$$

According to the new Cartesian sign convention, $OB' = +f_0 =$ focal length of the objective

$B'E = -u_e =$ distance of $A'B'$ from the eyepiece, acting as an object for it.

$$\therefore \quad m = -\frac{f_0}{u_e}$$

Again, for the eyepiece : $u = -u_e$ and $v = -D$

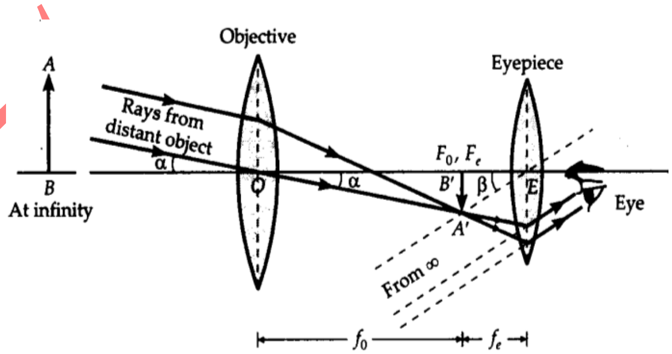
As, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

$\therefore$ $\frac{1}{-D} - \frac{1}{-u_e} = \frac{1}{f_e}$ or $\frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{D} = \frac{1}{f_e}\left(1 + \frac{f_e}{D}\right)$

Hence $m = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$.

Clearly for large magnifying power, $f_0 >> f_e$. The negative sign for the magnifying power indicates that the final image formed is real and inverted.

(b) When the final image of formed at infinity : Normal adjustment : As shown in figure, when a parallel beam of light is incident on the objective, it forms a real, inverted and diminished image $A'\ B'$ in its focal plane. The eyepiece is so adjusted that the image $A'\ B'$ exactly lies at its focus. Therefore, the final image is formed at infinity, and is highly magnified and inverted with respect to the object.



Magnifying power in normal adjustment : It is defined as the ratio of the angle subtended at the eye by the final image as seen through the telescope to the angle subtended at the eye by the object seen directly, when both the image and the object lie at infinity. As the object is very far off, the angle subtended by it at the eye is practically equal to the angle α subtended by it at the objective.

Thus, $\angle A'OB' = \alpha$

and let $\angle A'EB' = \beta$

$\therefore$ Magnifying power, $m = \frac{\beta}{\alpha} = \frac{\tan\beta}{\tan\alpha}$ $[\because \alpha, \beta \text{ are small angles}]$

$$= \frac{A'B'/B'E}{A'B'/OB'} = \frac{OB'}{B'E}$$

Applying new Cartesian sign convention,

$$OB' = +f_0 = \text{Distance of } A'B' \text{ from the objective along the incident light}$$

$$B'E = -f_e = \text{Distance of } A'\,B' \text{ from the eyepiece against the incident light}$$

$$\therefore \qquad m = -\frac{f_0}{f_e}.$$

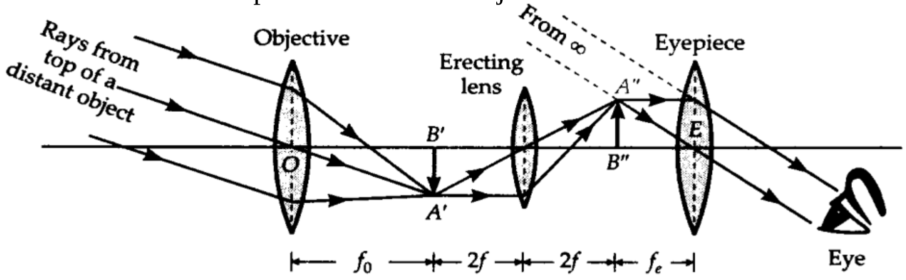
Clearly for large magnifying power, $f_0 >> f_e$. The negative sign for m indicates that the image is real and inverted.

Note :

- In a telescope, the objective has large focal length and large aperture while the eyepiece has small focal length and small aperture.
- A telescope is focussed on the distant object by varying distance between the objective and the eye-piece with the help of rack and pinion arrangement.
- The objective of the telescope should have large aperture because then a much wider beam of light is incident on it and is converged into a small cone which, on entering the eye, produces sufficient illumination on the retina. So even two distant faint stars which cannot be seen by naked eyes, become visible through such a telescope.
- In a telescope, the image is not actually magnified. A telescope simply increases the visual angle β. The visual angle β for the image is much larger than the visual angle α for the object. Consequently, the angular magnification α/β is quite large.
- In normal adjustment, the distance between the objective and the eyepiece = $f_0 + f_e$. When the final image is formed at the least distance of distinct vision, the magnifying power of the telescope is larger than that in the case of normal adjustment because the factor $\left(1+\frac{f_e}{D}\right) > 1$.
- An astronomical telescope forms an inverted image. As the celestial objects are oval in shape, so it does not matter whether the final image is inverted or erect.

Terrestrial Telescope

It is a refracting type telescope used to see erect images of distant earthly objects. It uses an additional convex lens between objective and eyepiece for obtaining an erect image. As shown in figure, the objective forms a real, inverted and diminished image, $A'B'$ of the distant object in its focal plane. Now the erecting lens is held at twice its focal length from the focal plane of the objective. This lens forms a real, inverted and equal size image $A''B'$ of $A'B'$. This image is now erect with respect to the distant object. The eyepiece is so adjusted that the image $A''\,B''$ lies at its principal focus. Hence the final image is formed at infinity and is highly magnified and erect with respect to the distant object.



As the erecting lens does not cause any magnification, the angular magnification of the terrestrial telescope is same as that of the astronomical telescope. When the image is formed at infinity, $m = \frac{f_0}{f_e}$.

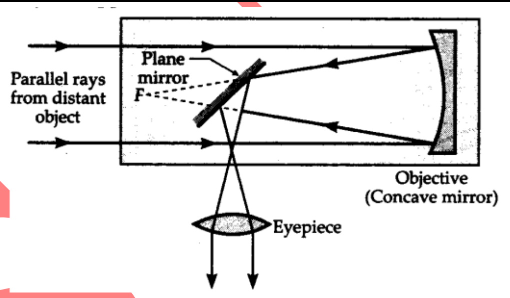
When the image is formed at the least distance of distinct vision, $m = \frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$.

Note :1. The length of the terrestrial telescope is much larger than the astronomical telescope. In normal adjustment, the length of a terrestrial telescope $= f_0 + 4f + f_e$, where f is the focal length of the erecting lens.

2. Due to extra reflection at the surfaces of the erecting lens, the intensity of the final image decreases.

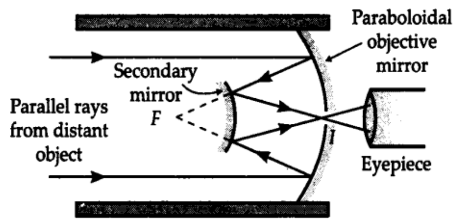
Reflecting telescopes

Newtonian reflecting telescope : The first reflecting telescope was set up by Newton in 1668. As shown in figure, , it consists of a large concave mirror of large focal length as the objective, made of an alloyt of copper and tin. A beam of light from the distant star is incident on the objective. Before the rays are focused at *F*, a plane mirror inclined at 45^o intercepts them and turns them towards an eyepiece adjusted perpendicular to the axis of the instrument. The eye–piece forms a highly magnified, virtual and erect image of the distinct object.



Cassegrain reflecting telescope : As shown in figure Cassegrainian type reflecting telescope. It consists of a large concave paraboloidal (primary) mirror having a hole at its centre. There is a small convex (secondary) mirror near the focus of the primary mirror.

The eyepiece is placed on the axis of the telescope near the hole of the primary mirror. The parallel rays from the distant object are reflected by the large concave mirror. Before these rays come to focus at *F*, they re reflected by the small convex mirror and are converged to a point *I* just outside the hole. The final image formed at *I* is viewed through the eyepiece.



As the first image at *F* is inverted with respect to the distant object and the second image *I* is erect with the respect to the first image *F*, hence the final image in inverted with respect to the object. Let f_0 be the focal length of the objective and f_e that of the eyepiece. For the final image formed at the least distance of distinct vision,

$$m = \frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$$

For the final image formed at infinity, $m = \frac{f_0}{f_e} = \frac{R/2}{f_e}$.

Advantages of a reflecting type telescope : A reflecting type telescope has gthe following advantages over a refracting type telescope :

1. A concave mirror of large aperture has high gathering power and absorbs very less amount of light than the lenses of large apertures. The final image formed in reflecting telescope is very bright. So even very distant or faint stars can be easily viewed.
2. Due to large aperture of the mirror used, the reflecting telescopes have high resolving power.
3. As the objective is a mirror and not a lens, it is free from chromatic aberration (formation of coloured image of a white object).
4. The use of paraboloidal mirror reduces the spherical aberration (formation of non-point, blurred image of a point object).

5. A mirror requires grinding and polishing of one surface only. So it costs much less to construct a reflecting telescope than a refracting telescope of equivalent optical quality.
6. A lens of large aperture tends to be very heavy and, therefore, difficult to make and support by its edges. On the other hand, a mirror of equivalent optical quality weighs less and can be supported over its entire back surface.

Note :

- The largest refracting telescope is at the Yerkes Observatory in Wisconsin, USA. It uses an objective lens of diameter 102 cm.
- the largest reflecting telescopes in the world are the pair of keck telescopes in Hawaii USA. They use reflecting mirrors of diameter 10m each.
- The largest telescope in India is in Kavalur, Tamilnadu. it is a Cassegrain reflecting telescope having objective of diameter 2.34 m. It was ground, polished, set up and is being used by the Indian Institute of Astrophysics, Bangalore.
- **Prism binocular :** It is a double telescope that uses two sets of totally reflecting prisms. This makes the final image erect which is very desirable for observations on earth. Binoculars are much more compact and easier to use than a refracting telescope, and allow use of both eyes.

Subjective Assignment – XII

1. The magnifying power of an astronomical telescope in the normal adjustment position is 100. The distance between the objective and the eyepiece is 101 cm. Calculate the focal lengths of the objective and the eyepiece.
2. An amateur astronomer wishes to estimate roughly the size of the sun using his crude telescope consisting of an objective lens of focal length 200 cm and an eye–piece of focal length 10cm. By adjusting the distance of the eye–piece from the objective, he obtains an image of the sun on a screen 40 cm behind the eyepiece. The diameter of the sun's image is measured to be 6.0 cm. What is the estimate of the sun's size, given that the average earth–sun distance is 1.5×10^{11} m.
3. A telescope objective of focal length 1m forms a real image of the moon 0.92 cm in diameter. Calculate the diameter of the moon taking its mean distance from the earth to be 38×10^{4} km. If the telescope uses an eyepiece of 5 cm focal length, what would be the distance between the two lenses for (i) the final image to be formed at infinity and (ii) the final image (virtual) at 25 cm from the eye.
4. A telescope has an objective of focal length 50 cm and eyepiece of focal length 5 cm. The least distance of distinct vision is 25 cm. The telescope is focused for distinct vision on a scale 200 cm away from the object. Calculate (a) the separation between the objective and eyepiece and (b) the magnification produced.
5. An astronomical telescope consisting of an objective of focal length 60 cm and an eyepiece of focal length 3cm is focused on the moon, so that the final image is formed at the least distance of distinct vision (25 cm) from the eyepiece. Assuming that the diameter of the moon subtends an angle of $\frac{1^\circ}{2}$ at the objective, calculate (a) The angular magnification and (b) the actual size of the image seen.
6. A terrestrial telescope has an objective of focal length 180 cm and an eyepiece of focal length 5.0 cm. The erecting lens has a focal length of 3.5 cm. What is the separation between the objective and the eyepiece? What is the magnifying power of the telescope? Can we use the telescope for viewing astronomical objects?
7. (a) A Galilean telescope obtains the final image erect (like in a terrestrial telescope) without an intermediate erecting lens. It does so by using a diverging lens for its eyepiece. Show that the angular magnification of a Galilean telescope is given by the formula : $m = -f_0/f_e$ (negative sign because f_e is negative).

   (b) For a Galilean telescope with $f_0 = 150$ cm, $f_e = -7.5\text{cm}$, what is the separation between the objective and the eyepiece?

(c) What is the main disadvantage of this type of telescope?

8. An eyepiece of a telescope consists of two plano–convex lenses L_1 and L_2 each of focal length f separated by a distance of $2f/3$. Where should L_1 be placed relative to the focus of the objective lens of the telescope so that the final image through L_2 in seen at infinity?
9. An astronomical telescope consists of two thin lenses set 36 cm apart and has a magnifying power 8. Calculate the focal length of the lenses.
10. An astronomical telescope when in normal adjustment has magnifying power 5. If the distance between two lenses is 24 cm, find the focal length of both the lenses.
11. A telescope has an objective of focal length 200 cm and eyepiece of focal length 5 cm. Calculate its magnifying power when the final image is formed (a) at infinity and (b) at distance of distinct vision.
12. A telescope has an objective of focal length 30 cm and an eyepiece of focal length 3.0 cm. It is focused on a scale distant 2.0 m. For seeing with relaxed eye, calculate the separation between the objective and the eyepiece.
13. The diameter of the moon is 3.5×10^3 km and its distance from the earth is 3.8×10^5 km. it is viewed by telescope which consists of two lenses of focal lengths 4m and 10cm. Find the angle subtended at eye by the final image.
14. On seeing with unaided eye, the visual angle of moon at the eye is 0.6^o. The focal lengths of the objective and the eyepiece of a telescope are respectively 200 cm and 5cm. What will the visual angle on seeing through the telescope?
15. A reflecting type telescope has a concave reflector of radius of curvature 120 cm. Calculate focal length of eyepiece to secure a magnification of 20.

Answers

1.	1cm, 100 cm	2.	1.5×10^9 m	3.	(i)105 cm , (ii)104.17 cm
4.	(a) 70.83 cm , (b) – 2	5.	(a) 22.4 (b) 4.9 cm	6.	199 cm, 36, yes
7.	(b) 142.5 cm	8.	$f/4$	9.	32 cm, 4 cm
10.	20 cm, 4 cm	11.	40, 48	12.	38.3 cm
13.	21.1^o	14.	2.4^o	15.	3 cm

Conceptual Problems

Q.1 What are real and virtual image? Distinguish between them.

Q.2 (a) An object is placed between two plane mirrors inclined at 60^o to each other. How many images do you expect to see?

(b) An object is placed between two plane parallel mirrors. Why do the distant images get fainter and fainter?

(c) Why are mirrors used in search–lights parabolic and not concave spherical?

(d) If you were driving a car, what type of mirror would you prefer to use for observing traffic at your back?

Q.3 Answer the following questions:

(a) A man holding a lighted candle in front of a thick glass mirror and viewing it obliquely sees a number of images of the candle. What is the origin of these multiple images?

(b) You read a newspaper because of the light that it reflects. Then why do you not see even a faint image of yourself in the newspaper?

(c) The wall of a room is covered with a perfect plane mirror, and two movie films are made, one recording the movement of a man and the other of his mirror image. From viewing the films later, can an outsider tell which is the mirror image film?

Q.4 Light incident normally on plane mirror attached to a galvanometer coil retraces backward as shown. A current in the coil produces a deflection of 3.5^o of the mirror. What is the displacement of the reflected spot of light on a screen placed 1.5 m away?

Q.5 A boy 1.50 m tall with his eye level at 1.38 m stands before a mirror fixed on a wall. Indicate by means of a ray diagram how the mirror should be positioned so that he can view himself fully. What should be the minimum length of the mirror? Does the answer depend on the eye level?

Q.6 Suppose that the left half of a concave mirror's reflecting surface is covered with non–reflective soot. What effect will this have on the image of an object placed in front of the mirror?

Q.7 A mobile phone lies along the principal axis of a concave mirror, as shown in figure. Show by suitable diagram the formation of its image. Explain why the magnification is not uniform, and distortion will occur depending on the location of the mobile with respect to the mirror.

Q.8 A person standing before a concave mirror cannot see his inverted image unless he stands beyond the centre of curvature. Why?

Q.9 The distances of an object and its real image, measured from the focus of a concave mirror, are a and b respectively. Show that $f^2 = ab$.

Q.10 A beam of light converges at a point on the screen. A plane parallel glass plate is introduced in the path of this converging beam. How will the point of convergence be affected? Draw the relevant ray diagram.

Q.11 A straight rod appears bent in water. Why?

Q.12 A microscope is focused on a dot at the bottom of a beaker. Some oil is poured into the beaker to a height of y cm and it is found necessary to raise the microscope through a vertical distance of x cm to bring the dot again into focus. Express refractive index of oil in terms of x and y.

Q.13 A light ray travels from medium 1 of refractive index μ_1 to medium 2 of refractive index μ_2, where $\mu_2 < \mu_1$. Writ e an expression for critical angle of incidence.

Q.14 A ray of light while traveling from a denser to a rarer medium undergoes total reflection. Derive the expression for the critical angle in terms of t he speed of light in the respective media.

Q.15 What is total internal reflection? Under what conditions does it take place? OR

(a) State the principle on which the working of an optical fibre is based.

(b) What are the necessary conditions for this phenomenon to occur?

Q.16 Explain the twinkling of stars. Why do the planets not show twinkling effect?

Q.17 Only the starts near the horizon twinkle while those overhead do not twinkle. Why?

Q.18 An empty test tube dipped into water in a beaker appears silvery, when viewed from a suitable direction. Why?

Q.19 (a) A concave mirror and a convex lens are held in water. What change, if any, do you expect to find in the focal length of either?

(b) On a hot summer day in a desert, one sees the reflected image of distant parts of the sky. (This is sometimes mistaken by the observer to be the reflection of t he sky in some distant lake of water. This illusion is called a mirage). Explain.

(c) What is the twinkling effect of starlight due to ?

(d) Watching the sunset on a beach, one can see the sun for several minutes after it has 'actually set'. Explain.

Q.20 A right–angle prism is placed before an object in the two positions shown in figure. The prism is made of crown glass with critical angle equal to 41^o. Trace the paths of two rays from P and Q normal to the hypotenuse in figure, and parallel to the hypotenuse in figure.

Q.21 The image of a candle is formed by a convex lens on a screen. The lower half of the lens is painted black to make it completely opaque. Draw the ray diagram to show the image formation. How will this image be different from the one obtained when the lens is not painted black?

Q.22 A convex lens made of material of refractive index 'n_2' is held in a reference medium of refractive index 'n_1'. Trace the path of a parallel beam of light passing through the lens when (i) $n_1 = n_{2'}$ (ii) $n_1 < n_2$ and (iii) $n_1 > n_2$.

Q.23 A concave lens made of material of refractive index 'n_2' is held in a reference medium of refractive index 'n_1'. Trace the path of parallel beam of light passing the lens when:

(i) $n_1 = n_{2'}$ (ii) $n_1 < n_2$ and (iii) $n_1 > n_2$

Q.24 (a) People usually prefer light–coloured dresses during summer and dark dresses during winter. Why?

(b) How would a blue object appear under sodium lamp light?

(c) What does a welder protect against when the wears a mask?

(d) Explain why the sky is blue, and the sun appears red at sunset.

Q.25 Answer the following questions:

(a) Do materials always have the same colour whether viewed by reflected light or through transmitted light?

(b) What colour do you observe when while light passes through a blue and yellow filter?

Q.26 A beam of white light on passing through a hollow prism gives no spectrum. Why?

Q.27 Dispersion is caused by refract ion not by reflection. Why?

Q.28 Four double convex lenses, with the following specifications are available:

Lens	*Focal Length*	*Aperture*
A	100 cm	10 cm
B	100 cm	5 cm
C	10 cm	2 cm
D	5 cm	2 cm

Which two of the given four lenses, should be selected as the objective and eyepiece to construct an astronomical telescope and why? What will be the magnifying power and normal length of the telescope tube so constructed?

Q.29 In a telescope, the objective has a large aperture while the eyepiece has a small aperture. Why?

Q.30 Give reasons for the following observations on the surface of moon:

(i) Sunrise and sunset are abrupt (ii) Sky appears dark (iii) A rainbow is never formed

Q.31 Parallel light from the collimator of a spectrometer is incident on the two faces of a prism which make the refracting angle A of the prism. The image of the collimator slit is observed in two different positions of the telescope of the spectrometer. If the angle of rotation of the telescope between the two positions is 144^o, what is the angle A of the prism?

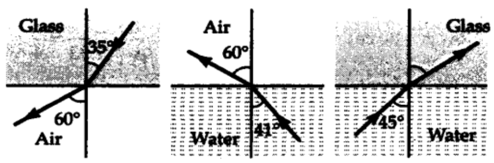
NCERT Exercise

1. A small candle 2.5 cm in size is placed 27 cm in front of a concave mirror of radius of curvature 36 cm. At what distance from the mirror should a screen be placed in order to receive a sharp image? Describe the nature and size of the image. If the candle is moved closer to the mirror, how would the screen have to be moved?

2. A 4.5 cm needle is placed 12 cm away from a convex mirror of focal length 15 cm. Give the location of the image and the magnification. Describe what happens as the needle is moved farther from the mirror.

3. A tank is filled with water to a height of 12.5 cm. The apparent depth of a needle lying at the bottom of the tank is measured by a microscope to be 9.4 cm. What is the refractive index of water? If water is replaced by a liquid of refractive index 1.63 up to the same height, by what distance would the microscope have to be moved to focus on the needle again?

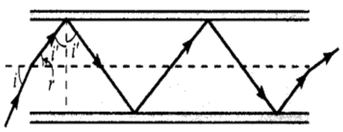
4. As shown in figure (a) and (b) show refraction of an incident ray in air at 60^o with the normal to a glass air and water air interface, respectively. Predict the angle of refraction of an incident ray in water at 45^o with the normal to a water glass interface as shown in figure (c).



(a) (b) (c)

5. A small bulb is placed at the bottom of a tank containing water to a depth of 80 cm. What is the area of the surface of water through which light from the bulb can emerge out ? Refractive index of water is 1.33. Consider the bulb to be a point source.
6. A prism is made of glass of unknown refractive index. A parallel beam of light is incident on a face of the prism. The angle of minimum deviation is measured to be 40°. What is the refractive index of the material of the prism? The refracting angle of the prism is 60°. If the prism is placed in water (refractive index 1.33), predict the new angle of minimum deviation of a parallel beam of light.
7. Double-convex lenses are to be manufactured from a glass of refractive index 1.55, with both faces of the same radius of curvature. What is the radius of curvature required if the focal length of the lens is to be 20 cm ?
8. A beam of light coverage to a point? A lens is placed in the path of the convergent beam 12 cm from P. At what point does the beam converge if the lens is (a) a convex lens of focal length 20 cm, (b) a concave lens of focal length 16 cm?
9. An object of size 3.0 cm is placed 14 cm in front of a concave lens of focal length 21 cm. Describe the image produced by the lens. What happens if the object is moved further away from the lens ?
10. What is the focal length of a combination of a convex lens of focal length 30 cm and a concave lens of focal length 20 cm? Is the system a converging or a diverging lens? Ignore thickness of the lenses.
11. A compound microscope consists of an objective lens of focal length 2.0 cm and an eyepiece of focal length 6.25 cm separated by a distance of 15 cm. How far from the objective should an object be placed in order to obtain the final image at (i) the least distance of distinct vision (25cm) &, (ii) infinity ? What is the magnifying power of the microscope in each case?
12. A person with a normal near point (25 cm) using a compound microscope with an objective of focal length 8.0 mm and eyepiece of focal length 2.5 cm can bring an object placed 9.0 mm from the objective in sharp focus. What is the separation between the two lenses? How much is the magnifying power of the microscope?
13. A small telescope has an objective lens of focal length 144 cm and an eyepiece of focal length 6.0 cm. What is the magnifying power of the telescope? What is the separation between the objective and the eyepiece?
14. (i) A giant refracting telescope at an observatory has an objective lens of focal length 15 m. If an eyepiece of focal length 1.0 cm is used, what is angular magnification of the telescope?
    (ii) If this telescope is used to view the moon, what is the diameter of the image of the moon formed by the objective lens? The diameter of moon is 3.48×10^6 m, and radius of lunar orbit is 3.8×10^8 m

15. Use the mirror equation to deduce that:
    (a) an object placed between *f* and 2*f* of a concave mirror produces a real image beyond 2*f*.
    (b) a convex mirror always produces a virtual image independent of the location of the object.
    (c) the virtual image produced by a convex mirror is always diminished in size and is located between the focus and the pole.
    (d) an object placed between the pole and focus of a concave mirror produces a virtual and enlarged image
16. A small pin fixed on a table top is viewed from above from a distance of 50 cm. By what distance would the pin appear to be raised f it is viewed from the same point through a 15 cm thick glass slab held parallel to the table ? Refractive index of glass = 1.5. Does the answer depend on the location of the slab?
17. As shown in the figure a cross-section of a 'light- pipe' made of a glass fiber of refractive index 1.68. The outer covering of the pipe is made of a material of refractive index 1.44. What is the range of the angles of the incident rays with the axis of the pipe for which total reflections inside the pipe take place as shown.



18. Answer the following questions:

(a) You have learnt that plane and convex mirrors produce virtual images of objects. Can they produce real image under some circumstances ? Explain.

(b) A virtual image, we always say, cannot be caught on a screen. Yet when we 'see' a virtual image, we are obviously bringing it on to the 'screen' (i.e., the retina) of our eye. Is there a contradiction ?

(c) A diver under water, looks obliquely at a fisherman standing on the bank of a lake. Would the fisherman look taller or shorter to the diver than what he actually is ?

(d) Does the apparent depth of a tank of water change if viewed obliquely? If so, does the apparent depth increase or decrease ?

(e) The refractive index of diamond is much greater than that of ordinary glass. Is this fact of some use to a diamond cutter ?

19. The image of a small electric bulb fixed on the wall to a room is to be obtained on the opposite wall 3 m away by means of a large convex lens. What is the maximum possible focal length of the lens required for the purpose ?

20. A screen is placed 90 cm from an object, the image of the object on the screen is formed by a convex lens at two different locations separated by 20 cm. Determine the focal length of the lens.

21. (a) Determine the 'effective focal length' of the combination of the two lenses in question 7, if they are placed 8.0 cm apart with their principal axes coincident. Does the answer depend on which side a beam of parallel light is incident? Is the notion of effective focal length of this system useful at all?

(b) An object 1.5 cm in size is placed on the side of the convex lens in the above arrangements. The distance between the object and the convex lens is 40 cm. Determine the magnification produced by the two-lens system, and the size of the image.

22. At what angle should a ray of light be incident on the face of a prism of refracting angle 60^o so that it just suffers total internal reflection at the other face? The refractive index of the prism is 1.524.

23. You are given prisms made of crown glass and flint glass with a variety of angles. Suggest a combination of prisms which will (a) deviate a pencil of white light without much dispersion, (b) disperse (and displace) a pencil of white light without much deviation.

24. For a normal eye, the far point is at infinity and the near point of distinct vision is about 25 cm in front of the eye. The cornea of the eye provides a converging power of about 40 dioptres, and the least converging power of the eyelens behind the cornea is about 20 diopters. From this rough data estimate range of accommodation (i.e., range of converging power of its eyelens) of a normal eye.

25. Does short–sightedness (myopia) or long–sightedness (hypermetropia) imply necessarily that the eye has partially lost its ability of accommodation? If not, what might cause these defects of vision?

26. A myopic person has been using spectacles of power – 1.0 dioptre for distant vision. During old age he also needs to use separate reading glass of power + 2.0 dioptres. Explain what may have happened.

27. A person looking at a person wearing a shirt with a pattern comprising vertical and horizontal lines is able to see the verticallines more distinctly than the horizontal ones. What is this defect due to? How is such a defect of vision corrected?

28 A man with normal near point (25 cm) reads a book with small print using a magnifying glass : a thin convex lens of focal length 5 cm.

(a) What is the closest and the farthest distance at which he can read the book when viewing through the magnifying glass?

(b) What is the maximum and the minimum angular magnification (Magnifying power) possible using the above simple microscope?

29. A card sheet divided into squares each of size 1 mm^2 being viewed at a distance of 9 cm held close to the eye.

(a) What is magnification produced by lens? How much is the area of each square in the virtual image? If the focal length of lens is 10 cm.

(b) What is the angular magnification (magnifying power) of the lens?

(c) Is the magnification in (a) equal to the magnifying power in (b)? Explain.

30. (a) At what distance should the lens be held from the figure in Q.29 in order to view the squares distinctly with the maximum possible magnifying power?

(b) What is the magnification in this case?

(c) Is the magnification equal to the magnifying power in this case? Explain.

31. What should be the distance between the object in Q.30 and the magnifying glass if the virtual image of each square in the figure is to have as area of 6.25 mm^2? Would you be able to see the squares distinctly with your eyes very close to the magnifier?

32. Answer the following questions:

(a) The angle subtended at the eye by an object is equal to the angle subtended at the eye by the virtual image produced by a magnifying glass. In what sense then does a magnifying glass provide angular magnification?

(b) In viewing through a magnifying glass, one usually positions one's eyes very close to the lens. Does angular magnification change if the eye is moved back?

(c) Magnifying power of a simple microscope is inversely proportional to the focal length of the lens. What then stops us from using a convex lens of smaller and smaller focal length and achieving greater and greater magnifying power?

(d) Why must both the objective and the eye-piece of a compound microscope have short focal lengths?

(e) When viewing through a compound microscope, our eyes should be positioned not on the eye-piece but a short distance away from it for best viewing. Why? How much should be that short distance between the eye and eye-piece?

33. An angular magnification (magnifying power) of 30 *X* is desired using an objective of focal length 1.25 cm and an eyepiece of focal length 5 cm How will you set up the compound microscope ?

34. A small telescope has an objective lens of focal length 140 cm and an eyepiece of focal length 5.0 cm. What is the magnifying power of the telescope for viewing distant objects when

(a) the telescope is in normal adjustment (i.e., when the final image is at infinity),

(b) the final image is formed at the least distance of distinct vision (25 cm) ?

35.(a) For the telescope described in Q. 34(a), what is the separation between the objective lens and the eyepiece ?

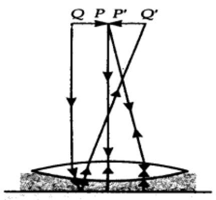
(b) If this telescope is used to view a 100 m tall tower 3 km away, what is the height of the image of the tower formed by the objective lens ?

(c) What is the height of the final image of the tower if it is formed at 25 cm?

36. A Cassegrain telescope uses two mirrors as shown in figure. Such a telescope is built with the mirror 20 mm apart. If the radius of curvature of the large mirror is 220 mm and the small mirror is 140 mm, where will the final image of an object at infinity be?

37. Light incident normally on plane mirror attached to a galvanometer coil retraces backward as shown. A current in the coil produces a deflection of 3.5° of the mirror. What is the displacement of the reflected spot of light on a screen placed 1.5m away?

38. In the figure an equi–convex lens (of refractive index 1.50) in contact with a liquid layer on top of a plane mirror. A small needle with its tip on the principal axis is moved along the axis until its inverted image is found at the position of the needle. The distance of the needle from the lens is measured to be 45.0 cm. The liquid is removed and the experiment is repeated. The new distance is measured to be 30.0 cm. What is the refractive index of the liquid.



Answers

1.	– 54 cm , – 5 cm, real	2.	6.67 cm , 2.5 cm	3.	1.33, 1.7 cm
4.	38.2°	5.	2.6 m^2	6.	1.532 , 10°20′
7.	22.0 cm	8.	(a) 7.5 cm (b) 48 cm	9.	– 8.4 cm , 1.8 cm
10.	– 60 cm	11.	(i) 2.5 cm , 20 (ii) 2.59 cm , 13.5		

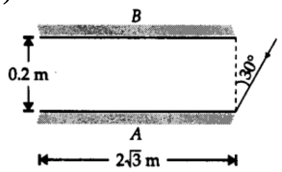
12. 11, 9.47 cm, 88 13. 24, 150 cm 14. (i) 1500 (ii) 13.73 cm
16. 5 cm 17. (i) $0 < i < 60^o$, (ii) $53.5^o < i < 90^o$
19. 0.75 m
20. 21.4 cm 21. (a) (i) – 220 cm (ii) – 420 cm (b) 0.652, 0.98 cm
22. 30^o 24. 22 to 24 dioptres 26. + 2 dioptres
28. (a) 4.2 cm , 5 cm (b) 6, 5 29. (i) 1 cm^2 (ii) 2.8 (iii) no
30. (i) – 7.14 cm (ii) 3.5 (iii) 3.5, yes 31. No
33. The separation between the objective and eye piece = 11.67 cm, object should be placed 1.5 cm from the objective
34. (i) 28, (ii) 33.6 35. (a) 145 cm, (b) 4.67 cm , (c) 28 cm
36. – 315 mm 37. 18.4 cm 38. 1.33

IIT Entrance Exam.

Multiple choice questions with one correct answer.

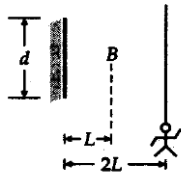
1. An electric bulb illuminates a plane surface. The intensity of illumination on the surface at a point 2m away from the bulb is 5×10^{-4} phot (lumen/sq. cm). The line joining the bulb to the point makes an angle of 60^o with the normal to the surface. The intensity of the bulb in candela is
   (a) $40\sqrt{3}$ (b) 40 (c) 20 (d) 40×10^{-4}

2. Two plane mirrors *A* and *B* are aligned parallel to each other as shown in the figure. A light ray is incident at an angle 30^o at a point just inside one end of *A*. The plane of incidence coincides with the plane of the figure. The maximum number of times the ray undergoes reflection (including the first one), before it emerges out, is



   (a) 28 (b) 30 (c) 32 (d) 34

3. A point source of light *B* is placed at a distance *L* in front of the centre of a mirror of width '*d*' hung vertically on a wall. A man walks in front of the mirror along a line parallel to the mirror at a distance 2*L* from it as shown in the figure. The greatest distance over which he can see the image of the light source in the mirror is

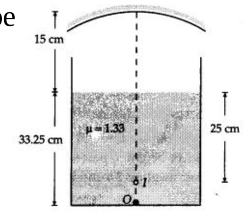


   (a) *d*/2 (b) *d* (c) 2*d* (d) 3*d*

4. When a ray of light enters a glass slab from air
   (a) its wavelength decreases (b) its wavelength increases
   (c) its frequency increases (d) neither its wavelength nor its frequency changes

5. A source emits sound of frequency 600 Hz inside water. The frequency heard in air (velocity of sound in water = 1500 m/s, velocity of sound in air = 300 m/s) will be
   (a) 300 Hz (b) 120 Hz (c) 600 Hz (d) 6000 Hz

6. A container is filled with water (μ = 1.33) upto to height of 33.25 cm. A concave mirror is placed 15 cm above the water level and the image of an object placed at the bottom is formed 25 cm below the water level. The focal length of the mirror is

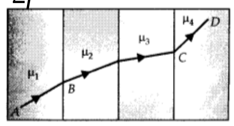


   (a) 10 cm (b) 15 cm (c) 20 cm (d) 25 cm

7. In an experiment to determine the focal length (f) for a concave mirror by *u*-*v* method, a student places the object pin *A* on the principal axis at a distance *x* from the pole *P*. The student looks at the pin and its inverted image from a distance keeping his/her eye in line with *PA*. When the student shifts his/her eye towards left, the image appears to the right of the object pin. Then

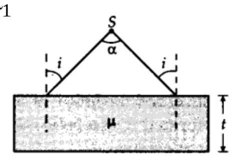
(a) $x < f$ (b) $f < x < 2f$ (c) $x = 2f$ (d) $x > 2f$

8. A ray of light passes through four transparent media with refractive indices μ_1, μ_2, μ_3 and μ_4 as shown in figure. The surfaces of all media are parallel. If the emerged ray CD is parallel to the incident ray AB, we must have



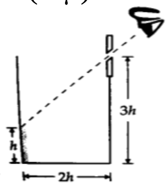
(a) $\mu_1 = \mu_2$ (b) $\mu_2 = \mu_3$ (c) $\mu_3 = \mu_4$ (d) $\mu_4 = \mu_1$

9. A diverging beam of light from a point source S having divergence angle α, falls symmetrically on a glass slab as shown. The angles of incidence of the two extreme rays are equal. If the thickness of the glass slab is t and the refractive index μ, then the divergence angle of the emergent beam is



(a) zero (b) α (c) $\sin^{-1}(t/\mu)$ (d) $2\sin^{-1}(t/\mu)$

10. An observer can see through a pin-hole the top end of a thin rod of height h, placed as shown in the figure. The breaker height is $3h$ and its radius h. When the beaker is filled with a liquid up to a height $2h$, he can see the lower end of the rod. Then, the refractive index of the liquid is



(a) 5/2 (b) $\sqrt{5/2}$ (c) $\sqrt{3/2}$ (d) $3/2$

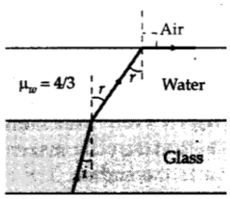
11. A ray of light travelling in water is incident on its surface open to air. The angle of incidence is θ, which is less than the critical angle. Then there will be

(a) only a reflected ray and no refracted ray (b) only a refracted ray and no reflected ray

(c) a reflected ray and a refracted ray and the angle between them would be less than $180^\circ - 2\theta$.

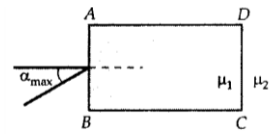
(d) a reflected ray and a refracted ray and the angle between them would be greater than $180^\circ - 2\theta$.

12. A ray of light is incident at the glass-water interface at an angle i. If it emerges finally parallel to the surface of water, then the value of μ_g would be



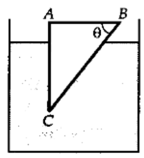
(a) $(4/3)\sin i$ (b) $1/\sin i$ (c) 4/3 (d) 1

13. A rectangular glass slab $ABCD$ of refractive index μ_1 is immersed in water of refractive index $\mu_2 (\mu_1 > \mu_2)$. A ray of light is incident at the surface AB of the slab as shown. The maximum value of the angle of incidence α_{max}, such that the ray comes out only from the other surface CD is given by



(a) $\sin^{-1}\left[\frac{\mu_1}{\mu_2}\cos\left(\sin^{-1}\frac{\mu_2}{\mu_1}\right)\right]$ (b) $\sin^{-1}\left[\mu_1\cos\left(\sin^{-1}\frac{1}{\mu_2}\right)\right]$ (c) $\sin^{-1}\frac{\mu_1}{\mu_2}$ (d) $\sin^{-1}\frac{\mu_2}{\mu_1}$

14. A glass prism of refractive index 1.5 is immersed in water (refractive index 4/3). A light beam incident normally on the face AB is totally reflected to reach on the face BC if



(a) $\sin\theta \geq \frac{8}{9}$ (b) $\frac{2}{3} < \sin\theta < \frac{8}{9}$ (c) $\sin\theta \leq \frac{2}{3}$

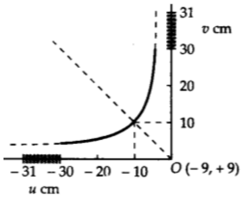
15. A point object is placed at the centre of a glass sphere of radius 6 cm and refractive index 1.5. The distance of the virtual image from the surface of the sphere is

(a) 2 cm (b) 4 cm (c) 6 cm (d) 12 cm

16. A convex lens A of focal length 20 cm and a concave lens of focal length 5 cm are kept along the same axis with a distance d between them. If a parallel beam of light falling on A leaves B as parallel beam, then the distance d (in cm) will be

(a) 25 (b) 15 (c) 30 (d) 50

17. The graph shows the relationship between object distance u and image distance v for a equi-convex lens. The focal length of the convex lens is



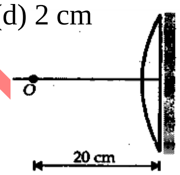
(a) 0.50 ± 0.05 cm (b) 0.050 ± 0.10 cm

(c) $5.00 + 0.05$ cm (d) $5.00 + 0.10$ cm

18. The size of the image of an object, which is at infinity, as formed by a convex lens of focal length 30 cm is 2 cm. If a concave lens of focal length 20 cm is placed between the convex lens and the image at a distance of 26 cm from the convex lens, calculate the new size of the image.

(a) 1.25 cm (b) 2.5 cm (c) 1.05 cm (d) 2 cm

19. A point object is placed at a distance of 20 cm from a thin planoconvex lens of focal length 15 cm. The plane surface of the lens is now silvered. The image created by the system is at



(a) 60 cm to the left of the system (b) 60 cm to the right of the system

(c) 12 cm to the left of the system (d) 12 cm to the right of the system

20. A hollow double concave lens is made of very thin transparent material. It can be filled with air or either of two liquids L_1 and L_2 having refractive indices μ_1 and μ_2 respectively $(\mu_2 > \mu_1 > 1)$. The lens will diverge a parallel beam of light, if it is filled with

(a) air and placed in air (b) air and immersed in L_1

(c) L_1 and immersed in L_2 (d) L_2 and immersed in L_1

21. A concave lens of glass, refractive index 1.5, has both surfaces of the same radius of curvature R. On immersion in a medium of refractive index 1.75, it will behave as

(a) convergent lens of focal length 3.5 R (b) convergent lens of focal length 3.0 R

(c) divergent lens of focal length 3.5 R (d) divergent lens of focal length 3.0 R

22. An eye specialist prescribes spectacles having combination of convex lens of focal length 40 cm in contact with a concave lens of focal length 25 cm. The power of this lens combination, in dioptre, is

(a) + 1.5 (b) – 1.5 (c) + 6.67 (d) – 6.67

23. A convex lens is in contact with concave lens. The magnitude of the ratio of their focal length is 2/3. Their equivalent focal length is 30cm. What are their individual focal lengths?

(a) – 75, 50 (b) – 10, 15 (c) 75, 50 (d) – 15, 10

24. Rays of light from the sun fall on a biconvex lens of focal length f and the circular image of the sun of radius r is formed on the focal plane of the lens. Then

(a) area of image is πr^2 and area is directly proportional of f

(b) area of the image is πr^2 and area is directly proportional of f^2

(c) intensity of the image increases if f is increased

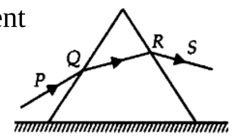
(d) If lower half of the lens is covered with black paper, area will become half.

25. Spherical aberration, in a thin lens can be reduced by

(a) using a monochromatic light (b) using a doublet combination

(c) using a circular annular mask over the lens (d) increasing the size of the lens

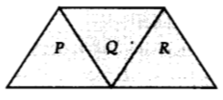
26. An equilateral prism is placed on a horizontal surface. A ray PQ is incident onto it. For minimum deviation



(a) PQ is horizontal (b) QR is horizontal

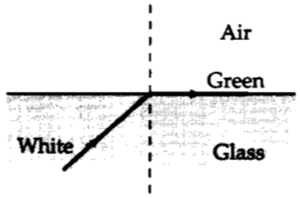
(c) RS is horizontal (d) any one will be horizontal

27. A given ray of light suffers minimum deviation in an equilateral prisms *P*. Additional prisms *Q* and *R* of identical shape and of the same material as *P* are now added as shown in the figure. The ray will suffer



(a) greater deviation (b) no deviation (c) same deviation as before (d) total internal reflection

28. A beam of white light is incident on glass–air interface from glass to air such that green light just suffers total internal reflection. The colours of the light which will come out to air are



(a) yellow, orange, red (b) violet, indigo, blue
(c) all colours (d) all colurs except green

29. Which one of the following spherical lenses does not exhibit dispersion? The radii of curvature of the surfaces of the lenses are as given in the diagrams.

(a) 

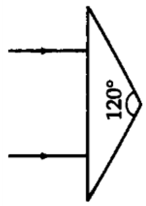
(b) 

(c) 

(d) 

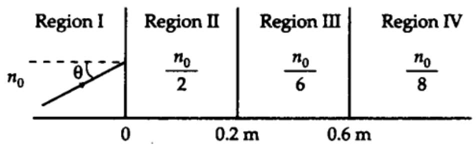
30. Two beams of red and violet colours are made to pass separately through a prism (angle of the prism is 60^0). In the position of minimum deviation, the angle of refraction will be
(a) 30° for both the colours (b) greater for the violet colour
(c) greater for the red colour (d) equal but not 30° for both the colours.

31. An isosceles prism of angle 120° has a refractive index 1.44. Two parallel monochromatic rays enter the prism parallel to each other in air as shown. The rays emerge from the opposite faces



(a) are parallel to each other (b) are diverging
(c) make an angle $2[\sin^{-1}(0.72) - 30°]$ with each other
(d) make in angle $2\sin^{-1}(0.72)$ with each other

32. A light beam is travelling from Region I to Region IV as shown in the figure. The refractive index in Regions, I, II, III and IV are $n_0, \frac{n_0}{2}, \frac{n_0}{6}$ and $\frac{n_0}{8}$, respectively. The angle of incidence θ for which beam just misses entering region IV is



(a) $\sin^{-1}\left(\frac{3}{4}\right)$ (b) $\sin^{-1}\left(\frac{1}{8}\right)$ (c) $\sin^{-1}\left(\frac{1}{4}\right)$ (d) $\sin^{-1}\left(\frac{1}{3}\right)$

33. In a compound microscope, the intermediate image is
(a) virtual, erect and magnified (b) real, erect and magnified
(c) real , inverted and magnified (d) virtual, erect and reduced

34. The focal lengths of the objective and the eye piece of a compound microscope are 2.0 cm and 3.0 cm, respectively. The distance between the objective and the eyepiece is 15.0 cm. The final image formed by the eyepiece is at infinity. The two lenses are thin. The distance in cm of the object and the image produced by the objective, measured from the objective lens, are respectively.
(a) 2.4 and 12.0 (b)2.4 and 15.0 (c) 2.0 and 12.0 (d) 2.0 and 3.0

Multiple choice questions with one or more than one correct answers

35. A ray of light travelling in a transparent medium falls on a surface separating the medium from air at an angle of incidence of 45°. The ray undergoes total internal reflection. If μ is refractive index of the medium w.r.t. air, select the possible value(s) of μ from the following:

(a)1.3 (b) 1.4 (c) 1.5 (d) 1.6

36. A concave mirror is placed on a horizontal table with its axis directed vertically upwards. Let *O* be the pole of the mirror and *C* its centre of curvature. A point object is placed at *C*. It has a real image, also located at *C*. If the mirror is now filled with water, the image will be

(a) real and will remain at *C* (b) real and located at a point between *C* and infinity

(c) virtual and located at a point between *C* and *O* (d) real and located at a point between *C* and *O*.

37. Which of the following form(s) a virtual and erect image for all positions of the object?

(a) convex lens (b) concave lens (c) convex mirror (d) concave mirror.

38. A spherical surface of radius of curvature *R* separates air (refractive index 1.0) from glass (refractive index 1.5). The centre of curvature is in the glass. A point object *P* placed in air is found to have a real image Q in glass. The line *PQ* cuts the surface at a point *O* and *PO* = *OQ*. The distance *PO* is equal to

(a) 5R (b) 3R (c) 2R (d) 1.5R

39. A double convex lens of refractive index μ_1 is immersed in a liquid of refractive index μ_2. The lens will act as

(a) diverging lens, if $\mu_1 > \mu_2$ (b) diverging lens, if $\mu_1 < \mu_2$

(c) converging lens, if $\mu_1 > \mu_2$ (d) converging lens, if $\mu_1 < \mu_2$

40. A converging lens is used to form an image on a screen. When the upper half of the lens is convered by an opaque screen,

(a) half the image will disappear (b) complete image will be formed

(c) intensity of image will decrease (d) intensity of image will increase

41. A real image of a distant object is formed by a plano-convex lens on its principal axis. Spherical aberration

(a) is absent (b) is smaller, if the curved surface of the lens faces the object

(c) is smaller, if the plane surface of the lens faces the object

(d) is the same, whichever side of the lens faces the object.

42. A diminished image of an object is to be obtained on a screen 1.0 m from it. This can be achieved by a appropriately placing

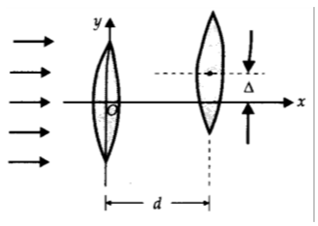
(a) a concave mirror of suitable focal length (b) a convex mirror of suitable focal length

(c) a convex lens of focal length less than 0.25 m (d) a concave lens of suitable focal length.

43. A short linear object of length b lies along the axis of a concave mirror of focal length f at a distance u from the pole of the mirror. The size of the image is approximately equal to

(a) $b\left(\frac{u-f}{f}\right)^{\frac{1}{2}}$ (b) $b\left(\frac{f}{u-f}\right)^{\frac{1}{2}}$ (c) $b\left(\frac{u-f}{f}\right)$ (d) $b\left(\frac{f}{u-f}\right)^{2}$

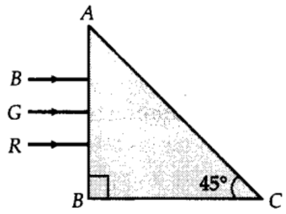
44. Two thin convex lenses of focal lengths f_1 and f_2 are separated by a horizontal distance *d* (where $d < f_1, d < f_2$) and their centres are displaced by a vertical separation Δ as shown in the figure. Taking the origin of coordinates *O*, at the centre of the first lens the *x* and *y* coordinates of the focal point of this lens system, for a parallel beam of rays coming from the left, are given by



(a) $x = \frac{f_1 f_2}{f_1 + f_2}$, $y = \Delta$ (b) $x = \frac{f_1(f_2 + d)}{f_1 + f_2 - d}$, $y = \frac{\Delta}{f_1 + f_2}$

(c) $x = \frac{f_1 f_2 + d(f_1 - d)}{f_1 + f_2 - d}$, $y = \frac{\Delta(f_1 - d)}{f_1 + f_2 - d}$ (d) $x = \frac{f_1 f_2 + d(f_1 - d)}{f_1 + f_2 - d}$, $y = 0$

45. A beam of light consisting of red, green and blue colours is incident on a right angled prism. The refractive index of the material of the prism for the above red, green and blue wavelengths are 1.39, 1.44 and 1.47 respectively. The prism will



(a) separate part of the red colour from the green and blue colours
(b) separate part of the blue colour from the red and green colours
(c) not separate even partially any colour from the other two colours.
(d) separate all the three colours from one another

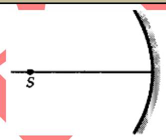
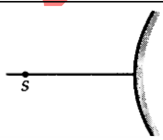
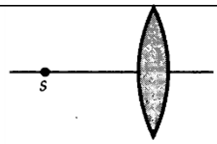
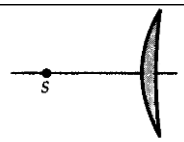
46. A thin prism P_1 with angle 4^o and made from glass of refractive index 1.54 is combined with another prism P_2 made from glass of refractive index 1.72 to produce dispersion without deviation. The angle of prism P_2 is
(a) 5.33^o (b) 4^o (c) 3^o (d) 2.6^o

47. Astronomical telescope has an angular magnification of magnitude 5 for distant objects. The separation between the objective and the eye piece is 36 cm and the final image is formed at infinity. The focal length f_0 of the objective and the focal length f_e of the eyepiece are
(a) $f_0 = 45$ cm and $f_e = -9$ cm (b) $f_0 = 50$ cm and $f_e = 10$ cm
(c) $f_0 = 7.2$ cm and $f_e = 5$ cm (d) $f_0 = 30$ cm and $f_e = 6$ cm

48. A planet is observed by an astronomical refractive telescope having an objective of focal length 16m and an eyepiece of focal length 2 cm.
(a) The distance between the objective and the eyepiece is 16.02 m
(b) The angular magnification of the planet is – 800
(c) The image of the planet is inverted (d) The objective is larger than the eyepiece

Matrix–Match type

49. An optical component and an object S placed along its optic axis are given in Column I. The distance between the object and the component can be varied. The properties of images are given in Column II. Match all the properties of images from Column II with the appropriate components given in Column I.

Column – I		**Column – II**	
(a)		(p)	Real image
(b)		(q)	Virtual image
(c)		(r)	magnified image
(d)		(s)	Image at infinity

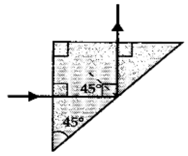
Answers

1.	B	**2.**	B	**3.**	D	**4.**	A	**5.**	C	**6.**	A	**7.**	B	**8.**	D
9.	B	**10.**	B	**11.**	C	**12.**	B	**13.**	A	**14.**	A	**15.**	C	**16.**	B
17.	C	**18.**	B	**19.**	C	**20.**	D	**21.**	A	**22.**	B	**23.**	D	**24.**	B
25.	C	**26.**	B	**27.**	C	**28.**	A	**29.**	B	**30.**	A	**31.**	C	**32.**	B
33.	C	**34.**	A	**35.**	C,D	**36.**	D	**37.**	B,C	**38.**	A	**39.**	B,C	**40.**	B,C
41.	B	**42.**	A,C	**43.**	D	**44.**	C	**45.**	A	**46.**	C	**47.**	D	**48.**	A,B,C,D

49. (A) $\rightarrow$ P, Q, R, S ; (B) $\rightarrow$ Q ; (C) $\rightarrow$ P, Q, R, S ; (D) $\rightarrow$ P, Q, R, S

AIEEE

1. To get three images of a single object, one should have two plane mirrors at an angle of
(a) 60^o (b) 90^o (c) 120^o (d) 30^o



2. A light ray is incident perpendicular to one face of a 90^o prism and is totally internally reflected at the glass–air interface. If the angle of reflection is 45^o , we conclude that the refractive index .
(a) $\mu < 1/\sqrt{2}$ (b) $\mu > \sqrt{2}$ (c) $\mu > 1/\sqrt{2}$ (d) $\mu < \sqrt{2}$

3. A fish looking up through the water sees the outside world, contained in a circular horizon. If the refractive index of water is 4/3 and the fish is 12 cm below the water surface, the radius of this circle (in cm) is
(a) $36\sqrt{7}$ (b) $36/\sqrt{7}$ (c) $36\sqrt{5}$ (d) $4\sqrt{5}$

4. Which of the following is used in optical fibres?
(a) Total internal reflection (b) Scattering (c) Diffraction (d) Refraction

5. Two lenses of power – 15D and + 5D are in contact with each other. The focal length of the combination is
(a) + 10 cm (b) – 20 cm (c) – 10 cm (d) + 20 cm

6. A thin glass (refractive index 1.5) lens has optical power of – 5D in air. Its optical power in a liquid medium with refractive index 1.6 will be
(a) 1 D (b) – 1 D (c) 25 D (d) 0.625 D

7. A plano–convex lens of refractive index 1.5 and radius of curvature 30 cm is silvered at the curved surface. Now this lens has been used to form the image of an object. At what distance from this lens, an object be placed in order to have a real image of the size of the object?
(a) 20 cm (b) 30 cm (c) 60 cm (d) 80 cm

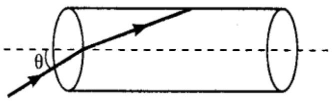
8. The refractive index of glass is 1.520 for red light and 1.525 for blue light. Let δ_1 and δ_2 be angles of minimum deviatin for red and blue light respectively in a prism of this glass, then
(a) δ_1 can be less than or greater than δ_2, depending upon the values of δ_1 and δ_2
(b) $\delta_1 > \delta_2$ (c) $\delta_1 < \delta_2$ (d) $\delta_1 = \delta_2$

9. The image formed by an objective of a compound microscope is
(a) virtual and diminished (b) real and diminished
(c) real and enlarged (d) virtual and enlarged

10. An astronomical telescope has a large aperture to
(a) reduce spherical aberration (b) have high resolution

(c) increase span of observation (d) have low dispersion

11. A transparent solid cylindrical rod has a refractive index of $\frac{2}{\sqrt{3}}$. It is surrounded by air. A light ray is incident at the midpoint of one end of the rod as shown in the figure. The incident angle θ for which the light ray grazes along the wall of the rod is



(a) $\sin^{-1}\left(\frac{1}{2}\right)$ (b) $\sin^{-1}\left(\frac{\sqrt{3}}{2}\right)$ (c) $\sin^{-1}\left(\frac{2}{\sqrt{3}}\right)$ (d) $\sin^{-1}\left(\frac{1}{\sqrt{3}}\right)$

12. In an optics experiment, with the position of the object fixed, a student varies the position of a convex lens and for each position, the screen is adjusted to get a clear image of the object. A graph between the object distance *u* and the image distance *v*, from the lens, is plotted using the same scale for the two axes. A straight line passing through the origin and making an angle of 45^{o} with the *x*–axis meets the experimental curve at *P*. The coordinates of *P* will be

(a) (2*f*, 2*f*) (b) $\left(\frac{f}{2}, \frac{f}{2}\right)$ (c) (f, f) (d) $(4f, 4f)$

Answers

1.	B	**2.**	B	**3.**	B	**4.**	B	**5.**	C	**6.**	C	**7.**	A	**8.**	C
9.	C	**10.**	B	**11.**	D	**12.**	A								

DCE and Indraprastha University Engineering Entrance Exam.

1. Two plane mirrors are inclined to each other at an angle of 60^{o}. A point object is placed in between them. The total number of images produced by both the mirrors is
(a) 2 (b) 4 (c) 5 (d) 6

2. A boy 1.5 m tall with his eye level at 1.38m stands before a mirror fixed on a wall. The minimum length of mirror required to view the complete image of boy is
(a) 0.75 m (b) 0.06 m (c) 0.69 m (d) 0.12

3. A pencil of light rays falls on a plane mirror and forms a real image, so the incident rays are
(a) parallel (b) diverging (c) converging (d) statement is false

4. For a real object, which of the following can produce a real image?
(a) plane mirror (b) concave lens (c) convex mirror (d) concave mirror

5. Which mirror is to be used to obtain a parallel beam of light from a small lamp?
(a) plane mirror (b) convex mirror (c) concave mirror (d) any one of the above.

6. When a plane electromagnetic wave enters a glass slab, then which of following will not change?
(a) wavelength (b) frequency (c) speed (d) amplitude.

7. If wavelength of light in air is 2400×10^{-10} m, then what will wavelength of light glass (μ = 1.5)?
(a) 1600 Å (b) 7200 Å (c) 1080 Å (d) None of these

8. Why is refractive index in a transparent medium greater than one?
(a) because the speed of light in vacuum is always less than speed in a transparent medium
(b) because the speed of light in vacuum is always greater than the speed in a transparent medium
(c) frequency of wave changes when it crosses medium (d) none of the above

9. The wavelength of sodium light in air is 5890 Å. The velocity of light in air is 3×10^{8} ms^{-1}. The wavelength of light in a glass of refractive index 1.6 would be close to
(a) 5890 Å (b) 3681 Å (c) 9424 Å (d) 15078 Å

10. To a fish under water, viewing obliquely a fisherman standing on the bank of a lake, the man looks
(a) taller than what he actually is (b) shorter than what he actually is
(c) the same height as he actually is (d) depends on the obliquity

11. A glass slab (μ = 1.5) of thickness 6 cm is placed over a paper. What is the shift in the letters?

(a) 4 cm (b) 2 cm (c) 1 cm (d) none of these

12. A transparent cube contains a small air bubble. Its apparent distance is 2 cm when seen through one face and 5 cm when seen through other face. If the refractive index of the material of the cube is 1.5, then real length of the edge of cube must be

(a) 7 cm (b) 7.5 cm (c) 10.5 cm (d) $\frac{14}{3}$ cm

13. A transparent cube of 0.21 m edge contains a small air bubble. Its apparent distance when viewed through one face of the cube is 0.10 m and when viewed from the opposite face is 0.04 m. The actual distance of the bubble from the second face of the cube is

(a)0.06m (b)0.17m (c) 0.05 m (d) 0.04 m

14. Light traveling from a transparent medium to air undergoes total internal reflection at an angle of incidence of 45°. Then refractive index of the medium may be

(a) 1.5 (b) 1.3 (c) 1.1 (d) $1/\sqrt{2}$

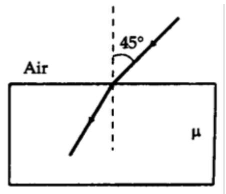
15. The critical angle is maximum when light travels from

(a) water to air (b) glass to air (c) glass to water (d) air to water

16. Critical angle for light going from medium (i) to (ii) is θ. The speed of light in medium (i) is v, then speed in medium (ii) is

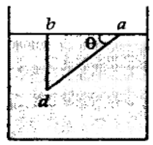
(a) $v(1-\cos\theta)$ (b) $v/\sin\theta$ (c) $v/\cos\theta$ (d) $v(1-\sin\theta)$

17. In the figure shown, for an angle of incidence 45°, at the top surface, what is the minimum refractive index needed for total internal reflection at vertical face?



(a) $\frac{\sqrt{2}+1}{2}$ (b) $\sqrt{\frac{3}{2}}$ (c) $\sqrt{\frac{1}{2}}$ (d) $\sqrt{2}+1$

18. A glass prism of μ = 1.5 is immersed in water as shown in the figure. A beam of light incident normally on the face *ab* is internally reflected from the face *ad* so as to incident normally on face *bd*. Given that refractive index of water is 4/3. What is the value of θ?

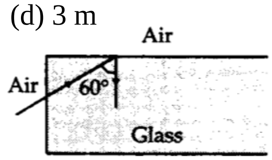


(a) $\theta > \sin^{-1}\left(\frac{8}{9}\right)$ (b) $\theta > \sin^{-1}\left(\frac{2}{3}\right)$ (c) $\theta < \sin^{-1}\left(\frac{2}{3}\right)$ (d) None of these

19. A point source of light is placed 4m below the surface of water of refractive index 5/3. The minimum diameter of a disc, which should be placed over the source, on the surface of water to cut–off all light coming out of water is

(a) infinite (b) 6m (c) 4 m (d) 3 m

20. A light ray from air is incident (as shown in figure) at one end of a glass fiber (refractive index, μ = 1.5) making an incidence angle 60° on the lateral surface, so that it undergoes a total internal reflection. How much time would it take to transverse the straight fibre of length 1 km.



(a) 3.33 μs (b) 6.67 μs (c) 5.77 μs (d) 3.85 μs

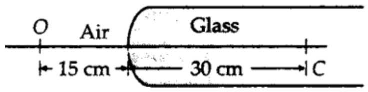
21. In optical fibres, propagation of light is due to

(a) diffraction (b) total internal reflection (c) reflection (d) refraction

22. Sparkling of diamond is due to

(a) reflection (b) dispersion (c) total internal reflection (d) high refractive index of diamond

23. A point object O is placed in front of a glass rod having spherical end of radius of curvature 30cm. The image would be formed at



(a) 30 cm left (b) infinity (c) 1 cm to the right (d) 18 cm to the left

24. The plane face of a planoconvex lens is silvered. If μ be the refractive index and R, the radius of curvature of curved surface, then the system will behave like a concave mirror of radius of curvature

(a) μR (b) $\frac{R}{(\mu-1)}$ (c) $\frac{R^2}{\mu}$ (d) $\left[\frac{(\mu+1)}{(\mu-1)}\right]R$

25. For a given lens, the magnification was found to be twice as larger as when the object was 0.15 m distant from it as when the distance was 0.2m. The focal length of the lens is

(a) 1.5 m (b) 0.20 m (c) 0.10 m (d) 0.05 m

26. Which of the following is a wrong statement?

(a) $D = \frac{1}{f}$, where f is the focal length and D is called the refractive power of a lens

(b) power is expressed in dioptre when f is in metres

(c) power is expressed in dioptre and does not depend on the system of unit used to measure f

(d) D is positive for convergent lens and negative for divergent lens.

27. Two lenses of focal lengths f_1 and f_2 are kept in contact coaxially. The resultant power of combination will be

(a) $\frac{f_1 f_2}{f_1 - f_2}$ (b) $\frac{f_1 + f_2}{f_1 f_2}$ (c) $f_1 + f_2$ (d) $\frac{f_1}{f_2} + \frac{f_2}{f_1}$

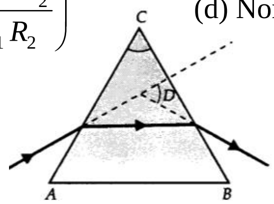
28. Two lenses of power 3D and–1D are kept in contact. What is focal length and nature of combined lens?

(a) 50 cm, convex (b) 200 cm, convex (c) 50 cm, concave (d) 200 cm, concave

29. If two thin lenses are kept coaxially together, then their power is proportional (R_1, R_2 being the radii of curved surfaces) to

(a) $R_1 + R_2$ (b) $\left(\frac{R_1 R_2}{R_1 + R_2}\right)$ (c) $\left(\frac{R_1 + R_2}{R_1 R_2}\right)$ (d) None of these

30. In the given figure, what is the angle of prism?



(a) A (b) B (c) C (d) D

31. A ray incident at 15° on one refracting surface of a prism of angle 60°, suffers a deviation of 55°. What is the angle of emergence?

(a) 95° (b) 45° (c) 30° (d) None of these

32. When white light enters a prism, it gets split into its constituent colours. This is due to

(a) high density of prism material (b) because μ is different for different wavelengths

(c) diffraction of light (d) velocity changes for different frequency.

33. Dispersion of light is caused due to

(a) wavelength (b) intensity of light (c) density of medium (d) none of these

34. A thin prism P_1 with angle 4° made from a glass of refractive index 1.54 is combined with another thin prism P_2 made from glass of refractive index 1.72 to produce dispersion without deviation. The angle of the prism P_2 is

(a) 5.33° (b) 4° (c) 3° (d) 2.6°

35. White light is incident on one of the refracting surfaces of a prism of angle 5^o. If the refractive indices for red and blue colours are 1.641 and 1.659 respectively, the angular separation between these two colours when they emerge out of the prism is
(a) 0.9^o (b) 0.09^o (c) 18^o (d) 12^o

36. The sky would appear red instead of blue if
(a) atmospheric particles scatter blue light more than red light
(b) atmospheric particles scatter all colours equally
(c) atmospheric particles scatter red light more than blue light (d) the sun was much hotter

37. A setting sun appears to be at an altitude higher than it really is. This is because of
(a) absorption of light (b) reflection of light (c) refraction of light (d) dispersion of light.

38. The reddish appearance of rising and setting sun is due to
(a) reflection of light (b) diffraction of light (c) scattering of light (d) interference of light

39. In the formation of a rainbow, the light from the sun on water droplets undergoes
(a) dispersion only (b) only total internal reflection
(c) dispersion and total internal reflection (d) none of the above

40. The angular magnification of a simple microscope can be increased by increasing
(a) focal length of lens (b) size of object (c) aperture of lens (d) power of lens

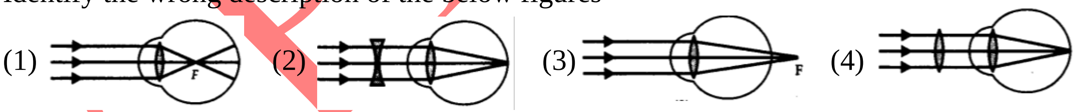
41. For compound microscope $f_0 = 1\text{cm}, \ f_e = 2.5 \text{ cm}$. An object is placed at distance 1.2 cm from objective lens. What should be length of microscope for normal adjustment?
(a) 8.5 cm (b) 8.3 cm (c) 6.5 cm (d) 6.3 cm

42. Magnifying power of an astronomical telescope for normal vision with usual notation is
(a) $-f_0/f_e$ (b) $-f_0 \times f_e$ (c) $-f_e/f_0$ (d) $-f_0 + f_e$

43. F_1 and F_2 are focal lengths of objective and eyepiece respectively of the telescope. The angular magnification for the given telescope is equal to
(a) $\frac{F_1}{F_2}$ (b) $\frac{F_2}{F_1}$ (c) $\frac{F_1 F_2}{F_1 + F_2}$ (d) $\frac{F_1 + F_2}{F_1 F_2}$

44. Focal length of objective and eyepiece of telescope are 200 cm and 4 cm respectively. What is length of telescope for normal adjustment?
(a) 196 cm (b) 204 cm (c) 250 cm (d) 225 cm

45. Identify the wrong description of the below figures



(a) 1 represents far-sightedness (b) 2 correction for short sightedness
(c) 3 represents far-sightedness (d) 4 correction for far-sightedness

46. For normal vision, what is minimum distance of object from eye?
(a) 30 cm (b) 25 cm (c) Infinite (d) 40 cm

47. The focal length of the objective and eyepiece of a telescope are respectively 100 cm and 2 cm. The moon subtends angle of 0.5°, the angle subtended by the moons image will be
(a) 10° (b) 25° (c) 100° (d) 75°

48. A person cannot clearly see distances more than 40 cm. He is advised to use lens of power
(a) – 2.5 D (b) 2.5 D (c) – 6.25 D (d) 1.5 D

49. The light gathering power of a camera lens depends on
(a) its diameter only (b) ratio of diameter and focal length
(c) product of focal length and diameter (d) wavelength of light used

50. Amount of light entering into the camera depends upon
(a) focal length of objective lens
(b) product of focal length and diameter of the objective lens

(c) distance of object from camera (d) aperture setting of the camera

51. Line spectrum can be obtained from
(a) sun (b) candle (c) mercury vapour lamp (d) electric bulb

52. The production of band spectra is caused by
(a) atomic nuclei (b) hot metals (c) molecules (d) electrons

53. White light is passed through a dilute solution by the emergent light is of potassium permanganate. The spectrum produced by the emergent light is
(a) band emission spectrum (b) line emission spectrum
(c) band absorption spectrum (d) line absorption spectrum

54. A typical optical fibre consists of a fine case of a material of refractive index μ_1 , surrounded by a glass or plastic cladding with refractive index μ_2. Then
(a) μ_2 is slightly less than μ_1 (b) μ_2 is slightly greater than μ_1
(c) μ_2 should be equal to μ_1 (d) the difference $\mu_2 - \mu_1$, should be strictly equal to 1

55. A thin lens of glass (μ = 1.5) of focal length + 10 cm is immersed in water (μ = 1.33). The new focal length is
(a) 20 cm (b) 40 cm (c) 48 cm (d) 12 cm

56. In order of increase the angular magnification of a simple microscope, one should increase
(a) the object size (b) the aperture of the lens
(c) the focal length of the lens (d) the power of the lens

Answers

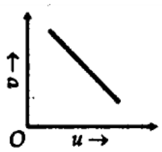
1.	C	**2.**	A	**3.**	C	**4.**	D	**5.**	C	**6.**	B	**7.**	A	**8.**	B
9.	B	**10.**	A	**11.**	B	**12.**	C	**13.**	A	**14.**	A	**15.**	C	**16.**	B
17.	B	**18.**	A	**19.**	B	**20.**	C	**21.**	B	**22.**	C	**23.**	A	**24.**	B
25.	A	**26.**	C	**27.**	B	**28.**	A	**29.**	B	**30.**	C	**31.**	D	**32.**	B
33.	A	**34.**	A	**35.**	B	**36.**	C	**37.**	C	**38.**	C	**39.**	C	**40.**	B
41.	A	**42.**	A	**43.**	A	**44.**	B	**45.**	A	**46.**	B	**47.**	B	**48.**	A
49.	A	**50.**	D	**51.**	C	**52.**	C	**53.**	A	**54.**	A	**55.**	B	**56.**	D

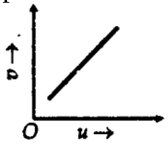
AIIMS Entrance Exam

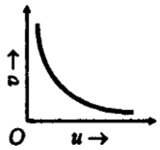
1. Two mirrors are kept at 60° to each other and a body is placed at middle. The total number of images formed is
(a) six (b) four (c) five (d) three

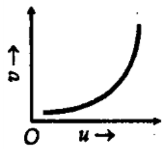
2. A point source kept at a distance of 100 m has a illumination *I*. To change the illumination to 16*I*, the new distance should become
(a) 250 m (b) 500 m (c) 750 m (d) 800 m

3. In an experiment to find the focal length of a concave mirror, a graph is drawn between the magnitude of *u* and *v*. The graph looks like :

(a) 

(b) 

(c) 

(d) 

4. A concave mirror of focal length 15 cm forms an image having twice the linear dimensions of the object. The position of the object, when the image is virtual, will be

(a) 22.5 cm (b) 7.5 cm (c) 30 cm (d) 45 cm

5. When a ray of light enters a glass slab , then
(a) its frequency and velocity change (b) only frequency changes
(c) its frequency and wavelength change (d) its frequency does not change

6. A light wave of frequency v and wavelength λ travels from air to glass. Then
(a) v changes (b) v does not change , λ changes (c) λ does not change (d) v and λ change

7. In refraction, light waves are bent on passing from one medium to the second medium, because in the second medium
(a) the frequency is different (b) the coefficient of elasticity is different
(c) the speed is different (d) the amplitude is smaller

8. A ray of light having wavelength 720 nm enters in a glass of refractive index 1.5. The wavelength of the ray within the glass will be
(a) 360 nm (b) 480 nm (c) 720 nm (d) 1080 nm

9. Light having wavelength λ and of intensity I_0 passes through a material of thickness d. The resultant intensity is
(a) $I = I_0 e^{-d\lambda}$ (b) $I = I_0(1-e^{-d\lambda})$ (c) $I = I_0(1-e^{-d/\lambda})$ (d) $I = I_0 e^{-d/\lambda}$

10. The apparent depth of water in cylindrical water tank of diameter $2R$ cm is reducing at the rate of x cm min^{-1} when water is being drained out at a constant rate. The amount of water drained (in cm^{-3}) is
(a) $\frac{x\pi R^2 \mu_1}{\mu_2}$ (b) $\frac{x\pi R^2 \mu_2}{\mu_1}$ (c) $\frac{2\pi R\mu_1}{\mu_2}$ (c) $\frac{2\pi R\mu_2}{\mu_1}$
Here, μ_1 = refractive index of air and μ_2 = refractive index of water.

11. An object is immersed in a fluid. In order that the object becomes invisible, it should
(a) behave as a perfect reflector (b) absorb all light falling on it (c) have refractive index one
(d) have refractive index exactly matching with that of the surrounding fluid.

12. Brilliance of a diamond is due to
(a) shape (b) cutting (c) reflection (d) total internal reflection

13. An endoscope is employed by a physician to view the internal parts of a body organ. It is based on the principle of
(a) refraction (b) reflection (c) total internal reflection (d) dispersion

14. 'Mirage' is a phenomenon due to
(a) reflection of light (b) refraction of light
(c) total internal reflection of light (d) diffraction of light.

15. A wire mesh consisting of very small squares is viewed at a distance of 8 cm through a magnifying converging lens of focal length 10 cm, kept close to the eye. The magnification produced by lens is
(a) 5 (b) 8 (c) 10 (d) 20

16. A lens is made of flint glass (refractive index = 1.5). When the lens is immersed in a liquid of refractive index 1.25, the focal length
(a) increases by a factor of 1.25 (b) increases by a factor of 2.5
(c) increases by a factor of 1.2 (d) decreases by a factor of 1.2

17. Two thin lenses of focal lengths f_1 and f_2 are placed in contact. The focal length of the composite lens will be
(a) $(f_1+f_2)/2$ (b) $(f_1+f_2)/f_1 f_2$ (c) $\sqrt{f_1 f_2}$ (d) $f_1 f_2/(f_1+f_2)$

18. Two lenses of power +12D and –2D are combined together. What is their equivalent focal length?
(a) 10 cm (b) 12.5 cm (c) 16.6 cm (d) 8.33 cm.

19. If two lenses of power + 1.5 D and + 10D are placed in contact, then the effective power of combination will be
(a) 2.5 D (b) 1.5 D (c) 0.5 D (d) 3.25 D

20. A doctor advices a patient to use spectacles with a convex lens of focal length 40 cm in contact with a concave lens of focal length 25 cm. What is the power of the resultant combination?
(a) 1.5 D (b) – 1.5D (c) 6.5 D (d) – 6.5 D

21. The angle of a prism is 6° and its refractive index for green light is 1.5. If a green ray passes through it, the deviation will be
(a) 30° (b) 15° (c) 3° (d) 0°

22. Cauchy's dispersion formula is
(a) $\mu = A + B\lambda^{-2} + C\lambda^{4}$ (b) $\mu = A + B\lambda^{2} + C\lambda^{-4}$ (c) $\mu = A + B\lambda^{-2} + C\lambda^{-4}$ (d) $\mu = A + B\lambda^{2} + C\lambda^{4}$

23. Sky appears to be blue in clear atmosphere due to light's
(a) diffraction (b) dispersion (c) scattering (d) polarization

24. One can not see through fog, because
(a) fog absorbs the light (b) light surfers total reflection at droplets
(c) refractive index of the fog is infinity (d) light is scattered by the droplets

25. A leaf which contains only green pigments is illuminated by a laser light of wavelength 0.6328 μm. It would appear to be
(a) brown (b) black (c) red (d) green

26. Fraunhofer lines of the solar system is an example of
(a) emission lines spectrum (b) emission band spectrum
(c) continuous emission spectrum (d) line absorption spectrum

27. Flash light equipped with a new set of batteries, produces bright white light. As the batteries wear out,
(a) the light intensity gets reduced with no change in its colour
(b) light colour changes first to yellow and then red with no change in intensity
(c) it stops working suddenly, while giving white light
(d) colour changes to red and also intensity gets reduced.

28. Match the elements of Table I and Table II :

Table I	**Table II**
1. Myopia	(i) Bifocal lens
2. Hypermetropia	(ii) Cylindrical lens
3. Presbyopia	(iii) Concave lens
4. Astigmatism	(iv) Convex lens

(a) 1 –(iii), 2– (iv) , 3–(i), 4–(ii) (b) 1–(iv), 2–(iii) , 3–(i) , 4–(ii)
(c) 1–(i), 2–(ii), 3–(iii), 4–(iv) (d) 1–(ii), 2–(iv), 3–(i), 4–(iii)

29. A person using a lens as a simple microscope sees an
(a) inverted virtual image (b) inverted real magnified image
(c) upright virtual image (d) upright real magnified image

30. The astronomical telescope consists of objective and eyepiece. The focal length of the objective is
(a) equal to that of eyepiece (b) greater than that of the eyepiece
(c) shorter than that of the eyepiece (d) five times shorter than that of the eyepiece

31. A telescope has an objective lens of focal length 200 cm and an eyepiece with focal length 2 cm. If this telescope is used to see a 50 metre tall building at a distance of 2 km, what is the height of the image of the building formed by the objective lens?

(a) 5 cm (b) 10 cm (c) 1 cm (d) 2 cm

32. Four lenses of focal length ÷10 cm, + 50 cm, + 100cm and +200cm are available for making an astronomical telescope. To produce the largest magnification, the focal length of eyepiece should be
(a) + 10cm (b) + 50cm (c) +100cm (d) + 200cm

33. The focal length of the objective and eye lenses of a microscope are 1.6 cm and 2.5 cm respectively. The distance between the two lenses is 21.7 cm. If the final image is formed at infinity, what is the linear magnification?
(a) 11 (b) 110 (c) 1.1 (d) 44

34. The camera lens has an aperture of f and the exposure time is 1/60s. What will be the new exposure time if the aperture becomes 1.4 f?
(a) $\frac{1}{42}s$ (b) $\frac{1}{56}s$ (c) $\frac{1}{72}s$ (d) $\frac{1}{31}s$

35. What should be the maximum acceptable angles at the air–core interface of an optical fibre if n_1 and n_2 are the refractive indices of the core and cladding, respectively.
(a) $\sin^{-1}(n_2/n_1)$ (b) $\sin^{-1}\sqrt{n_1^2-n_2^2}$ (c) $\tan^{-1}\frac{n_2}{n_1}$ (d) $\tan^{-1}\frac{n_1}{n_2}$

Answers

1.	A	**2.**	A	**3.**	C	**4.**	B	**5.**	D	**6.**	B	**7.**	C	**8.**	B
9.	D	**10.**	B	**11.**	D	**12.**	D	**13.**	C	**14.**	C	**15.**	A	**16.**	B
17.	D	**18.**	A	**19.**	A	**20.**	B	**21.**	C	**22.**	C	**23.**	C	**24.**	D
25.	B	**26.**	D	**27.**	A	**28.**	B	**29.**	D	**30.**	B	**31.**	A	**32.**	A
33.	B	**34.**	D	**35.**	B										

CBSE PMT Prelims Exam.

1. Ray optics is valid, when characteristic dimensions are
(a) much smaller than the wavelength of light (b) much larger than the wavelength of light
(c) of the same order as the wavelength of light (d) of the order of one millimeter

2. A tall man of height 6 feet, want to see his full image. Then required minimum length of the mirror will be
(a) 12 feet (b) 3 feet (c) 6 feet (d) any length

3. The refractive index of water is 1.33. What will be the speed of light in water?
(a) 3×10^8 ms^{-1} (b) 2.26×10^8 ms^{-1} (c) 4×10^8 ms^{-1} (d) 1.33×10^8 ms^{-1}

4. A beam of monochromatic light is refracted from vacuum into a medium of refractive index 1.5. The wavelength of refracted light will be
(a) same (b) dependent on intensity of refracted light (c) larger (d) smaller

5. Green light of wavelength 5460 Å is incident on an air–glass interface. If the refractive index of glass is 1.5, the wavelength of light in glass would be (Given velocity of light in air, $c=3\times10^8$ ms^{-1}).
(a) 3640 Å (b) 5460 Å (c) 4861 Å (d) None of the above

6. If ${}^i\mu_j$ represents refractive index, when a light ray goes from medium i to medium j, then the product ${}^2\mu_1\times{}^3\mu_2\times{}^4\mu_3$ is equal to
(a) ${}^3\mu_1$ (b) ${}^3\mu_2$ (c) ${}^4\mu_1$ (d) ${}^4\mu_2$

7. The refractive index of air w.r.t. glass is 2/3. The refractive index of diamond w.r.t. air is 12/5. Then, the refractive index of glass w.r.t. diamond will be
(a) 5/8 (b) 8/9 (c) 5/18 (d) 18/5

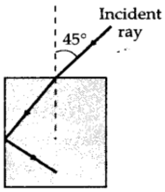
8. A microscope is focused on a mark on a piece of paper and then a slab of glass of thickness 3 cm and refractive index 1.5 is placed over the mark. How should the microscope be moved to get the mark in focus again?
(a) 2 cm upward (b) 1 cm upward (c) 4.5 cm downward (d) 1 cm downward

9. A bubble in glass slab (μ = 1.5) when viewed from one side appears at 5 cm and 2 cm from other side, then thickness of slab is
(a) 3.75 cm (b) 3 cm (c) 10.5 cm (d) 2.5 cm

10. Light enters at an angle of incidence in a transparent rod of refractive index n. For what value of the refractive index of the material of the rod the light once entered into it will not leave it through its lateral face whatsoever be the value of angle of incidence?
(a) $n = 1.1$ (b) $n = 1$ (c) $n > \sqrt{2}$ (d) $n = 1.3$

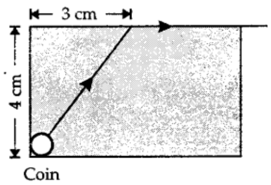
11. A disc is placed on a surface of pond which has refractive index 5/3. A source of light is placed 4 m below the surface of liquid. The minimum radius of disc needed so that light is not coming out is
(a) ∞ (b)3m (c) 6 m (d) 4m

12. For the given incident ray as shown in figure, the condition of total internal refraction of this ray, the required refractive index of prism will be



(a) $\frac{\sqrt{3}+1}{2}$ (b) $\frac{\sqrt{2}+1}{2}$ (c) $\sqrt{\frac{3}{2}}$ (d) $\sqrt{\frac{7}{6}}$

13. A small coin is resting on the bottom of a beaker filled with liquid. A ray of light from the coin travels upto the surface of the liquid and moves along its surface. How fast is the light travelling in the liquid?



(a) 2.4×10^8 m/s (b) 2.0×10^8 m/s
(c) 1.2×10^8 m/s (d) 1.8×10^8 m/s

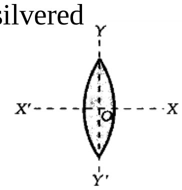
14. Optical fibres are based on
(a) total internal reflection (b) less scattering (c) refraction (d) less absorption coefficient.

15. A convex lens is dipped in a liquid, whose refractive index is equal to the refractive index of the lens. Then, its focal length will
(a) become zero (b) become infinite (c) remain unchanged
(d) become small, but non-zero.

16. A planoconvex lens is made of refractive index 1.6. If the radius of curvature of the curved surface is 60 cm, then focal length of the lens is
(a) 50 cm (b) 100 cm (c) 200 cm (d) 400 cm

17. Focal length of a convex lens of refractive index 1.5 is 2 cm. Focal length of lens, when immersed in a liquid of refractive index of 1.25 will be
(a) 10 cm (b) 7.5 cm (c) 5 cm (d) 2.5 cm

18. A plano-convex lens is made of a material of refractive index μ =1.5. The radius of curvature of curved surface of the lens is 20 cm. If its plane surface is silvered, the focal length of the silvered lens will be
(a) l0 cm (b)20 cm (c) 40 cm (d) 80 cm



19. An equiconvex lens is cut into two halves along (i) XOX' and (ii) YOY' as shown in the figure. Let f, f' and f'' be the focal lengths of complete lens, of each half in case (i) and of each half in case (ii) respectively, Choose the correct statement from the following :
(a) $f' = 2f$ and $f'' = f$ (b) $f' = f$ and $f'' = f$ (c) $f' = 2f$ and $f'' = 2f$ (d) $f' = f$ and $f'' = 2f$

20. A bulb is located on a wall. Its image of equal size is to be obtained on a parallel wall with the help of convex lens. The lens is placed at a distance *d* ahead of second wall. Then required focal length will be

(a) only $d/4$ (b) only $d/2$ (c) more than d/4 but less than $d/2$ (d) less than $d/4$

21. A luminous object is placed at a distance of 30 cm from the convex lens of focal length 20 cm. On the other side of the lens, at what distance from the lens, a convex mirror of radius of curvature 10 cm be placed in order to have an upright image of the object coincident with it?

(a) 12 cm (b) 30 cm (c) 50 cm (d) 60 cm

22. A lens is placed between a source of light and a wall. It forms images of areas A_1 and A_2 on the wall for it two different positions. The area of the source of light is

(a) $\sqrt{A_1 A_2}$ (b) $\frac{A_1+A_2}{2}$ (c) $\frac{A_1-A_2}{2}$ (d) $\frac{1}{A_1}+\frac{1}{A_2}$

23. If a convex lens of focal length 80 cm and a concave lens of focal length 50 cm are combined together, what will be their resulting power?

(a) + 6.5 D (b) – 6.5 D (c) + 7.5 D (d) – 0.75 D

24. A convex lens and a concave lens, each having same focal length of 25 cm, are put in contact to form a combination of lenses. The power of the combination (in diopeters) is

(a) zero (b) 25 (c) 50 (d) infinite

25. A beam of light composed of red and green ray is incident obliquely at a point on the face of rectangular glass slab. When coming out on the opposite parallel face, the red and green ray emerge from

(a) two points propagating in two different non-parallel directions

(b) two points propagating in two different parallel directions

(c) one point propagating in two different directions (d) one point propagating in the same direction

26. The refractive index of the material of an equilateral prism is $\sqrt{3}$. What is the angle of minimum deviation?

(a) 45^o (b) 60^o (c) 37^o (d) 30^o

27. A ray is incident at an angle of incidence *i* on one surface of a prism of small angle *A* and emerges normally from the opposite surface. If the refractive index of the material of the prism is μ, the angle of incidence *i* is nearly equal to

(a) A/μ (b) $A/2\mu$ (c) μA (d) $\mu A/2$

28. The refractive index of the material of a prism is $\sqrt{2}$ and its refracting angle is 30^o. One of the refracting surfaces of the prism is made a mirror inwards. A beam of monochromatic light entering the prism from the other face will retrace its path after reflecting from the mirrored surface, if its angle of incidence on the prism is

(a) 45^o (b) 60^o (c) 0^o (d) 30^o

29. The focal length of a converging lens is measured for violet, green and red colours. It is f_V, f_G and f_R respectively. We will get

(a) $f_V = f_G$ (b) $f_G = f_R$ (c) $f_V < f_R$ (d) $f_V > f_R$

30. If f_V and f_R are the focal lengths of a convex lens for violet and red light respectively and F_V and F_R are the respective focal lengths of a concave lens, then we must have

(a) $f_V > f_R$ and $F_V < F_R$ (b) $f_V < f_R$ and $F_V < F_R$

(c) $f_V > f_R$ and $F_V > F_R$ (d) $f_V < f_R$ and $F_V > F_R$

31. Rainbow is formed due to combination of

(a) refraction and scattering (b) refraction and absorption

(c) dispersion and total internal reflection (d) dispersion and focusing

32. The blue colour of the sky is due to the phenomenon of

(a) scattering (b) dispersion (c) reflection (d) refraction

33. Four lenses of focal length ± 15cm and $\pm$ 150 cm are available for making a telescope. To produce the largest magnification, the focal length of the eyepiece should be

(a) + 15 cm (b) + 150 cm (c) – 150 cm (d) – 15 cm

34. For relaxed eye, the magnifying power of a microscope is

(a) $\frac{v_0}{u_0} \times \frac{D}{f_e}$ (b) $\frac{v_0}{u_0} \times \frac{f_e}{D}$ (c) $\frac{u_0}{v_0} \times \frac{D}{f_e}$ (d) $\frac{u_0}{v_0} \times \left(-\frac{D}{f_e}\right)$

35. An astronomical telescope of ten fold angular magnification has a length of 44 cm. The focal length of the object is

(a) 4 cm (b) 40 cm (c) 44 cm (d) 440 cm

36. Exposure time of a camera lens at the $f / 2.8$ setting is 1/200 seconds. The correct time of exposure of f/5.6 is

(a) 0.20 second (b) 0.40 second (c) 0.02 second (d) 0.04 second

Answers

1.	B	**2.**	B	**3.**	B	**4.**	D	**5.**	A	**6.**	C	**7.**	A	**8.**	B
9.	C	**10.**	C	**11.**	C	**12.**	C	**13.**	D	**14.**	A	**15.**	B	**16.**	B
17.	C	**18.**	B	**19.**	D	**20.**	B	**21.**	C	**22.**	A	**23.**	D	**24.**	A
25.	B	**26.**	B	**27.**	C	**28.**	A	**29.**	C	**30.**	D	**31.**	C	**32.**	A
33.	A	**34.**	A	**35.**	B	**36.**	C								

WAVE OPTICS

Nature of light : Introductory Concepts

Nature of light : Various theories about the nature of light have been proposed from time to time. Some of the main theories are as follows:

1. ***Corpuscular theory of light:*** *Newton*, the great among the greatest, proposed in 1675 A.D. that light consists of tiny particles called *corpuscles* which are shot out at high speed by a luminous object. This theory could explain the reflection, refraction and rectilinear propagation of light.

2. ***Wave theory of light:*** In 1678, Dutch scientist *Christian Huygens*, suggested that light travels in the form of longitudinal waves just as sound propagates through air. He proposed that light waves propagate *luminiferous ether*. Later on, the existence of such a medium was discarded due to its contradictory properties. *Frensel* and *Young* showed that light propagates as a transverse wave. This successfully explained the reflection, refraction as well as interference, diffraction and polarization of light waves.

3. ***Electromagnetic nature of light waves:*** In 1873, *Maxwell* suggested that light propagates as electric and magnetic field oscillations. These are called electromagnetic waves which require no medium for their propagation. Also, these waves are transverse in nature.

4. ***Planck's quantum theory of light:*** According to *Max Planck*, light travels in the form of small packets of energy called photons. In 1905, *Albert Einstein* used this theory to explain photoelectric effect (emission of electrons from a metal surface when light falls on it).

   So we see that in phenomena like interference, diffraction and polarization, light behaves as a wave while in photoelectric effect, it behaves as a particle. *de Broglie* suggested that *light has a dual nature, i.e.,* it can behave as particles as well as waves.

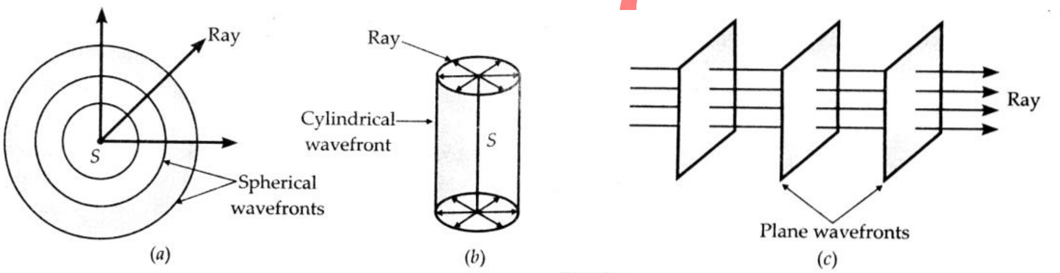
Wavefronts and Rays

A wavefront is defined as the continuous locus of all such particles of the medium which are vibrating in the same phase at any instant.

Thus a wavefront is a surface of constant phase. The speed with which the wavefront moves outwards from the source is called the ***phase speed.***

Different types of wavefronts: The geometrical shape of a wavefront depends on the source of disturbance. Some of the common shapes are:

1. **Spherical wavefront:** In the case of waves travelling in all directions from a point source, the wvaefronts are spherical in shape. This is because all such points which are equidistant from the point source will lie on the sphere (figure) and the disturbance starting from the source S will reach all these points simultaneously.



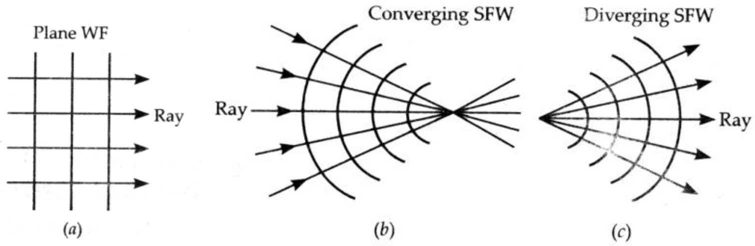
2. **Cylindrical wavefront:** When the source of light is linear in shape, such as a fine rectangular slit, the wavefront is cylindrical in shape. This is because the locus of all such points which are equidistant from the linear source will be a cylinder (figure.)
3. **Plane wavefront:** As a spherical or cylindrical wavefront advances, its curvature decreases progressively. So a small portion of such a wavefront at a large distance from the source will be a plane wavefront (figure)

Ray of light

It is seen that whatever is the shape of a wavefront, the disturbance travels outwards along straight lines emerging from the source, i.e., the energy of a wave travels in a direction perpendicular to the wavefront. *An arrow drawn perpendicular to a wavefront in the direction of propagation of a wave is called a* ***ray.*** A ray of light represents the path along which light travels.

1. Rays are perpendicular to wavefronts.

2. The time taken for light to travel from one wavefront to another is the same along any ray.



Huygen's Principle of Secondary Wavelets

Huygen's principle : Huygens' principle is the basis of wave theory of light. It tells how a wavefront, propagates through a medium. According to ***Huygens' principle,*** *each point on a wavefront is a source of secondary waves, which add up to give a wavefront at any later time.*

This principle is based on the following assumptions:

1. *Each point on a wavefront acts as a fresh source of new disturbance, called secondary waves or wavelets.*

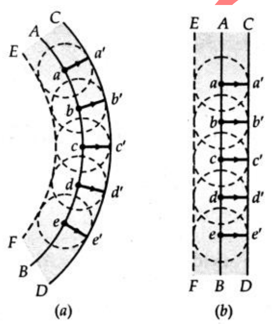
2. *The secondary wavelets spread out in all directions with the speed of light in the given medium.*

3. *The new wavefront at any later time is given by the forward envelope (tangential surface in the forward direction) of the secondary wavelets at that time.*

Huygens' Construction

It is a geometrical method of locating the new position and shape of a wavefront at any instant from its known position and shape at any other instant. The various steps involved are as follows:

1. Consider a spherical (figure a) or plane (figure b) wavefront moving towards right. Let AB be its position at any instant of time. The region on its left hs received the wave while region on the right is undisturbed.



2. According to Huygens' principle, each point on AB becomes a source of secondary disturbance, which travels with the same speed c. To find the new wavefront after time t, we draw spheres of radii ct, from each point on AB.

3. The forward envelope or the tangential surface CD of the secondary wavelets gives the new wavefront after time t.

4. The lines aa', bb', cc' etc., are perpendicular to both AB and CD. Along these lines, the energy flows from AB to CD. So these lines represent the ray. Rays are always normal to wavefronts.

No backward Wavefront is Possible

There cannot be backward flow of energy during the propagation of a wave. It can be shown mathematically that amplitude of secondary wavelets is proportional to $(1 + \cos\theta)$, where θ is the angle between the ray at the point of consideration and the direction of secondary wavelets. For a backward wavefront $\theta = \pi$, so that $1 + \cos\theta = 0$. Thus the resultant amplitude of all the secondary wavelets at any point on the backward wavefront is zero.

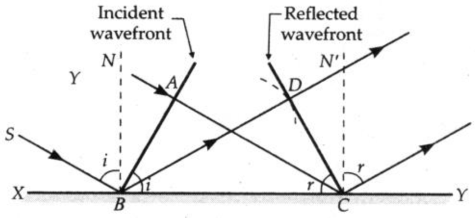
NOTE

- A wavefront is a surface of constant phase.
- A ray of light is the path along which light travels. It is always normal to the wavefront.
- In a homogeneous and isotropic medium (i.e., a medium having uniform composition and the same properties in all direction), the speed of light is same in all directions and the secondary wavelets are spherical. The rays are then perpendicular to both the wavefronts and the time of travel measured along any ray from one wavefront to the next is always same.

- Only the front portions of the secondary wavelets add up to give rise to a wavefront in the forward direction. The back portions of the secondary wavelets add up to zero, so no backward wavefront is possible.
-

Reflection on the Basis of Wave Theory

Consider a plane wavefront AB incident on the plane reflecting surface being perpendicular to the plane of paper.



First the wavefront touches the reflecting surface at B and then at the successive points towards C. In accordance with Huygens' principle, from each point on BC, secondary wavelets start growing with the speed c. During the time the disturbance from A reaches the point C, the secondary wavelets from B must have spread over a hemisphere of radius BD = AC = ct, where t is the time taken by the disturbance to travel from A to C.

The tangent plane CD drawn from point C over this hemisphere of radius ct will be *new reflected wavefront.*

Let angles of incidence and reflection be i and r respectively. In ΔABC and ΔDCB, we have

$\angle BAC = \angle CDB$ [Each is 90]

$BC = BC$ [Common]

$AC = BD$ [Each is equal to ct]

∴ $\Delta ABC \cong \Delta DCB$

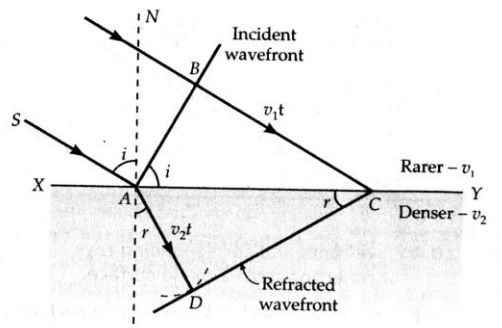
Hence $\angle ABC = \angle DCB$

or $i = r$

i.e., the angle of incidence is equal to the angle of reflection. This proves the first law of reflection.

Refraction on the Basis of Wave Theory

Consider a plane wavefront AB incident on a plane surface XY, separating two media 1 and 2, as shown in figure. Let v_1 and v_2 be the velocities of light in the two media, with $v_2 < v_1$.



The wavefront first strikes at point A and then at the successive points towards C. According to Huygen's principle, from each point on C. According to Huygen's principle, from the each on AC, the secondary wavelets start growing in the second medium with speed v_2. Let the disturbance take time t to travel from B to C, then BC = v_1t. During the time the disturbance from B reaches the point C, the secondary wavelets from point A must have spread over a hemisphere of radius AD = v_2t in the second medium.

The tangent plane CD drawn from point C over this hemisphere of radius v_2t will be the new refracted wavefront. Let the angles of incidence and refraction be i and r respectively.

From right ΔABC, we have

$$\sin \angle BAC = \sin i = \frac{BC}{AC}$$

From right ΔADC, we have

$$\sin \angle DCA = \sin r = \frac{AD}{AC}$$

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{BC}{AD} = \frac{v_1 t}{v_2 t} \quad \text{or} \quad \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}^1\mu_2 \quad \text{(a constant)}$$

This proves **Snell's law of reflection.** The constant $^1\mu_2$ is called the *refractive index* of the second medium with respect to first medium.

Effect on Wavelength, Frequency and Speed During Refraction

Consider a source of light at rest in one medium and the observer at rest in another medium. Let there be no relative motion between the two media so that the geometry of the source, medium and observer does not change with time. Then the light will take a definite time to travel from the source to the observer.

Suppose the source emits a wavefront after every time interval T and also each wavefront takes time T to travel from the source to the observer. Then the observer will receive $\nu = 1/T$ wavefronts per second. Thus *the frequency ν remains the same as light travels from one medium to anther.* In fact, frequency ν is the characteristic of the source.

As the speed of light v_1 and v_2 are different in the two media, the wavelengths λ_1 and λ_2 will also be different. Using the relation $v = \nu\lambda$, we get

$$\frac{\mu_1}{\mu_2} = \frac{v_1}{v_2} = \frac{\nu\lambda_1}{\nu\lambda_2} = \frac{\lambda_1}{\lambda_2}$$

Hence *the wavelength in a medium is directional to the phase speed (or wave speed) and inversely proportional to its refractive index.*

NOTE

The refractive index of a medium with respect to vacuum is

$$\mu = \frac{speed\ of\ light\ in\ vacuum}{speed\ of\ light\ in\ medium} = \frac{c}{v}$$

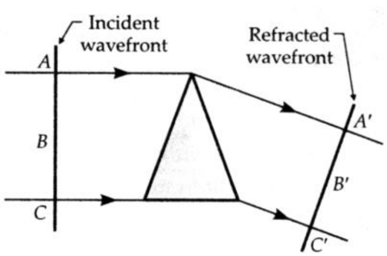
Since any medium is optically denser than vacuum, so $\mu > i$

Consequently, $c > v$

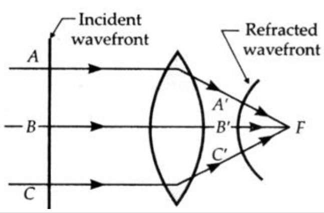
Thus the speed of light in an optically rarer medium is greater than that in an optically denser medium.

Behaviour of a Prism, Lens and Mirror

Behaviour of a prism: Figure shows the refraction of a plane wavefront through a thin prism. Since the speed of light in glass is smaller than that in air, therefore, the lower part C of the plane wavefront which travels through the greatest thickness of the glass prism is slowed down the most and the upper part A, which travels through the minimum thickness of the glass prism, is slowed down the least. This explains the tilting of a plane wavefront after refraction through a glass prism.

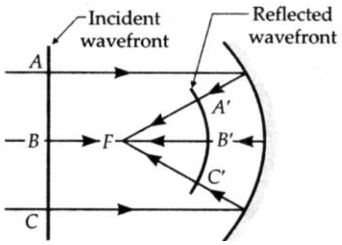


Behaviour of a convex lens: Figure shows the refraction of a plane waveront through a convex lens. The central part B of the plane wavefront travels through the greatest thickness of the lens and is, therefore, slowed down the most. The marginal parts A and C of the wavefront travel through a minimum thickness of the lens and are, therefore, slowed down the least. So the emerging wavefront is spherical and converges to a focus F.



Behaviour of a concave mirror: Figure shows the reflection of a plane wavefront from a concave mirror.

The central part B of the incident wavefront has to travel the greatest distance before getting reflected, compared to the marginal parts A and C. Therefore, the central portion B of the reflected wavefront is closer to the mirror than the marginal portions A' and C". Hence the reflected wavefront is spherical and converges to a focus.



Assignment – I

Q.1 Monochromatic light of wavelength 600 nm is incident from air on a glass surface. What are the wavelength, frequency and speed of refracted light? Refractive index of glass 1.5.

Q.2 The refractive index of diamond is 2.47 and that of window glass is 1.51. How much faster does light travel in window glass than in diamond?

Q.3 Calculate the time which light will take to travel normally through a glass plate of thickness 1 mm. Refractive index of glass is 1.5 and velocity of light is 3×10^8 ms^{-1}.

Q.4 White light consists of waves of wavelengths between 400 nm to 700 nm. What will be the wavelength range if this light goes through water (μ = 1.33)?

Q.5 The optical path of monochromatic light is the same if it travels 2.0 cm thickness of glass or 2.25 cm thickness of water. If the refractive index of water is 1.33, what is the refractive index of glass?

Q.6 The number of waves in a 4 cm thick strip of glass is the same as in 5 cm thick water layer, when the same monochromatic light t ravels in them. If the refractive index of water is 4/3, what will be that of glass?

Q.7 The absolute refractive index of air is 1.0003 and wavelengths of yellow light in vacuum is 6000 Å. Find the thickness of air column which will contain one more wavelength of yellow light than in the same thickness of vacuum.

Q.8 The speed of the yellow light in a certain liquid is 2.4×10^8 ms^{-1}. Find the refractive index of the liquid.

Q.9 The wavelength range of the light that is visible to an average human being is 400 nm to 700 nm. What is the frequency range of this visible light?

Q.10 The wavelength of light coming from a sodium source is 589 nm. What will be its wavelength in water? Refractive index of water is 1.33.

Q.11 Light travels a certain distance in water in 3 μs. How much time it would take for light to travel the same distance in air? Refractive index of water = 4/3.

Q.12 Red light of wavelength 750 nm enters a glass plate of refractive index 1.5. If the velocity of light in vacuum is 3×10^8 ms^{-1}, calculate in the glass (i) frequency (ii) velocity and (iii) wavelength of light.

Q.13 The absolute refractive indices of glass and water are 3/2 and 4/3. Determine the ratio of the speeds of light in glass and water.

Q.14 The refractive index of glass is 1.5 and that of water is 1.3, the speed of light in water is 2.25×10^8 ms^{-1}. What is the speed of light in glass?

Q.15 The ratio of the thickness of the strips of two transparent media A and b is 3 : 2. If light takes the same time in passing through both of them, then what is the refractive index of B with respect to A?

Q.16 The speed of light in air is 3×10^8 ms^{-1}. If refractive index of glass is 1.5, find the time taken by light to travel a distance of 10 cm in glass.

Q.17 A light wave has a frequency of 5×10^{14} Hz. Find the difference in its wavelengths in alcohol of refractive index 1.35 and glass of refractive index 1.5.

Answers

1.	400 nm	2.	7.72×10^7 ms^{-1}	3.	5×10^{-12} s
4.	525 nm	5.	1.50	6.	5/3
7.	2 mm	8.	1.25		
9.	4.3×10^{14} Hz to 7.5×10^{14} Hz			10.	443 nm
11.	2.25 μs	12.	(i) 4×10^{14} Hz, (ii) 2×10^8 ms^{-1}, (iii) 500 nm		
13.	8 : 9	14.	1.95×10^8 ms^{-1}	15.	1.5
16.	5×10^{-10} s	17.	445 Å		

Principle of Superposition of Waves

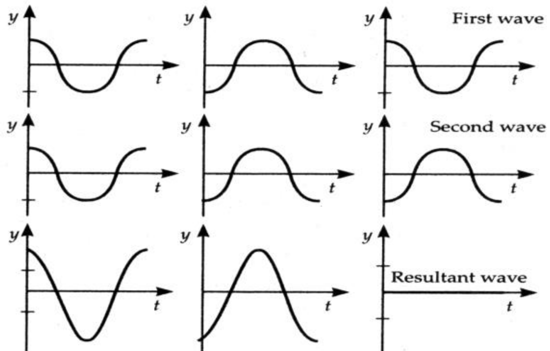
When a number of waves travel through a medium simultaneously, each wave travels independently of the others i.e., as if all other waves were absent. The resultant wave is obtained by the ***principle of superposition of waves*** which can be stated as follows:

When a number of waves traveling through a medium superpose on each other, the resultant displacement at any point at a given instant is equal to the vector sum of the displacements due to the individual waves at that point.

If $\vec{y}_1, \vec{y}_2, \vec{y}_3, ...\vec{y}_n$ are the displacement due to the different waves acting separately, then according to the principle of superposition, the resultant displacement when all the waves act together is given by the vector sum:

$$y = \vec{y}_1 + \vec{y}_2 + \vec{y}_3 + ...\vec{y}_n$$

When the two superposing waves are in the same phase i.e., the crest of one falls over the crest of another (figure a) or the trough of one falls over the trough of another (figure b), their displacements get added. When the two waves meet in opposite phases i.e., the crest of one falls over the trough of another (figure c), their displacement get subtracted.

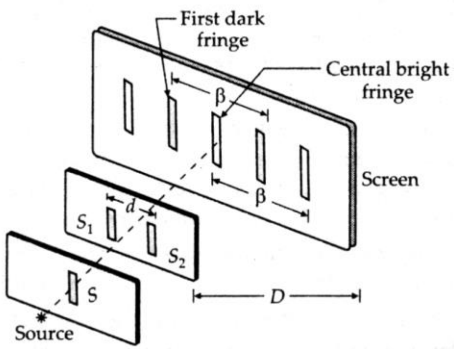


Interference of Light: Young's Double Slit Experiment

When two light waves of the same frequency and having zero or constant phase difference traveling in the same direction superpose each other, the intensity in the region of superposition gets redistributed, becoming maximum at some points and minimum at others. This phenomenon is called ***interference of light.***

Young's double slit experiment. In 1801, *Thomas Young* was the first person to demonstrate experimentally the interference of light.

In this experiment, a source of monochromatic light (e.g., a sodium vapour lamp) illuminates a rectangular narrow slit S, about 1 mm wide, as shown in figure. S_1 and S_2 are two parallel narrow slits which are arranged symmetrically and parallel to the slit S at a distance of about 10 cm from it. The separation between S_1 and S_2 is ≈ 2 mm and width of each slit is ≈ 0.3 m. An observation screen is

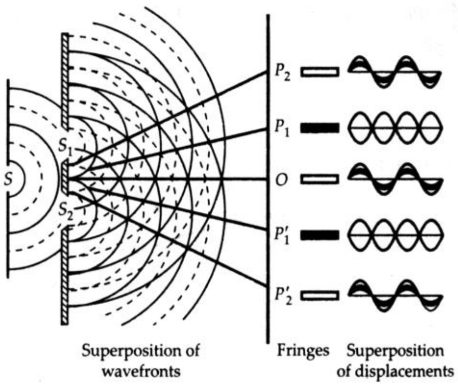


placed at a distance of ≈ 2m from the two slits. Alternate bright and dark bands appear on the observation screen. These are called ***interference fringes.*** When one of the slits, S_1 or S_2 is closed, bright and dark fringes disappear and the intensity of light becomes uniform.

Explanation:

Figure shows a section of Young's experiment in the plane of paper. According to Huygen's principle, cylindrical wavefronts emerge out from slit S, whose sections have been shown by circular arcs. The solid curves represent crests and the dotted curves represent troughs. As $SS_1 = SS_2$, these waves fall on the slits S_1 and S_2 act as two *coherent sources* of monochromatic light. Interference takes place between the waves diverging from these sources.

At the lines leading to O, P_2 and P'_2, the crest of one wave falls over the crest of other the crest of other wave or the trough of one wave falls over the trough of other wave, the amplitudes of the two waves get added up and hence the intensity ($I \propto a^2$) becomes maximum.



This is called ***constructive interference.*** So on the observation screen, we obtain a number of alternate bright and dark fringes, parallel to the two slits.

Conditions for Constructive and Destructive Interference

Expression for intensity at any point in interference pattern: Suppose the displacements of two light waves from two coherent sources S_1 and S_2 at point P on the observation screen at any time t are given by

$y_1 = a_1 \sin \omega t$ and $y_2 = a_2 \sin(\omega t + \phi)$

where a_1 and a_2 are the amplitude of the two waves, ϕ is the constant phase difference between the two waves. By the superposition principle, the resultant displacement at point P is

$y = y_1 + y_2 = a1 \sin \omega t + a_2 \sin(\omega t + \phi)$

$= a_1 \sin \omega t + a_2 \sin \omega t \cos \phi + a_2 \cos \omega t \sin \phi$

or $y = (a_1 + a_2 \cos \phi) \sin \omega t + a_2 \sin \phi \cos \omega t$

Put $a_1 + a_2 \cos \phi = A \cos \theta$ ... (1)

and $a_2 \sin \phi = A \sin \theta$ ... (2)

Then $y = A \cos \theta \sin \omega t + A \sin \theta \cos \omega t$ or $y = A \sin(\omega t + \theta)$

Thus, the resultant wave is also a harmonic wave of amplitude A and it leads the first harmonic wave by phase angle θ. To determine A, squaring and adding equations (1) and (2), we get

$A^2 \cos^2 \theta + A^2 \sin^2\theta = (a_1 + a_2 \cos \phi)^2 + a_2^2 \sin^2 \phi$

or $A^2 = a_1^2 + a_2^2 (\cos^2\phi + \sin^2\phi) + 2a_1a_2 \cos\phi$

or $A^2 = a_1^2 + a_2^2 + 2a_1a_2 \cos \phi$ ... (3)

But intensity of a wave $\propto$ (amplitude)^2

We write $I = kA^2$, $I_1 = ka_1^2$ and $I_2 = ka_2^2$

where k is proportionality constant. the equation (3) can be written as

$kA_2 = ka_1^2 + k_2^2 + 2\sqrt{ka_1}\sqrt{ka_2}\cos\phi$ ... (4)

or $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

This equation gives the total intensity at a point where the phase difference is ϕ. Hence I_1 and I_2 are the intensities which the two individual sources produce on their own. The total intensity also contains a third term $2\sqrt{I_1 I_2}\cos\phi$. It is called ***interference term.***

Constructive interference: The resultant intensity at the point P will be maximum when

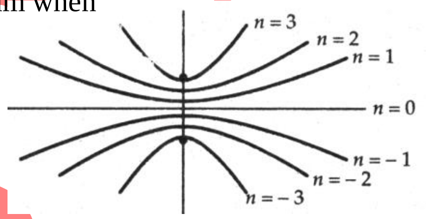
$$\cos\phi = 1 \quad \text{or} \quad \theta = 0, 2\pi, 4\pi, ...$$

Since a phase difference of 2π corresponds to a path difference of λ, therefore, if p is the path difference between the two superposing waves, then

$$\frac{2\pi p}{\lambda} = 0, 2\pi, 4\pi, ... \quad \text{or} \quad p = 0, \lambda, 2\lambda, 3\lambda, ... = n\lambda$$

Hence the resultant intensity at a point is maximum when the phase difference between the two superposing waves is an even multiple of π or path difference is an integral multiple of π or difference is an integral multiple of wavelength λ. This is the condition of constructive interference.

Destructive interference: The resultant intensity at point P will be minimum when



$$\cos\phi = -1 \quad \text{or} \quad \phi = \pi, 3\pi, 5\pi, ...$$

or $$\frac{2\pi p}{\lambda} = \pi, 3\pi, 5\pi, ...$$

or $$p = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}, ... = (2n+1)\frac{\lambda}{2}$$

Hence the resultant intensity at a point is minimum when the phase difference between the two superposing waves is an odd multiple of π or the path difference is an odd multiple of $\lambda/2$. This is the condition of destructive interference.

Coherent and incoherent sources

Two sources of light which continuously emit light waves of same frequency (or wavelength) with a zero or constant phase difference between them, are called ***coherent sources.***

Two sources of light which do not emit light waves with a constant phase difference are called ***incoherent sources.***

Need of coherent sources for the production of interference patter: When two monochromatic waves of intensity I_1, I_2 and phase difference ϕ meet at a point, the resultant intensity is given by

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$

The last term $2\sqrt{I_1 I_2}\cos\phi$ is called ***interference term.*** There are *two* possibilities:

1. If $\cos\phi$ remains constant with time, the total intensity at any point will be constant. The intensity will be maximum $\left(\sqrt{I_1} + \sqrt{I_2}\right)$ at points where $\cos\phi$ is + 1 and minimum $\left(\sqrt{I_1} - \sqrt{I_2}\right)^2$ at points where $\cos\phi = 1$. The sources in this case are coherent.
2. If $\cos\phi$ varies continuously with time assuming both positive and negative values, the average value of $\cos\phi$ will be zero over time interval of measurement. Then interference term averages to zero. There will be same intensity, $I = I_1 + I_2$ at every point i.e., there will be general illumination on the observation screen. The two sources in the case are incoherent.

   Hence to observe interference, we need to have tow sources with the same frequency and with a stable phase difference. Such a pair of sources are called ***coherent sources.***

Two independent sources cannot be coherent

This is because of the following reasons:

1. Light is emitted by individual atoms and not by the bulk of matter acting as a whole.

2. Even a tiniest source consists of millions of atoms, and emission of light by them takes place independently.
3. Even an atom emits an unbroken wave of about 10^{-8} second due to its transition from a higher energy stable to a lower energy state.

The phase difference and hence the interference pattern changes 10^8 times in one second. Our eyes cannot see such rapid changes and a uniform illumination is seen on the screen. So two independent light sources cannot produce a sustained interference.

Two coherent sources can be obtained from a single parent source. Some of the methods of producing coherent sources are as follows:

1. In *Young's double slit experiment,* the two sources S_1 and S_2 get light from the same source S. Whatever phase changes occur in S_1, the same phase changes occur in S_2. The relative phase difference between S_1 and S_2 remains constant with time. So they act as coherent sources.
2. In *Fresnel's biprism method,* two coherent sources are obtained from the same parent source, by refraction.
3. In *Lloyd's mirror method,* a source and its reflected image act as two coherent sources.

Conditions for obtaining two coherent sources of light:

1. The *two sources of light must be obtained from single source by some method.* Then the relative phase difference between the two light waves from the sources will remain constant with time.
2. *The two sources must give monochromatic light.* Otherwise, different colours will produce different interference patterns and fringes of different colours will overlap.
3. *The path difference between the weaves arriving on the screen from the two sources must not be large.* It should not exceed 30 cm. Then the phase difference produced due to path difference will not be constant. There will be general illumination on the screen.

NOTE

- To observe interference of light, the two sources of light must be coherent.
- In contrast to light from an ordinary source, the laser light is highly monochromatic and coherent. So *two independent laser sources can produce interference fringes* and the path difference may be several metres in this case.
- **Methods of producing coherent source:** There are two general methods of producing coherent sources:

1. ***By division of wavefront:*** In this method, a wavefront is divided into two or more parts by use of slits, mirrors, lenses or prisms. *For example,* Young's double slit method. Frenel's biprism and Lloyd's mirror.
2. ***By division of amplitude:*** Here the amplitude of the wave is divided into two or more parts by partial reflection or refraction. The divided parts travel along different paths and are made to superpose to produce interference. *For example,* the brilliant colours seen in thin films of transparent materials like soap film, oil film, etc.

Assignment – II

Q.1 Two plane monochromatic waves propagating in the same direction with amplitudes A and 2A and differing in phase by $\pi/3$ superpose. Calculate the amplitude of the resultant wave.

Q.2 Two sources of intensity I and 4 I are used in an interference experiment. Find intensity at points where waves from two sources superimpose with a phase difference (i) zero (ii) $\pi/2$ and (iii) π

Q.3 In a Young's double slit experiment, the intensity of light at a point other screen where the path difference is λ is k units. Find the intensity at a point where the path difference is (i) $\lambda/4$, (ii) $\lambda/3$ and (iii) $\lambda/2$

Q.4 Find the ratio of the intensity at the centre of a bright fringe to the intensity at a point one–quarter of the distance between two fringes from the centre.

Q.5 Find the ratio of intensities of two points P and Q on a screen in a Young's double slit experiment when waves from sources S_1 and S_2 have phase difference of (i) $\pi/3$ and (ii) $\pi/2$ respectively.

Q.6 Find the ratio of intensities at two points in a screen in Young's double slit experiment, when waves from the two slits have path difference of (i) 0 and (ii) $\lambda/4$

Q.7 The phase difference between two light waves reaching a point is $\pi/2$. What is the resultant amplitude if he individual amplitudes are 3 mm and 4mm?

Q.8 Two light waves superposing at the midpoint of the screen are coming from coherent sources of light of phase difference 3π. Their amplitudes are 1 cm each. What will be the resultant amplitude are 1 cm each. What will be the resultant amplitude at the given point?

Q.9 Two coherent monochromatic light beams of intensities I and 4I are superposed. What will be the maximum and minimum possible intensities?

Q.10 In Young's double slit experiment, what is the intensity at a point on screen where the two waves arrive having a phase difference of (i) 60^o (ii) 90^o and (iii) 120^o? Assume that intensity of each source is I_0.

Q.11 Find the ratio of intensities of two points P and Q on a screen in Young's double slit experiment when waves from sources S_1 and S_2 have phase difference of (i) 0^o and (ii) $\pi/2$ respectively.

Answers

1.	$\sqrt{7}\ A$	2.	(i) 9 I, (ii) 5 I, (iii) I	3.	(i) k/2, (ii) k/4, (iii) 0
4.	2 : 1	5.	3 : 2	6.	2 : 1
7.	5 mm	8.	zero	9.	9I, I
10.	$3I_0$, $2I_0$, I_0	11.	2 : 1		

Theory of Interference Fringes: Fringe Width

Suppose a narrow slit S is illuminated by monochromatic light of wavelength λ S_1 and S_2 are two narrow slits at equal distance from S. Being derived from the same parent source S, the slits S_1 and S_2 act as two *coherent sources*, separated by a small distance d. Interference fringes are obtained on a screen placed at distance D from the sources S_1 and S_2.

Consider a point P on the screen at distance x from the centre O. The nature of the interference at the point P depends on path difference,

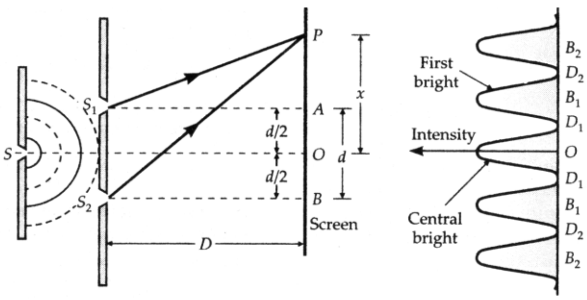
$$p = S_2P - S_1P$$

From right–angled ΔS_2 BP and ΔS_1 AP,

$$S_2P^2 - S_1P^2 = [S_2B^2 + PB^2] - [S_1A_2 + PA^2] = \left[D^2 + \left(x + \frac{d}{2}\right)^2\right] - \left[D^2 + \left(x - \frac{d}{2}\right)^2\right]$$

or $(S_2P - S_1P)(S_2P + S_1P) = 2xd$

or $$S_2P = S_1P = \frac{2xd}{S_2P + S_1P}$$



In particle, point P lies very close to o, therefore $S_1P \simeq S_2P \simeq D$. Hence

$$p = S_2P - S_1P = \frac{2\ xd}{2\ D}$$

or $$p = \frac{xd}{D}$$

Positions of bright fringes: For constructive interference,

$$p = \frac{xd}{D} = n\lambda$$

or $$x = \frac{nD\lambda}{d} \text{ where } n = 0, 1, 2, 3, ...$$

Clearly, the positions of various bright fringes are as follows:

For n = 0, $x_0 = 0$ *Central bright fringe*

For n = 1, $x_1 = \frac{D\lambda}{d}$ *First bright fringe*

For n = 2, $x_2 = \frac{2D\lambda}{d}$ *Second bright fringe*

For n = n, $x_n = \frac{nD\lambda}{d}$ *nth bright fringe*

Positions of dark fringes: For destructive interference,

$$p = \frac{xd}{D} = (2n-1)\frac{\lambda}{2} \quad \text{or} \quad x = (2n-1)\frac{D\lambda}{2d} \text{ where } n = 1, 2, 3, ...$$

Clearly, the positions of various dark fringes are as follows:

For n = 1, $x_1' = \frac{1}{2}\frac{D\lambda}{d}$ *First dark fringe*

For n = 2, $x_2' = \frac{3}{2}\frac{D\lambda}{d}$ *Second dark fringe*

For n = n, $x_n' = (2n-1)\frac{D\lambda}{2d}$ *nth dark fringe*

Since the central point O is equidistant from S_1 and S_2, the path difference p for it is zero. There will be a bright fringe at the centre O. But as we move from O upwards or downwards, alternate dark and bright fringes are formed.

Fringe width: *It is the separation between two successive bright or dark fringes,*

Width of a dark fringe = Separation between two consecutive bright fringes

$$= x_n - x_{n-1} = \frac{nD\lambda}{d} - \frac{(n-1)D\lambda}{d} = \frac{D\lambda}{d}$$

Width of a bright fringe

= Separation between two consecutive dark fringes

$$= x_n' - x_{n-1}'$$

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

Clearly, both the bright and dark fringes are of equal width. Hence the expression for the fringe width in Young's double slit experiment can be written as

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

As β is independent of n (the order of fringe), therefore, all the fringes are of equal width. In the case of light, λ is extremely small, D should be much larger than d, so that the fringe width β may be appreciable and hence observable.

Measurement of wavelength: Young's double slit experiment can be used to determine the wavelength of a monochromatic light. The interference pattern is obtained in the focal plane of a micrometer eyepiece and with its help fringe width β is measured. By measuring the distance d between the two coherent sources and their distance D from the eyepiece, the value of wavelength λ can be calculated as

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

NOTE

In Young's double slit experiment, the width of the central bright fringe is equal to the distance between the first dark fringes on the two sides of the central bright fringe. So the ***width of the central bright fringe*** is given by

$$\beta_0 = 2x_1' = 2\times\frac{D\lambda}{2d} = \frac{D\lambda}{d}$$

As all the bright and dark fringes are of the same width, the ***angular width of a fringe*** is given by

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

If ***Young's double slit apparatus is immersed in a liquid*** of refractive index μ, the wavelength of light decreases to $\lambda' (= \lambda/\mu)$ and so the fringe width reduces to

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

Assignment – III

Q.1 In Young's double experiment, the two parallel slits are made one millimeter apart and a screen is placed on metre away. What is the fringe separation when blue green light of wavelength 500 nm is used?

Q.2 Laser light of wavelength 630 nm incident on a pair of slits produces an interference pattern in which the bright fringes are separated by 8.1 mm. A second light produces an interference pattern in which the fringes are separated by 7.2 mm. Calculate the wavelength of the second light.

Q.3 Yellow light of wavelength 6000 Å produces fringes of width 0.8 mm in Young's double slit experiment. What will be the fringe width if the light source is replaced by another monochromatic source of wavelength 7500 Å and the separation between the slits is doubled?

Q.4 The fringe width in a Young's double slit interference pattern is 2.4×10^{-4} m, when red light of wavelength 6400 Å is used. By how much will it change, if blue light of wavelength 4000 Å is used.

Q.5 In a two slit experiment with monochromatic light, fringes are obtained on a screen placed at some distance D from the slits. If the screen is moved 5×10^{-2} m towards the slits, the change in fringe width is 3×10^{-5} m. If the distance between the slits is 10^{-3} m, calculate the wavelength of the light used.

Q.6 In Young's double slit experiment, using light of wavelength 400 nm, interference fringes of width 'X' are obtained. The wavelength of light is increased to 600 nm and the separation between the slits is halved. If one wants the observed fringe width on the screen to be the same in the two cases, find the ratio of the distance between the screen and the plane of the interfering sources in the two arrangements.

Q.7 In Young's experiment, the width of the fringes obtained with light of wavelength 6000 Å is 2.0 mm. Calculate the fringe width if the entire apparatus is immersed in a liquid medium of refractive index 1.33.

Q.8 In Young's double slit experimental the light has a frequency of 6×10^{14} Hz and distance between the centres of adjacent fringes is 0.75 mm. If the screen is 1.5 m away, what is the distance between the silts?

Q.9 In a Young's double slit experimental, red light of wavelength 6000 Å is used and the nth bright fringe is obtained at a point P on the screen. Keeping the same setting, the source is replaced by green light of 5000 Å and now (n + 1)th bright fringe is obtained at the point P. Calculate the value of n.

Q.10 Two slits 0.125 mm apart are illuminated by light of wavelength 4500 Å. The screen is one metre away from the plane of the slits. Find the separation between the second bright fringes on both sides of the central maximum.

Q.11 In Young's double slit experiment, the slits are 0.2 mm apart and the screen is 1.5 m away. It is observed that the distance between the central bright fringe and fourth dark fringe is 1.8 cm. Find the wavelength of light used.

Q.12 In a Young's double slit experiment, the slits are separated by 0.5 mm and screen is placed 1.0 m away. It is found that the ninth bright fringe is at a distance of 8.835 mm from the second dark fringe. Find the wavelength of light used.

Q.13 In a Young's double experiment, the slits are 1.5 mm apart. When the slits are illuminated by a monochromatic light source and the screen is kept 1 m apart from the slits, width of 10 fringes is measured as 3.93 mm. Calculate the wavelength of light used. What will be the width of 10 fringes when the distance between the slits and the screen is increased by 0.5 m. The source of light used remains the same.

Q.14 A double slit is illuminated by light of wavelength 6000 Å. The slits are 0.1 cm apart and the screen is placed 1 m away. Calculate (i) the angular position of 10^{th} maximum in radian and (ii) separation of the adjacent minima.

Q.15 Sodium light has two wavelengths λ_1 = 589 nm and λ_2 = 589.6 nm. As the path difference increases, when is the visibility of the fringes minimum?

Answers

1.	0.5 mm	2.	560 nm	3.	0.5 mm
4.	0.9×10^{-4} m	5.	6000 Å	6.	3 :1
7.	1.5 mm	8.	1 mm	9.	n = 5
10.	14.4 mm	11.	6.86×10^{-7} m	12.	5890 Å
13.	5.895×10^{-3} m	14.	0.6 mm	15.	0.29 mm

Assignment – IV

Q.1 In Young's double slit experiment the slits are separated by 0.24 mm. The screen is 1.2 m away from the slits. The fringe width is 0.3 cm. Calculate the wavelength of the light used in the experiment.

Q.2 In Young's double slit experiment, while using a source of light of wavelength 4500 Å, the fringe width obtained is 0.4 cm. If the distance between the slits and the screen is reduced to half, calculate the new fringe width.

Q.3 In a Young's double slit experiment, interference fringes were produced on a screen placed at 1.5 m from the two slits 0.3 mm apart and illuminated by light of wavelength 6400 Å. Find the fringe width.

Q.4 Green light of wavelength 5100 Å from a narrow slit is incident on a double slit. If the overall separation of 10 fringes on a screen 200 cm away is 2 cm, find slit separation.

Q.5 In Young's double slit experiment the fringe width obtained is 0.6 cm, when light of wavelength 4800 Å is used. If the distance between the screen and the slit is reduced to half, what should be the wavelength of light used to obtain fringes 0.0045 m wide?

Q.6 In Young's double slit experiment, the width of fringes obtained from a source of light of wavelength 5000 Å is 3.6 mm. Calculate the fringe width if the apparatus is immersed in a liquid of refractive index 1.2.

Q.7 The two slits in Young's double slit experiment are separated by a distance of 0.03 mm. An interference pattern is produced on a screen 1.5 m away. The 4^{th} bright fringe is at a distance of 1 cm from the central maximum. Calculate the wavelength of light used.

Q.8 The two parallel silts used for Young's interference experiment are 0.5 mm apart. The screen on which fringes are projected is 1.5 m from the silts. How far is the third dark fringe from the central bright one? Wavelength of light used is 6000 Å?

Q.9 In Young's double slit experiment, red light of wavelength 620 nm is used and the two slits are 0.3 mm apart. Interference fringes observed on a screen are found to be 1.3 mm apart. Calculate (i) the distance of slits from the screen and (ii) the fringe width if this distance is doubled.

Q.10 When two narrow slits separated by a small distance are illuminated by a light of wavelength 5×10^{-7} m, interference fringes of width0.5 mm are obtained on a screen. What should be the wavelength of light source to obtain fringes 0.3 mm wide, if the distance between the screen and the slits is reduced to half of the initial value?

Q.11 In a Young's double slits experiment, the distance between the slit s and the screen is 1.60 m. Using light of wavelength 6×10^{-7} m, the distance between the centre of the interference pattern and fourth bright fringe on either side is 16 mm. Calculate the slit separation.

Q.12 In Young's double slit experiment, light of wavelength 6000 Å is used to get an interference pattern on a screen. The fringe width changes by 1.5 mm, when the screen is brought towards the double slit by 50 cm. Find the distance between the two slits.

Q.13 In Young's experiment, two coherent sources are 1.5 mm apart and fringes are obtained at a distance of 2.5 m from them. If the sources produce light of wavelength 589.3 nm, find the number of fringes in the interference patter, which is 4.9×10^{-3} m wide.

Q.14 In a Young's double slit experiment, the interference fringes are obtained on a screen 0.75 m apart. The third dark band is at a distance of 5.5 mm from the central fringe. (i) Determine the wavelength of light used if the two slits are 0.15 mm apart. (ii) What will be the4 wavelength of light used if the entire apparatus is immersed in a liquid of refractive index 4/3?

Q.15 In Young's experiment, interference pattern is obtained on a screen at a distance of 1 m from slits separately by 0.05 cm and illuminated by sodium light of wavelength 5893 Å. Calculate distance between 4^{th} bright fringe on one side and 3^{rd} bright fringe on other side of central fringe.

Q.16 Among two interfering sources, let A be ahead in phase by 54^{o} relative to B. It the observation be taken from point P, such that PB – PA = 1.5 λ, deduce the phase difference between the waves from A and B reaching P.

Q.17 In Young's experiment, what will be the phase difference between the light waves reaching (i) third bright fringe and (ii) third dark fringe from the central fringe. Take λ = 5000 Å.

Q.18 In a Young's double slit interference pattern at a point, we observe the 10^{th} bright fringe (order maxima) for wavelength 7000 Å. What order maxima will be visible if the source of light is replaced by light of wavelength 5000Å?

Q.19 In Young's double slit experiment, light waves of $\lambda = 5.4 \times 10^2$ nm and $\lambda = 6.85 \times 10^1$ nm are used in turn, keeping the same geometry of the set up. Calculate the ratio of the fringe widths in the two cases.

Q.20 In a Young's double slit experiment, the two slits are 2 mm apart and the screen is positioned 140 cm away from the plane of the slits. The silts are illuminated with light of wavelength 600 nm. Find the distance of the third bright fringe, from the central maximum, in the interference pattern obtained on the screen.

If the wavelength of the incident light were changed to 480 nm, find the shift in the position of third bright fringe from the central maximum.

Q.21 In Young's double slit experiment, two slits are separated by 3 mm distance and illuminated by light of wavelength 480 nm. The screen is 2 m from the plane of the slits. Calculate the separation between the 8^{th} bright fringe and the 3^{rd} dark fringe observed with respect to the central bright fringe.

Answers

1.	6000 Å	2.	0.2 cm	3.	3.2 mm
4.	0.51 mm	5.	7.2×10^{-6} m	6.	3.0 mm
7.	5000 Å	8.	0.45 cm	9.	(i) 0.629 m, (ii) 2.6 mm
10.	6×10^{-7} m	11.	0.24 mm	12.	0.2 mm
13.	5	14.	(i) 4.4×10^{-7} m, (ii) 3.3×10^{-7} m		
15.	8.25 mm	16.	$3.3\ \pi$		
17.	(i) 6π ; 15000 Å, (ii) 5π, 12500 Å			18.	14
19.	7.9	20.	1.26 mm, 0.25 mm	21.	1.76 mm

Conditions for Sustained Interference

In order to observe an interference pattern, it is necessary that the positions of maxima and minima do not keep on changing with time, otherwise the maxima and minima of intensity will mix up to produce uniform illuminations. *The interference pattern, in which the positions of maxima and minima of intensity on the observation screen do not change with time, is called a* ***sustained or permanent interference pattern.***

Conditions for sustained interference: The necessary conditions for obtained a sustained and observable interference pattern of light are as follows:

1. The two sources should continuously emit waves of same frequency of wavelength.
2. The two sources of light should be *coherent*, *i.e.*, they must vibrate either in the same phase of with a constant phase difference between them.
3. For a better contrast between maxima and minima of intensity, the amplitudes of the interfering waves should be equal.
4. The two sources should be narrow, otherwise interference will occur between waves of different parts of the same source and contract will be poor.
5. The interfering waves must travel nearly along the same direction.
6. The sources should be *monochromatic*, otherwise fringes of different colours will overlap just to give a few observable fringes.
7. The interfering waves should be in the same state of polarization.
8. To have sufficient fringe width, the distance between the two coherent sources should be small and the distance between the two sources and the screen should be large.

Intensity Distribution Curves for Interference

Intensity distribution curve for interference: Suppose two interfering waves have the same amplitude a. The intensity of a bright fringe will be

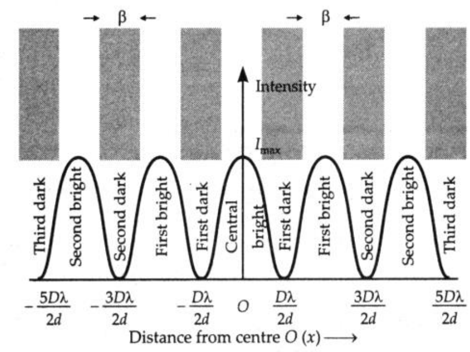
$$I_{max} = k\,(a + a)^2 = 4ka^2 = \text{constant}$$

So all bright fringes will have the same maximum intensity. The intensity of a dark fringe will be

$$I_{min} = k\,(a - a)^2 = 0$$

So all dark fringes will be perfectly dark.

On plotting the intensities of bright and dark fringes against distance x from O, we get a curve as shown in figure.



The intensity is maximum at the central point O. Then it becomes zero and maximum alternately on either side of O, depending on x is odd multiple of $\frac{D\lambda}{2d}$ and integral multiple of $\frac{D\lambda}{d}$ respectively.

Conservation of Energy in Interference

In an interference pattern, the intensities at the points of maxima and minima are such that

$$I_{max} \propto (a_1 + a_2)_2 \text{ and } I_{min} \propto (a_1 - a_2)^2$$

$$\therefore \qquad I_{av} \frac{(a_1+a_2)^2+(a_1-a_2)^2}{2} \text{ or } I_{av}\, a_1^2+a_2^2$$

If there is no interference between the light waves from the two sources, then intensity at every point would be same. That is,

$$I = I_1 + I_2 \propto a_1^2+a_2^2$$

which is same as I_{av} in the interference pattern. So there is no violation of the law of conservation of energy in interference. Whatever energy disappears from a dark fringe, an equal energy appears in a bright fringe.

Comparison of Intensities at Maxima and Minima

Let a_1 and a_2 be the amplitudes and I_1 and I_2 be the intensities of light waves from two different sources.

As intensity ∝ amplitude^2 $\quad \therefore \quad \frac{I1}{I2}=\frac{a_1^2}{a_2^2}.$

Amplitude at a maximum in interference pattern $= a_1 + a_2$

Amplitude at a minimum in interference pattern $= a_1 - a_2$

Therefore, the ratio of intensities at maxima and minima is

$$\frac{I_{max}}{I_{min}}=\frac{(a_1+a_2)^2}{(a_1-a_2)^2}=\left(\frac{a_1}{a_2}+1\right)^2 \quad \text{or} \quad \frac{I_{max}}{I_{min}}=\left[\frac{r+1}{r-1}\right]^2$$

where $r=\frac{a_1}{a_2}=\sqrt{\frac{I_1}{I_2}}$ = amplitude ratio of the two waves.

NOTE

The intensity of light through a slit is proportional to its width. It w_1 and w_2 are the widths of the two slits S_1 and S_2, then

$$\frac{w_1}{w_2}=\frac{I_1}{I_2}=\frac{a_1^2}{a_2^2}=r^2.$$

Assignment – V

Q.1 What is the ratio of slit widths if the amplitudes of light waves from them have a ratio of $\sqrt{2}:1$?

Q.2 Two coherent sources have intensities in the ratio 25 : 16. Find the ratio of the intensities of maxima to minima, after interference of light occurs.

Q.3 If the two slits in Young's double–slit experiment have width ratio 4 : 1, deduce the ratio of intensities at maxima and minima in the interference pattern.

Q.4 In Young's double slit experiment, the ratio of intensity at the maxima and minima in the interference experiment is 25 : 9. What will be the ratio of widths of the two slits?

Q.5 Two coherent sources of light of intensity ratio β interfere. Prove that in the interference pattern,

$$\frac{I_{max}-I_{min}}{I_{min}+I_{min}}=\frac{2\sqrt{\beta}}{1+\beta}$$

Q.6 Two coherent sources, whose intensity ratio is 16 :1 produce interference fringes. Calculate the ratio of intensity of maxima and minima in the fringe system.

Q.7 The two slits in Young's experiment have widths in a ratio 100 : 1. Find the ratio of flight intensity at the maxima and minima in the interference pattern.

Q.8 If the two slits in Young's experiment have width ratio 4 : 9, deduce the ratio of intensity at maxima and minima in interference pattern.

Q.9 The ratio of intensity at maxima and minima is 25 : 16. What will be the ratio of the width of the two slits in Young's double slit experiment?

Q.10 Two coherent sources whose intensity ratio is 81 : 1 produce interference fringes. Calculate the ratio of intensity of maxima and minima in the fringe system.

Q.11 The width of one of the two slits in a Young's double slit experiment is double of the other slit. Assuming that the amplitude of the light coming from a slit is proportional to the slit width, find the ratio of the maximum to the minimum intensity in the interference pattern.

Answers

1.	2 : 1	2.	81 : 1	3.	9 : 1
4.	16 : 1	5.	$\frac{2\sqrt{\beta}}{\beta+1}$	6.	25 : 9
7.	3 : 2	8.	25 : 1	9.	81 : 1
10.	25 : 16	11.	9 : 1		

Interference pattern with while light

White light consists of colours from violet to red with wavelength range from 4000 Å to 7000 Å. Different component colours of white light produce their own interference pattern. At the centre of the screen, the path difference is zero for all such components. So bright fringes of different colours overlap at the centre. Consequently, the central fringe is white.

Now fringe width $\beta = D\lambda/d$ i.e., $\beta \propto \lambda$. Since the violet colour has the lowest λ, the closest fringe on either side of the central while fringe is violet, while the farthest fringe is red. After a few fringes, the interference pattern is lost due to large overlapping of the fringes and uniform white illumination is seen on the screen.

Interference in Thin Films

A thin film means an extremely small thickness of a transparent medium. A soap film or a thin film of oil spread over water, when seen in the reflected white light, shows beautiful colours. This is due to the interference between the light waves reflected by the upper and lower surfaces of thin films. As they both originate from the same source, they are coherent waves.

Consider a parallel sided thin film of thickness t and refractive index μ. Suppose a ray SA of monochromatic light is incident on its upper surface. This ray suffers partial reflections and refractions successively at points A, B, C etc; giving a set of parallel reflected rays R_1, R_2, ... and a set of *parallel transmitted rays* T_1, T_2, ... When these rays are focused by our eyelens, interference patterns are visible.

Interference in reflected light: Draw CE perpendicular to AR_1. Then the path difference between two successive reflected rays R_1 and R_2 is

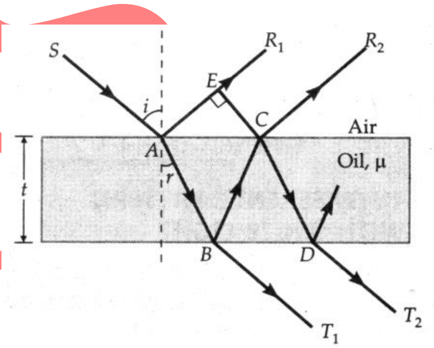
$$p = (AB + BC) \text{ in thin film} - AE \text{ is air}$$

$$= \mu\,(AB + BC) \text{ in air} - AE \text{ in air}$$

or $\quad p = 2\,\mu t \cos r \qquad$ [From the geometry of the figure]

where r is the angle of refraction. As the ray R_1 is reflected by the upper surface of thin film (denser medium), it suffers an extra path difference of λ/2.

∴ $\quad \text{Net path difference} = 2\mu t \cos r + \dfrac{\lambda}{2}$



For a bright fringe:

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

or $\quad 2\mu t \cos r = (2n - 1)\,\dfrac{\lambda}{2}$

or $\quad 2ut \cos r = (2n + 1)\,\dfrac{\lambda}{2}$, n = 0, 1, 2, 3, ...

For a dark fringe:

$$2\mu t \cos r + \frac{\lambda}{2} = (2n + 1)\,\frac{\lambda}{2}$$

or $\quad 2\mu t \cos r = n\lambda$, n = 0, 1, 2, 3, ...

Interference in transmitted light

As the transmitted rays do not suffer any reflection from the surface of a denser medium, the path difference between any two successive rays will be

$$p = 2\mu t \cos r$$

∴ For a bright fringe,

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

For a dark fringe,

$$2\mu t \cos r = (2n + 1)\,\frac{\lambda}{2}$$

Obviously, the conditions for maxima and minima in the reflected system are just opposite to those for the transmitted system. Thus the reflected and transmitted systems are *complimentary, i.e.,* a film which appears bright by reflected light, will appear dark by transmitted light and *vice versa.*

Assignment – VI

Q.1 White light may be considered to have λ from 4000 Å to 7500 Å. If an oil film has thickness 10^{-6} m, deduce the wavelengths in the visible region for which the reflection along the normal direction will be (i) weak, (ii) strong. Take μ of the oil as 1.40.

Q.2 In a certain region of a wedge–shaped film, 10 fringes are observed with a light source of wavelength 4358 Å. If the wavelength of the light source is changed to 5893Å, then how many fringes will be observed in the same region of the film?

Q.3 For light of wavelength $\lambda = 6.0 \times 10^{-7}$ m, it is found that in a thin film of air, 9 fringes occur between two points. Deduce the difference of film thickness between these points.

Q.4 A parallel beam of sodium light of wavelength 5890 Å is incident on a thin glass plate of refractive index 1.5 such that the angle of refraction in the plate is 60^o. Calculate the smallest thickness of the plate which will make it dark by reflection.

Q.5 A soap film is illuminated by white light incident at an angle of 30^o. The reflected light is examined by a spectroscope in which a dark band corresponding to wavelength 6000 Å is found. Calculate the minimum thickness of the film. Given refractive index of film = 4/3.

Q.6 White light reflected at perpendicular incident from a soap film has, in the visible spectrum, an interference maximum at 6000 Å and a minimum at 4500 Å with no minimum in between. If μ = 4/3 for the film, what is the film thickness?

Q.7 A soap film of μ = 4/3 is illuminated by white light incident at an angle of 45^o. The transmitted light is examined by spectroscope and bright fringe is found to be for wavelength of 6000 Å. Find the minimum thickness of the film.

Q.8 White light is incident on a soap film at an angle of $\sin^{-1}\frac{4}{5}$ and the reflected light on examination by the spectroscope shows dark bands. The consecutive dark bands correspond to wavelengths 6100 Å and 6000Å. If the refractive index of the film is 4/3, calculate its thickness.

Q.9 A soap film 5×10^{-5} cm thick is viewed at an angle of 35^o to the normal. Find the wavelength of light in the visible spectrum which will be absent from reflected light (μ = 1.33). Given wavelength range of the visible spectrum is 3900 Å to 7800 Å.

Q.10 A thin film of thickness 4×10^{-5} cm and μ = 1.5 is illuminated by white light incident normal to its surface. What wavelength in the visible range be intensified in the reflected beam?

Q.11 In a thin film, between two points A and B, eight fringes are observed with light of wavelength 5461 Å. How many fringes will be observed between the same two points A and B if the wavelength of light used is 6500 Å?

Q.12 With a thin air film between two points, 6 fringes appear when light of wavelength 5890 Å is used. Calculate the difference in the thickness of the film between the two points.

Q.13 White light is incident normally on a plane parallel thin film of U = 1.5. Find the minimum thickness of the film for which light of λ = 4000 Å is absent from the reflected light.

Q.14 A soap film of refractive index 4/3 and thickness 1.5×10^{-4} cm is illuminated by white light incident at angle of 45^o. The reflected light is examined by a spectroscope in which a dark band corresponding to the wavelength 5×10^{-5} cm is found. Find the order of the interference band.

Q.15 White light is incident on a soap film of μ = 4/3 at an angle of 30^o. On examining the transmitted light with a spectrometer, a dark band of wavelength 5.5×10^{-7} m is found. Find the minimum thickness of the film.

Answers

2.	7.4 fringes	3.	2.7 microns	4.	3928 Å
5.	2.42×10^{-7} m	6.	3.375×10^{-5} m	7.	2.6×10^{-7} m
8.	1.716×10^{-5} m	9.	6000 Å, 4000 Å	10.	4800 Å

11.	6.72 fringes	12.	1.767 micron	13.	1.33×10^{-7} m
14.	n = 7	15.	1.11×10^{-7} m		

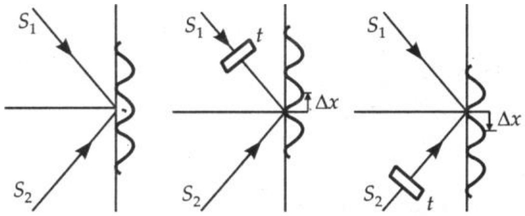
Displacement of Interference Fringes

When a thin transparent sheet of thickness t and refractive index μ is inserted in the path of one of the interfering beams, the extra path difference introduced is

Δp = length t in transparent medium

– length t in air

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



Suppose the present position of the particular fringe is

$$x = \frac{Dp}{d}$$

Then the new position of the same fringe will be

$$x' = \frac{D}{d}(p + \Delta p)$$

Hence the lateral displacement of the particular fringe on the screen is

$$\Delta x = x' - x = \frac{D\Delta p}{d}$$

or $$\Delta x = \frac{D}{d}(\mu - 1)t = \frac{\beta}{\lambda}(\mu - 1)t \qquad \left[\beta = \frac{D\lambda}{d} \quad \therefore \frac{D}{d} = \frac{\beta}{\lambda}\right]$$

As the shift is independent of n, every fringe (including the central fringe) or the entire fringe system is laterally displaced by Δx.

Assignment – VI

Q.1 Fringes are produced with monochromatic light of wavelength 5.45×10^{-5} cm. A thin glass plate of refractive index 1.5 is then placed normally in the path of one of the interference beams and the central bright band of the fringe system is found to move into the position previously occupied by the third bright band from the system. Find the thickness of the glass plate.

Q.2 A two slit young's interference experiment is done with monochromatic light of wavelength 6000Å. The slits are 2 mm apart and fringes are observed on a screen placed 10 cm away from the slits and it is found that the plate of thickness 0.5 mm is introduced in the path of one of the slits. What is the refractive index of the transparent plate?

Q.3 Monochromatic light of wavelength 600 nm is used in a Young's double slit experiment. One of the slits is covered by a transparent sheet of thickness 1.8×10^{-5} m made of a material of refractive index 1.6. How many fringes will shift due to the introduction of the sheet?

Q.4 Find the thickness of a plate which will produce a change in optical path equal to half the wavelength λ of the light passing through it normally. The refractive index of the plate is μ.

Q.5 When a thin sheet of a transparent material of thickness 7.2×10^{-4} cm is introduced in the path of one of the interfering beams, the central fringe shifts to a position occupied by the sixth bright fringe.
If $\lambda = 6 \times 10^{-5}$ cm, find the refractive index of the sheet.

Q.6 In Young's double slit experiment, on inserting a thin plate of glass in the path of one of the interfering beams, it is found that the central bright fringe shifts into the position previously occupied by the 6th bright fringe. If the wavelength of light used is 6×10^{-5} cm and the refractive index of glass plate is 1.5 for this wavelength, calculate the thickness of the plate.

Q.7 A glass plate of 1.2×10^{-6} m thickness is placed in the path of one of the interfering beams in a biprism arrangement using monochromatic light of wavelength 6000 Å. If the central band shifts by a distance equal to the width of the bands, find the refractive index of glass.

Answers

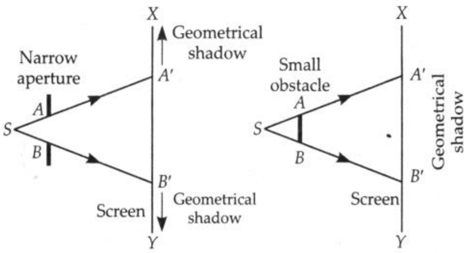
1.	32.7×10^{-5} cm	2.	1.2	3.	18		
4.	$\dfrac{\lambda}{2(\mu-1)}$	5.	1.5	6.	14.5	7.	1.5

Diffraction of Light

Light travels in a straight line. However, when light passes through a small hole, there is a certain amount of spreading of light. Similarly, when light passes by an obstacle, it appears to bend round the edges of the obstacle and enters its geometrical shadow.

The phenomenon of bending of light around the corners of small obstacles or apertures and its consequent spreading into the regions of geometrical shadow is called ***diffraction of light.***

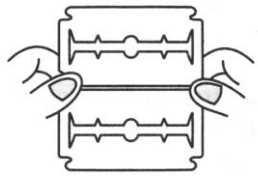
Consider a narrow aperture AB illuminated with light from a source S, as shown in figure. XY is a screen placed at large distance from AB. According to rectilinear propagation of light, only the portion A' B' of the screen should be illuminated. However, it is seen that light enters the region of the geometrical shadow beyond A' and B'. The shadow is not sharp.



Similarly, when an obstacle AB (e.g., a very small disc) is placed in the path of light, we expect a dark shadow A' B' on the screen, as shown in figure.

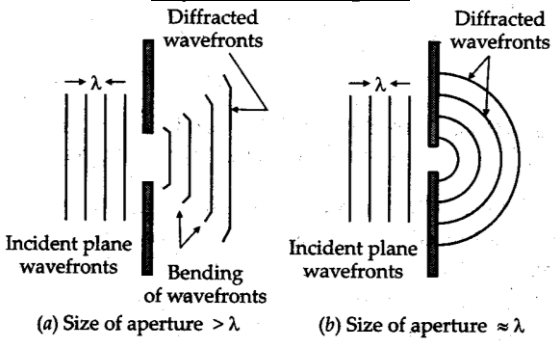
However, we observe a circular bright band at the centre, surrounded by dark and bright rings alternately. This shows that light bends around the edges, i.e., light shows diffraction.

Experiments



1. Hold two blades so that their edges are parallel and form a narrow slit in between. Look through the slit on the straight filament of a clear glass bulb. With slight adjustment of the slit, a diffraction pattern of alternate bright and dark bands is seen.
2. Look at a street lamp through a piece of fine cloth. The lamp appears as an enlarged disc. The threads in mutually perpendicular directions enclose a number of slits which form a pattern of several weaker images of the slits.
3. A pinhole placed at a distance of 2m from a sodium lamp forms alternate bright and dark bands on a screen placed behind the pinhole.

Size of aperture or obstacle for observing diffraction: Suppose plane waves are made to fall on a screen having a small aperture. The waves emerging out of the aperture are observed to be slightly curved at the edges. This is diffraction. If the size of the aperture is large compared to the wavelength of the waves, the amount of bending is small (figure). If the size of the aperture is small, comparable to the wavelength λ of the waves, then the diffracted waves are almost spherical (figure). Hence *the diffraction effect is more pronounced if the size of the aperture or the obstacle is of the order of the wavelength of the waves.*



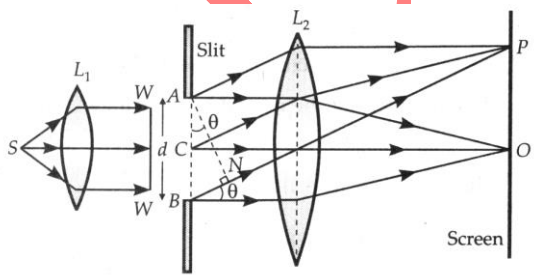
Fresnel and Fraunhoffer Diffraction

Two types of diffraction: The diffraction phenomena can be divided into *two* categories:

1. ***Fresnel's diffraction:*** In Fresnel's diffraction, the source and screen are placed close to the aperture or the obstacle and light after diffraction appears converging towards the screen and hence no lens is required to observe it. The incident wave fronts are either spherical or cylindrical.
2. ***Fraunhoffer's diffraction:*** In Fraunhoffer's diffraction, the source and screen are placed at large distances (effectively at infinity) from the aperture or the obstacle and converging lens is used to observe the diffraction pattern. The incident wavefront is planar one.

Diffraction at a Single Slit

Diffraction at a single slit: A source S of monochromatic light is placed at focus of a convex lens L_1. A parallel beam of light and hence a plane wavefront WW gets incident on a narrow rectangular slit AB of width d.



The incident wavefront disturbs all parts of the slit AB simultaneously. According to Huygens' theory, all parts of the slit AB will become source of secondary wavelets, which all start in the same phase. These wavelets spread out in all directions, thus causing diffraction of light after it emerges through slit AB. Suppose the diffraction pattern is focused by a convex lens L_2 on a screen placed in its focal plane.

Central maximum: All the secondary wavelets going straight across the slit AB are focused at the two corresponding points of the two halves of the slit reach the point O in the same phase, they add constructively to produce a *central bright fringe.*

Calculation of path difference: Suppose the secondary wavelets diffracted at an angle θ are focused at point P. The secondary wavelets start from different parts of the slit in same phase but they reach the point P in different phases. Draw perpendicular AN from A on to the ray from B. Then the path difference between the wavelets from A and B will be

$$p = BP - AP = BN = AB \sin\theta = d \sin\theta.$$

Positions of Minima: Let the point P be so located on the screen that the path difference, $p = \lambda$ and angle $\theta = \theta_1$. Then from the above equation, we get

$$d \sin\theta_1 = \lambda$$

We can divide the slit AB into two halves AC and CB. Then the path difference between the wavelets from A and C will be $\lambda/2$. Similarly, corresponding to every point in the upper half AC, there is a point in the lower half CB for which the path difference is $\lambda/2$. Hence the wavelets from the two halves reach the point P always in opposite phases. They interfere destructively so as to produce a minimum.

Thus the condition for ***first dark fringe*** will be

$$d = \sin \theta_2 = 2\lambda$$

Similarly, the condition for ***second dark fringe*** will be

$$d \sin \theta_2 = 2\lambda$$

Hence the condition for ***nth dark fringe*** can be written as

$$d \sin \theta_n = n\lambda, \quad n = 1, 2, 3, ...$$

The directions of various minima are given by

$$\theta_n = \sin \theta_n = n\frac{\lambda}{d}$$

$$[\text{As } \lambda << d, \text{ so } \sin \theta_n \approx \theta_n)$$

Positions of Secondary Maxima

Suppose the point P is so located that $p = \frac{3\lambda}{2}$

When $\theta = \theta'_1$, then $\quad d \sin \theta'_1 = \frac{3}{2}\lambda$

We can divide the slit into three equal parts. The path difference between two corresponding points of the first two parts will be $\lambda/2$. The wavelets from these points will interfere destructively. However, the wavelets from the third part of the slit will contribute to some intensity forming a secondary maximum. The intensity of this maximum is much less than that of the central maximum.

Thus the condition for the ***first secondary maximum*** is

$$d \sin \theta'_1 = \frac{3}{2}\lambda$$

Similarly, the condition for the ***secondary maximum*** is

$$d \sin \theta'_2 = \frac{5}{2}\lambda$$

Hence the condition for ***nth secondary maximum*** can be written as

$$d \sin \theta'_n = (2n+1)\frac{\lambda}{2}, \; n = 1, 2, 3, ...$$

The directions of secondary maxima are given by

$$\theta'_n \simeq \sin \theta'_n = (2n+1)\frac{\lambda}{2d}$$

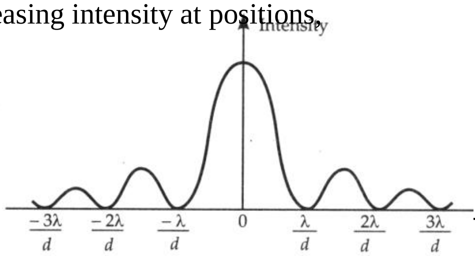
The intensity of secondary maxima a decreases a n increases.

Intensity distribution curve

If we plot a graph between the intensities of maxima and minima against the diffraction angle θ, we get a graph of the type shown in figure. It has a broad central maximum in the direction ($O = 0^o$) of incident light. On either side of the central maximum, it has secondary maxima of decreasing intensity at positions,

$$\theta = \pm(2n+1)\frac{\lambda}{2d} \qquad \text{and} \qquad \text{minima at positions,}$$

$$\theta = \pm n\frac{\lambda}{d} \qquad (n \neq 0)$$



The intensities of secondary maxima relating to the intensity of central maximum are in ratio,

$$1:\frac{1}{21}:\frac{1}{61}:\frac{1}{21}......$$

Thus the intensity of the first secondary maximum is just 4% of that of the central maximum.

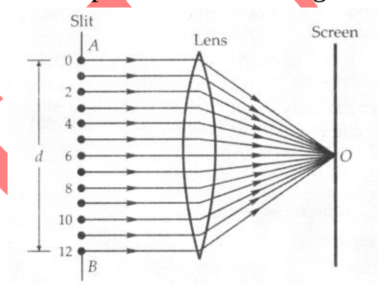
Intensity of secondary maxima decreases with the order of the maximum

The reason is that the intensity of the central maximum is due to the constructive interference of wavelets from all parts of the slit, the first secondary maximum is due to the contribution of wavelets from one third part of the slit (wavelets from remaining two parts interfere destructively), the second secondary maximum is due to the contribution of wavelets from the one fifth part only (the remaining four parts interfere destructively) and so on. Hence the intensity of secondary maximum decreases with the increase in the order n of the maximum.

NOTE

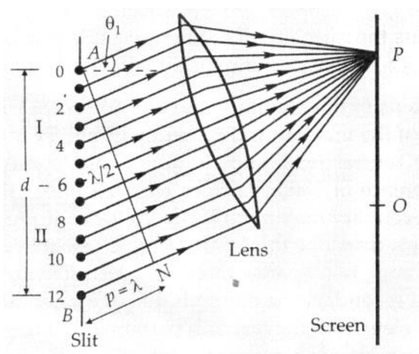
- **Explanation of diffraction fringes**

  Central maximum: All the wavelengths going straight ($\theta = 0^o$) across the slit are focused at the central point O of the screen, as shown in figure. The wavelets from any two corresponding points such as (0, 12), (2, 10), (4, 8) etc. from the two halves of the slit have zero path difference. the undergo constructive interference to produce central bright fringe.

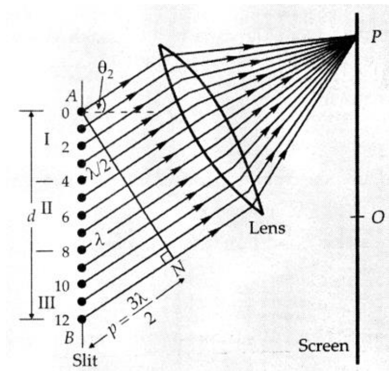


First dark fringe: If angle θ is such that the path difference, p = d sin θ = λ, then the path difference between the rays from A and B when they reach P is λ, as shown in figure. If we divide the slit into two halves I and II, of 6 parts each, then obviously the wavelets form 0 and 6 will have a path difference of λ/2 or a phase difference of π. They interfere destructively. Similarly, the wavelet pairs (1, 7), (2, 8), (3,9), (4, 10), (5, 11) and (6, 12) of the two halves will interfere destructively. Hence will interfere destructively. Hence the condition for first dark fringe is

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



First secondary maximum: Suppose the angle θ is such that the path difference, p = d sin θ = 3λ/2. We can divide the slit into three equal regions I, II and III, as shown in figure. The path difference between any two corresponding points of regions I and II will be λ/2 or phase difference will be π. The wavelets from these points will interfere destructively. The wavelets from III region of the slit will contribute to some intensity forming a secondary maximum. The intensity of this maximum is much less than the central maximum. The condition for the first secondary maximum can be written as



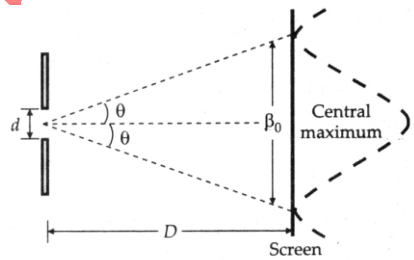
Widths of Central and Secondary Maxima

Angular width of central maximum: The angular width of the central maximum is the angular separation between the directions of the first minima on the two sides of the central maximum, as shown in figure.

The directions of first minima on either side of central maximum are given by

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

This angle is called ***half angular width of central maximum.***



∴ Angular width of central maximum = $2\theta = \frac{2\lambda}{d}$

Linear width of central maximum: If D is the distance of the screen from the single slit, then the linear which of central maximum will be

$$\beta_0 = D \times 2\theta = \frac{2D\lambda}{d} \qquad \left[2\theta(rad) = \frac{Arc}{Radius} = \frac{\beta_0}{D}\right]$$

Linear width of a secondary maximum

The angular width of nth secondary maximum is the angular separation between the directions of nth and (n + 1)th minima.

Direction of nth minimum, $\theta_n = n\frac{\lambda}{d}$

Direction of (n + 1)th minimum,

$$\theta_{n+1} = (n+1)\frac{\lambda}{d}$$

∴ Angular width of nth secondary maximum

$$= \theta_{n+1} - \theta_n = (n+1)\frac{\lambda}{d} - n\frac{\lambda}{d} = \frac{\lambda}{d}$$

Hence the linear width of nth secondary maximum = Angular width × D

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

Clearly, $\beta_0 = 2\beta$

Thus the central maximum of a diffraction pattern is twice as wide as any secondary maximum.

Clearly, width of a secondary maximum

$$\propto \frac{1}{slit\ width}$$

As the slit width is increased, the secondary maxima get narrower. If the slit is sufficiently wide, the secondary maxima disappear and only the central maximum is obtained which is the sharp image of the slit. Thus a distinct diffraction pattern is possible only if the slit is very narrow.

Validity of Ray Optics: Fresnel's Distance

A parallel beam of light of wavelength λ on passing through an aperture of size d gets diffracted into a beam of angular width,

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

If a screen is placed at distance D, this bream spreads over a linear width, $x = \frac{D\lambda}{d}$

If the diffraction spread x is small, the concept of ray optics will be valid.

If we have an aperture of size d = 10 mm and use light of wavelength $\lambda = 6 \times 10^{-7}$ m, then the beam after travelling a distance of 3m will get diffracted through a width.

$$x = \frac{D\lambda}{d} = \frac{3\times6\times10^{-7}}{10\times10^{-3}}$$

$$= 18 \times 10^{-5} \text{ m} = 0.18 \text{ mm}$$

This diffraction spreading is not quite large. Thus ray optics is valid in many common situations. It is useful here to define what is called Fresnel's distance, D_F.

*The distance at which the diffraction spread of a beam is equal to the size of the aperture is called **Fresnel's distance.*** i.e., when x = d, $D = D_F$.

$$\therefore \quad d = \frac{D_F\lambda}{d} \quad \text{or} \quad D_F = \frac{d_2}{\lambda}$$

If $D < D_F$, then there will not be too much broadening by diffraction i.e., the light will travel along straight lines and the concepts of ray optics will be valid.

As $\quad D < D_F \quad$ or $\quad D < \frac{d_2}{\lambda} \quad$ or $\quad d > \sqrt{\lambda D}$

For a given value of D, the quantity $\sqrt{\lambda D}$ is called the ***size of Fresnel zone*** and is denoted by d_F.

i.e., $\quad d_F = \sqrt{\lambda D}$

Hence the concepts of ray optics can be conveniently used without introducing any appreciable error is the size of the aperture is greater than the size of the Fresnel zone,

i.e., $\quad d > d_F$.

Assignment – VII

Q.1 Fraunhoffer diffraction from a single slit of width 1.0 μm is observed with light of wavelength 500 nm. Calculate the half angular width of the central maximum.

Q.2 Light of wavelength 600 nm falls normally on a slit of width 1.2 μm producing Fraunhoffer diffract ion pattern on a screen. Calculate the angular position of the first minimum and the angular width of the central maximum.

Q.3 Microwaves of frequency 24, 000 MHz are incident normally on a rectangular slit of width 5 cm. Calculate the angular spread of the central maximum of the diffraction pattern of the slit.

Q.4 A slit of width 'd' is illuminated by red light of wavelength 6500 Å. For what value of 'd' will (i) the first minimum fall at an angle of diffraction of 30^o and (ii) the first maximum fall at an angle of diffraction of 30^o.

Q.5 Light of wavelength 550 nm is incident as parallel bream on slit of width 0.1 mm. Find the angular width and the linear width of the principal maxima in the resulting diffraction pattern on a screen kept at a distance of 1.1 m from the slit. Which of these widths would not change if the screen were moved to a distance of 2.2 m from the slit?

Q.6 A screen is placed 2m away from a single narrow slit. Calculate the slit width if the first minimum lies 5 mm on either side of central maximum. Incident plane waves have a wavelength of 5000 Å.

Q.7 A parallel beam of light of wavelength 600 nm is incident normally on a slit of width 'd'. If the distance between the slits and the screen is 0.8 m and the distance of 2^{nd} order maximum from the centre of the screen is 15 mm, calculate the width of the silt.

Q.8 Determine the angular separation between central maximum and first order maximum of the diffraction pattern due to a single slit of width 0.25 mm when light of wavelength 5890 Å is incident on it normally.

Q.9 Parallel light of wavelength 5000 Å falls normally on a single slit. The central maximum spreads out to 30^o on either side of the incident light. Find the width of the slit. For what width of the slit the central maximum would spread out to 90^o from the direction of the incident light?

Q.10 A slit of width 0.025 mm is placed in front of lens of focal length 50 cm. The slit is illuminated with light of wavelength 5900Å. Calculate the distance between the centre and first dark band of diffraction pattern obtained on a screen placed at the focal plate of the lens.

Q.11 Two wavelengths of sodium light 590 nm, 596 nm are used, in turn, to study the diffraction taking place at a single slit of aperture 2×10^{-4} m. The distance between the slit and the screen is 1.5 m. Calculate the separation between the positions of first maximum of the diffraction pattern obtained in the two cases.

Q.12 A laser operates at a frequency of 3×10^{14} Hz and has an aperture of 10^{-2} m. What will be the angular spread?

Q.13 A laser beam has a wavelength of 7×10^{-7} m and aperture 10^{-2} m. The beam is sent to moon, the distance of which from earth is 4×10^5 km. Find (i) the angular spread and (ii) a real spread when the beam reaches the moon.

Q.14 A laser light beam of power 20 mW is focused on a target by a lens of focal length 0.05 m. If the aperture of the laser be 1 mm and the wavelength of its light 7000 Å, calculate the angular spread of the laser, the area of the target hit by it, and the intensity of the impact on the target.

Q.15 Calculate the distance that a beam of light of wavelength 500 nm can travel without significant broadening, if the diffracting aperture is 3 mm wide.

OR

For what distance is ray optics a good approximation when the aperture is 3 mm wide and the wavelength is 500 nm?

Q.16 Light of wavelength 5×10^{-7} m is diffracted by an aperture of width 2×10^{-3} m. For what distance traveled by the diffracted beam does the spreading due to diffraction become greater than the width of the aperture?

Q.17 Light of wavelength 600 nm is incident on an aperture of size 2 mm. Calculate the distance upto which light can travel such that its spread is less than the size of the aperture.

Answers

1.	30^o	2.	30^o	3.	$\frac{1}{2}$ rad
4.	(i) 1.3×10^{-6} m, (ii) 1.95×10^{-6} m				
5.	(i) 1.1×10^{-2} rad, (ii) 12.1 mm			6.	0.2 mm
7.	80 μm	8.	3.534×10^{-3} rad	9.	5×10^{-7} m
10.	11.8 mm	11.	6.75 mm	12.	1.22×10^{-4} rad
13.	(i) 8.54×10^{-5} rad, (ii) 1.197×10^{9} m^2				
14.	(a) 8.54×10^{-4} radian, (b) 1.823×10^{-15} m^2, (c) 10.97×10^{12} Wm^{-2}				
15.	18 m	16.	8 m	17.	6.67 m

Assignment – VIII

Q.1 A slit 4.0 cm wide is irradiated with microwaves of 2.0 cm. Find the angular spread of central maximum assuming incidence normal to the plane of the slit.

Q.2 The slit of width 'd' is illuminated by light of wavelength 5000 Å. For what value of 'd' will the first maximum fall at angle of diffraction of 30^o?

Q.3 The light of wavelength 600 nm is incident normally on a slit of width 3 mm. Calculate the linear width of central maximum on a screen kept 3 m away from the slit.

Q.4 Light, of wavelength 500 nm, falls, from a distant source, on a sit 0.50 mm wide. Find the distance between the two dark bands, on either side of the central bright band, of the diffraction pattern observed, on a screen placed 2m from the slit.

Q.5 A 0.02 cm wide slit is illuminated at normal incidence by light of wavelength 6000 Å (i) find the width of the central maximum band on the screen placed 1m away from the slit. (ii) What should be the fringe width if the apparatus is immersed in water whose refractive index is 4/3?

Q.6 A Fraunhoffer diffraction pattern due to a single slit of width 0.2 mm is being obtained on a screen placed at a distance of 2m from the slit. The first minima lie at 5 mm on either side of the central maximum on the screen. Find the wavelength of light used.

Q.7 A parallel beam of monochromatic light of wavelength 5000Å is incident normally on a narrow slit of width 0.25 mm. The diffraction pattern is observed on a screen placed at the focal plane of a convex lens placed close to t he slit between slit and screen. Find the angular separation between the first secondary maxima on either side of the central maximum.

Q.8 A screen is placed 50 cm from a single slit which is illuminated with light of wavelength 6000 Å. if the distance between the first and third minima in the diffraction pattern is 3.0 mm, what is t he width of the slit?

Q.9 A laser beam has a wavelength of 6×10^{-7} m and aperture of 6×10^{-2} m. The beam is sent towards the moon which is at a distance of 4×10^{8} m from the earth. Calculate (i) the angular spread of the beam and (ii) the areal spread when it reaches the moon.

Q.10 A laser beam has a power of 100 mw. It has an aperture of 5×10^{-10} m and emits a wavelength 6943 Å. The beam is focused with a lens of focal length 0.1 m. Calculate the areal spread and intensity of the image.

Q.11 The width of an aperture is 4 mm and wavelength is 5000 Å. Calculate the distance upto which ray optics is valid.

Q.12 A parallel beam of light of wavelength 600 nm is incident normally on a slit of width 'd'. If the distance between the slits and the screen is 0.8 m and the distance of 2^{nd} order minimum from the centre of the screen is 9.5 mm, calculate the width of the slit.

Q.13 Two towers are built on hill 50 km apart and the line joining them passes 30 m above a hill halfway in between. What is the longest wavelength of radio waves which can be sent between the towers with out serious diffraction effects?

Answers

1.	$\pm 60^o$	2.	1.5×10^{-6} m	3.	1.2 mm
4.	4 mm	5.	(i) 0.6 cm (ii) 0.45 cm	6.	5000 Å
7.	6×10^{-3} rad	8.	0.2 mm		
9.	(i) 1.22×10^{-5} rad, (ii) 2.381×10^{7} m				
10.	2.87×10^{-10} m^2, 2.48×10^{8} Wm^{-2}			11.	32 m
12.	0.1 mm	13.	0.036 m		

Diffraction as a Limit on Resolving Power

All optical instruments like lens, telescope, microscope etc., act as apertures. Light on passing through them undergoes diffraction. This puts the limit on their resolving power. If we have two nearby point objects, their images may give rise to diffraction patterns which overlap on each other, making the identification or resolution of the two objects difficult.

Limit of Resolution

The smallest linear or angular separation between two point objects at which they can be just separately seen or resolved by an optical instrument is called the limit of resolution of the instrument.

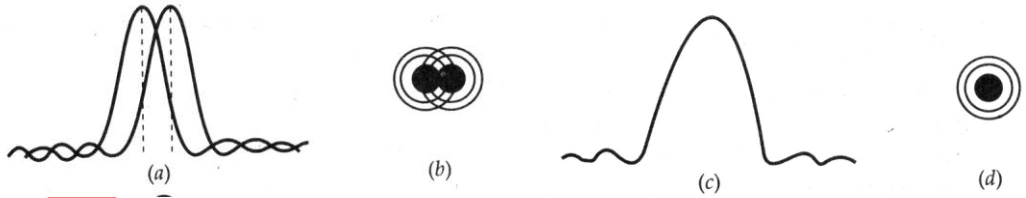
Resolving power

The resolving power of an optical instrument is its ability to resolve or separate the images of two nearby point objects so that they can be distinctly seen. It is equal to the reciprocal of the limit of resolution of the optical instrument.

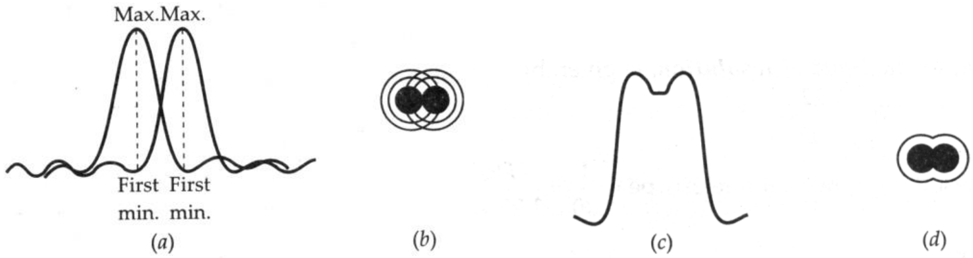
The smaller the limit of resolution of an optical instrument, greater is its resolving power.

Rayleigh's criterion for resolution

It we look through a telescope at two starts lying closed together, their different patterns overlap and the resultant pattern is little broader but otherwise similar to that of a single star, as shown in figure. So the two stars cannot be resolved or separately seen.



According to Rayleigh's *criterion, the images of two point objects are just resolved when the central maximum of the diffraction pattern of one falls over the first minimum of the diffraction pattern of the other, as shown in figure. When see through the telescope, the resultant diffraction has a well–marked depression at the top, showing that these are really two starts and not one.* Thus the images of two starts have been just resolved.

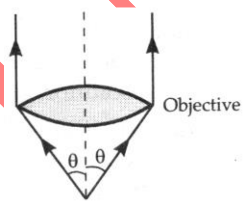


Resolving power of a microscope

The resolving power of a microscope is defined as reciprocal of the smallest distance between two point objects at which they can be just resolved when seen through the microscope.

The smallest distance between two point objects at which they can be just resolved by the microscope, or the **limit of resolution,** is given by

$$d = \frac{\lambda}{2\mu \sin\theta}$$



∴ Resolving power of a microscope = $\frac{1}{d} = \frac{2\mu \sin\theta}{\lambda}$

Here,

λ = the wavelength of light used,

θ = half the angle of cone of light from each point object or the angle subtended by each point object on the radius of the objective (figure)

μ = the refractive index of the medium between the point object and the objective of the microscope.

The factor $\mu \sin\theta$ is called the ***numerical aperture*** (for eye, $\mu \sin\theta = 0.004$). The smaller the limit of resolution 'd', the greater will be the resolving power. The resolving power of a microscope increase when an oil of high refractive microscope increases when an oil of high refractive index (μ) is used between the object and the objective (called the ***oil immersion objective)*** of the microscope.

Resolving power of a telescope:

The resolving power of a telescope is defined as the reciprocal of the smallest angular separation between two distant objects whose images can be just resolved by it.

The smallest linear angular separation between two distant objects whose images can be just resolved by the telescope, or the ***limit of resolution,*** is given by

$$d\theta = \frac{1.22\,\lambda}{D}$$

∴ Resolving power of a telescope = $\frac{1}{d\theta} = \frac{D}{1.22\lambda}$

Here

λ = the wavelength of light,

D = the diameter of the telescope objective, and

$d\theta$ = the angle subtended by the two distant objects at the objective.

Thus larger the aperture of the objective and smaller the wavelength of light used, the greater will be the resolving power of the telescope.

Resolving power of human eye

The diameter of the pupil of human eye is about 2 mm. If we take λ = 5000 Å, then the smallest angular separation between two distant point objects that the human eye can resolve will be

$$d\theta = \frac{1.22\lambda}{D} = \frac{1.22\times5000\times10^{-10}}{2\times10^{-3}} = 0.305\times10^{-3}\ rad \approx 1'$$

Thus, the human eye can see two point objects distinctly if they subtend, at the eye, an angle equal to one minute of arc. This angle is called the *limit of resolution of* the eye. The reciprocal of this angle or limit of resolution gives the resolving power of the eye.

Further, if d is the separation between two point objects at a distance of 1 km which can be just resolved by human eyes, then

$$0.305\times10^{-3} = \frac{d}{10^3} \quad \text{or} \quad d = 0.305\,m = 30.5\ cm$$

Thus the human eyes can see two objects separated by 30 cm just resolved from a distance of 1 km.

Assignment – XI

Q.1 Assume that light of wavelength 6000 Å is coming from a start. What is the limit of resolution of a telescope whose objective has a diameter of 100 inch?

Q.2 A telescope is used to resolve two starts separated by 4.6×10^{-6} rad. If the wavelength of light used is 5460 Å, what should be the aperture of the objective of the telescope?

Q.3 The objective of an astronomical telescope has a diameter of 150 mm and a focal length of 4.0 m. The eyepiece has a focal length of 25.0 mm. Calculate the magnifying and resolving powers of the telescope. What is the distance between the objective and the eyepiece? Take λ = 6000 Å

Q.4 Calculate the separation of two points on the moon that can be resolved using 600 cm telescope. Given the distance of the moon from the earth is 3.8×10^{10} cm. The wavelength most sensitive to the eye is 5.5×10^{-5} cm.

Q.5 A telescope has an objective of diameter 60 cm. The focal lengths of the objective and eye–piece are 2.0 m and 1.0 respectively. The telescope is directed to view two distant almost point sources of light (e.g. two starts of a binary). The sources are at roughly the same distance (= 10^4 light years) along the line of slight but are separated transverse to the line of sight but are separated transverse to the line of sight by a distance of 10^{10} m. Will the telescope resolve the two objects i.e. will it see two distinct starts?

Q.6 Calculate the resolving power of a microscope if its numerical aperture is 0.12 and the wavelength of light used is 6000 Å.

Q.7 Calculate the numerical aperture of a microscope required to just resolve two points separated by a distance of 10^{-4} cm, using light of wavelength 5.8×10^{-5} cm, d = 10^{-4} cm.

Q.8 The smallest object detail that can be resolved with a certain microscope with light of wavelength 6000 Å is 3.5×10^{-5} cm. Find the numerical aperture of the objective (i) when used dry and (ii) when immersed in an oil of refractive index 1.5

Q.9 Assuming the diameter of the eye pupil to be 2.0 mm, calculate the smallest angular separation at which two point objects can be distinctly seen when viewed in light of wavelength 6000 Å.

Q.10 Roughly calculate the limit of resolution of 100 cm telescope with visible light of wavelength λ= 5500 Å.

Q.11 Calculate the resolving power of this telescope, assuming the diameter of the objective lens to be 6 cm and the wavelength of light used to be 540 nm.

Q.12 The objective of a telescope has a diameter of 125 cm. Calculate the smallest angular separation of two stars, measured in seconds, that may be resolved by it. Mean wavelength of light = 6000 Å.

Q.13 What is the aperture of the objective of a telescope of 6×10^{-6} rad. Given $\lambda = 5.8\times10^{-5}$ cm.

Q.14 Two point objects, separated by a distance of 6×10^{-5} cm, are to be resolved using a microscope. Calculate the numerical aperture if light of wavelength 546 nm is used.

Q.15 Calculate the limit of resolution of a microscope if an object of numerical aperture 0.12 is viewed by using light of wavelength 6×10^{-7} m.

Answers

1.	2.9×10^{-7} rad	2.	0.1488 m	3.	160, 2.049×10^5, 4.025 m
4.	4180 cm	5.	1.22×10^{-6} rad	6.	4×10^5 m^{-1}
7.	0.29	8.	(i) 0.86, (ii) 1.44	9.	3.66×10^{-4} rad
10.	6.71×10^{-7} rad	11.	9.1×10^4	12	0.12 second of arc
13.	11.79 cm	14.	4.55×10^{-3}	15.	2.55×10^{-8} cm

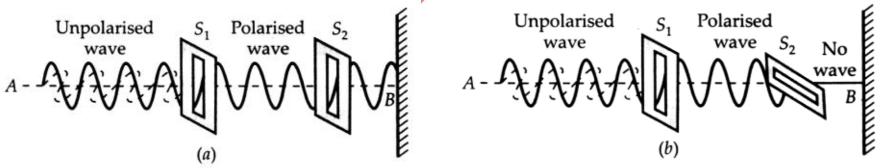
Polarisation of Waves

The waves are of *two* types: *Transverse* and *Longitudinal.* Both types of these waves undergo reflection, refraction, interference and diffraction. The difference is that only transverse waves can be polarized.

A transverse wave is which vibrations are present in all possible directions, in a plane perpendicular to the direction of propagation, is said to be ***unpolarised.*** *If the vibrations of a wave are present in just one direction in a plane perpendicular to the direction of propagation, the wave is said to be* ***polarized or plane polarized.*** *The phenomenon of restricting the oscillations of a wave to just one direction in the transverse plane is called* ***polarization of waves.***

Experimental Demonstration with Mechanical Waves

Consider a long string AB passing through two rectangular slits S_1 and S_2, as shown in figure. The end B of the string is tied to a hook in a wall and the free end A is jerked in all possible directions perpendicular top the length of the string so as to generate transverse waves in it. The portion AS_1 of the string has vibrations in all directions perpendicular to AB, so that the wave is unpolarised. The first slit S_1 will permit only those vibrations to pass through it which are parallel to the slit S_1 and will cut off all other vibrations. Thus the wave emerging from the slit S_1 is plane polarized. The slit S_1 is called the *polarizer.* If the second silt S_2, called the *analyzer*, is held parallel to S_1, the wave from S_1 will pass through S_2 unchanged. If S_2 is held perpendicular to S_1, no vibrations will emerge from the slit S_2. The indicates that the slit S_1 has polarized the incoming wave in the vertical plane.



Longitudinal Waves cannot be Polarized

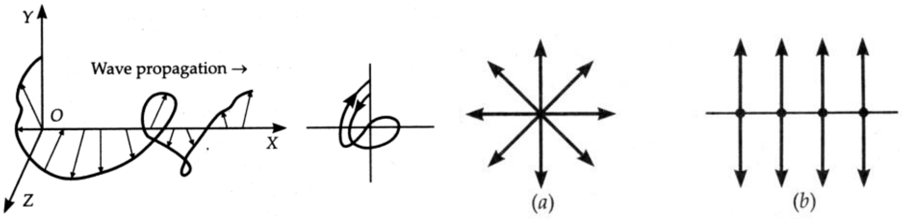
This is because these waves are *symmetrical* about the direction of propagation.

Unpolarised and Plane Polarised Light

Unpolarised light

In ordinary light, electric field vector vibrates in all directions in a plane perpendicular to the direction of propagation. *A light which has vibrations in all directions in a plane perpendicular to the direction of propagation is said to be* ***unpolarised light.*** The light from the sun, a sodium lamp, an incandescent bulb or a candle is unpolarised. The electric field vector of such a light takes all possible directions in the transverse plane, rapidly and randomly, during the time of measurement.

Figure (a) is the pictorial representation of unpolarised light propagating out of the plane of paper. It shows vibrations in all directions in the transverse plane. Figure (b) is also a pictorial representation of an unpolarised light. Here double arrows represent the vibrations in the plane of paper and small dots represent vibrations perpendicular to the plane of paper.



Plane polarized or linearly polarized light

*If the electric field vector of a light wave vibrates just in one direction perpendicular to the direction of wave propagation, then it is said to be **linearly polarized.*** Since in a linearly polarized wave, the vibrations at all points, at all times, lie in the same plane, so it is also called a ***plane polarized wave.*** Figure(a) shows the regular variation of the electric field vector of a linearly polarized light along Y–axis. Its tip vibrates back and forth along a straight line.

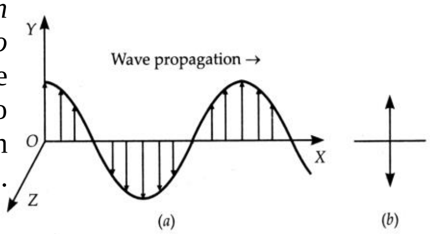
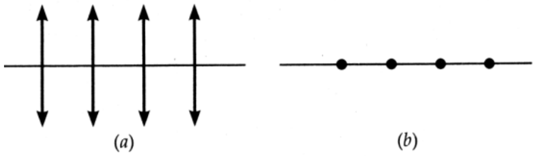


Figure (a) and (b) show the pictorial representations for plarised light.



Polarisers

A device that plane–polarizes the unpolarised light passed through it is called a polarizer.

Some commonly used polarisers are as follows:

1. ***Tourmaline Crystal:*** The tourmaline crystal is so cut that its plane contains its optic axis. When unpolarised light is incident on it normally, it allows only such electric field vibrations to pass through it which are parallel to its axis. Such crystal can be used to polarize a beam of unpolarised light.

2. ***Nicol Prism:*** It is an optical device used for producing and analyzing plane polarized light. It consists of two pieces of calcite suitably cut and struck together with Canada balsam.

3. ***Polaroid:*** A polaroid is a thin commercial sheet in the form of circular disc which makes use of the property of selective absorption to produce an intense beam of plane polarized light.

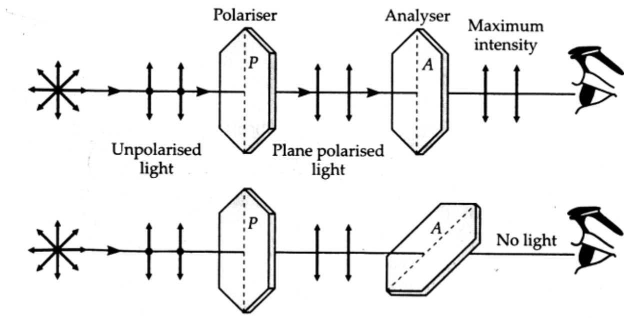
Law of Malus

When a plane polarized light is seen through an analyzer, the intensity of transmitted light varies as the analyzer is rotated in its own plane about the incident direction. *When a beam of completely plane polarized light is passed through analyzer, the intensity 'I' of transmitted light varies directly as the square of the cosine of the angle 'θ' between the transmission directions of polarizer and analyzer.* This statement is known as the ***law of Malus.***

Mathematically,

$$I \propto \cos^2\theta \quad \text{or} \quad I = I_0 \cos^2\theta$$

Here I_0 is the maximum intensity of transmitted light. It may be noted that I_0 is equal to half the intensity of unpolarised light incident on the polarizer.



Explanation of the Law

As shown in figure, suppose that the planes of polarizer and analyzer are inclined to each other at an angle θ. Let I_0 be the intensity and a the amplitude of the plane polarized light transmitted by the polarizer.

The amplitude a of the light incident on the analyzer has *two* rectangular components:

1. a cos θ, parallel to the plane of transmission of the analyser, and
2. a sin θ, perpendicular to the plane of transmission of the analyser.

So only the component a cos θ is transmitted by the analyser. The intensity of light transmitted by the analyser is

$$I = k(a\cos\theta)^2 = ka^2\cos^2\theta \qquad \text{or} \qquad I = I_0\cos^2\theta$$

where $I_0 = ka^2$, is the maximum intensity of light transmitted by the analyser (when $\theta = 0^o$). The above equation is the ***law of Malus.***

Special Cases

1. When $\theta = 0^o$ or 180^o, $\cos\theta = \pm 1$, so that $I = I_0$

   So *when the transmission directions of polarizer and analyser are parallel or antiparallel to each other, the maximum intensity of plane polarized light is transmitted by the analyser and is equal to the intensity emerging from the polarizer.*

2. When $\theta = 90^o$, $\cos\theta = 0$, so that $I = 0$

   So when the transmission directions of polarizer and analyser are perpendicular to each other, the intensity of light transmitted through the analyser is zero.

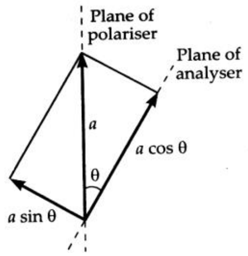
3. When a beam of unpolarised light is incident on the polarizer,

$$I = I_0\,\overline{\cos^2\theta} = I_0 \times \frac{1}{2}\overline{(1+\cos 2\theta)}$$

$$= \frac{1}{2}I_0(1+\overline{\cos 2\theta}) = \frac{1}{2}I_0(1+0) = \frac{1}{2}I_0.$$

Intensity Curve

As the angle 'θ' between the transmission directions of polarizer and analyser is varied, the intensity 'I' of the light transmitted by the analyser varies as a function of $\cos^2\theta$.



Assignment – XII

Ray and Wave Optics

Q.1 Two polaroids are used to study polarization. One of them (the polarizer) is kept fixed and the other (five analyzer) is initially kept with its axis parallel to the polarizer axis. The analyzer is then rotated through angles of 45^o, 90^o and 180^o in turn. How would the intensity of light coming out of the analyzer be effected for these angles of rotation, as compared to the initial intensity and why?

Q.2 Two polaroids are crossed to each other. If one of them is rotated through 60^o, then what percentage of the incident unpolarised light will be transmitted by the polaroids?

Q.3 Two polaroids are placed 90^o to each other. What happens when N –1 more polaroids are inserted between two crossed polaroids (at 90^o to each other). Their axes are equally spaced. How does the transmitted intensity behave for large N?

Q.4 A Polaroid examines two adjacent plane polarized light beams A and B whose planes of polarization are mutually at right angles. In one position of the Polaroid, the beam B shows zero intensity. From this position a rotation of 30^o shows the two beams of equal intensities. Find the intensity ratio I_A/ I_B of the two beams.

Q.5 An e.m. beam has an intensity of 20 Wm^{-2} and is linearly polarized in the vertical direction. Find the intensity of the transmitted beam by a polarioid when its plane of transmission makes an angle of 60^o with the vertical.

Q.6 A polarizer and an analyzer are oriented so that the maximum light is transmitted. What is the fraction of maximum light transmitted when analyzer is rotated through (i) 30^o (ii) 60^o?

Q.7 Unpolarised light falls on two polarizing sheets placed one on the top of the other. What must be the angle between the characteristic directions of the sheets if the intensity of the transmitted light is (a) one–third of the maximum intensity of the transmitted beam (b) one third of the intensity of the incident beam.

Q.8 When polarizer and analyzer have their axes inclined to one another at 30^o, the amount of light transmitted is 5 SI units. What is the maximum intensity of light transmitted and at what angle between the two?

Q.9 The intensity of light–beam is 10 Wm^{-2} and it is plane–polarized in vertical direction. It passes through a polaroid whose transmission axis is inclined at angle of 30^o with the vertical. The transmitted light–beam passes through a second polaroid whose transmission axis is inclined at an angle of 90^o with the vertical. (i) What will be the intensity of light emerging form the second polaroid? (ii) If the first polaroid is removed, then?

Q.10 Four polaroids are so placed that the transmission axis of each is inclined at an angle of 30^o from the axis of the previous polaroid in the same direction. If unpolarised light–beam of intensity I_0 falls on the first polaroid, then what will be the intensity of the light emerging from the last polaroid?

Q.11 Two 'crossed' polaroids A and B are placed in the path of a light–beam. In between these, a third polaroid C is placed whose polarization axis makes an angle θ with the polarization axis of the polaroid A. If the intensity of light emerging from the polaroid A is I0, then show that the intensity of light emerging from polaroid B will be 1/4 $I_0 \sin^2 2\theta$.

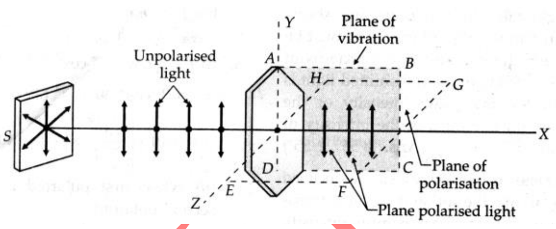
Answers

1.	I_0	2.	37.5 %
3.	I_0	4.	1 : 3
5.	5 W m^{-2}	6.	(i) 0.75, (ii) 0.25
7.	$\pm 55^o$, $\pm 35^o$	8.	(a) 6.67 SI unit, $\theta = 0^o$ or $\pm 180^o$
9.	(i) 1.875 Wm^{-1}, (ii) zero	10.	0.21 I_0

Planes of Polarisation and Vibration

When ordinary light is passed through a tourmaline crystal, the light is plane polarized and the vibrations of the electric field vector take place just in one direction perpendicular to the direction of propagation of light.

The plane containing the direction of vibration and the direction of wave propagation is called the ***plane of vibration.***

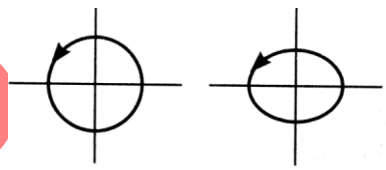


The plane passing through the direction of wave propagation and perpendicular to the plane of vibration is called the ***plane of polarization.*** *No vibrations occur in the plane of polarization.*

Circularly and Elliptically Polarised Lights

Circularly Polarised Light

If the tip of the electric field vector of a light wave traces a circle, the light is said to be circularly polarized. It can be regarded as the combination of two plane polarized vibrations of equal amplitudes in two mutually perpendicular directions with a phase difference of $\pi/2$.



(a) (b)

Elliptically Polarised Light

It the tip of the electric field vector of a light wave traces an ellipse, the light is said to be elliptically polarized. It can be regarded as the combination of two plane polarized vibrations of unequal amplitudes in the mutually perpendicular directions with a phase difference of $\pi/2$.

Methods of Producing Plane Polarised Light

Ordinary light can be polarized by using any of the following phenomena:

1. Reflection
2. Scattering
3. Double refraction
4. Selective absorption

Polarisation by Reflection: Brewster Law

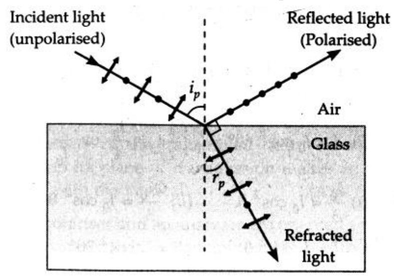
When ordinary light is incident on the surface of a transparent medium, the reflected light is partially plane polarized. The extent of polarization depends on the angle of incidence. For a particular angle of incidence the reflected light is found to be completely polarized with its vibrations perpendicular to the plane of incidence.

The angle of incidence of which a beam of unpolarised light falling on a transparent surface is reflected as beam of completely plane polarized light is called ***polarizing or Brewster angle.*** It is denoted by i_p.

At the plarising angle, the reflected and transmitted rays are perpendicular to each other, as shown in figure. Suppose i_p is the plarising angle of incidence and r_p, the corresponding angle of refraction. Then

$$i_p + r_p = 90^o$$

or $$r_p = 90^o - i_p$$



From Snell's law, the refractive index of the transparent medium is

$$\mu = \frac{\sin i_p}{\sin r_p} = \frac{\sin i_p}{\sin(90^o - i_p)} = \frac{\sin i_p}{\cos i_p} \quad \text{or} \quad \mu = \tan i_p$$

This relation is known as **Brewster law.** The *law states that the tangent of the polarizing angle of incidence of a transparent medium is equal to its refractive index.* The value of Brewster angle depends on the nature of the transparent refracting medium and the wavelength of light used.

Explanation

The incident unpolarised light has both types of vibrations, one perpendicular (dots) and other parallel to the plane of incidence. At the polarizing angle of incidence (i_p), the reflected and refracted rays are perpendicular to each other. The electrons oscillating in the transparent medium produce the reflected wave. These vibrations move in two directions transverse to the refracted wave. As the arrows are parallel to the direction of reflected wave, they cannot send energy along the direction of reflected light. Hence the reflected light consists of vibrations perpendicular to the plane of incidence (dots) only i.e., the reflected light is plane polarized.

Assignment – XIII

Q.1 Unpolarized light is incident on a plane glass. What should be the angle of incidence so that the reflected rays are perpendicular to each other?

Q.2 Yellow light is incident on the smooth surface of a black of dense flint glass for which the refractive index is 1.6640. Find the polarizing angle. Also find the angle of refraction.

Q.3 A ray of light strikes a glass plate at an angle of 60^o. If the reflected and refracted rays are perpendicular to each other, find the refractive index of glass.

Q.4 At what angle of incidence will the light reflected from water (μ = 1.3) be completely polarized? Does this angle depend on the wavelength of light?

Q.5 For a given medium, the polarizing angle is 60^o. What will be the refractive index and the critical angle for this medium?

Q.6 The velocity of light in air is 3×10^8 ms^{-1} and that in water is 2.2×10^8 ms^{-1}. Find the polarizing angle of incidence.

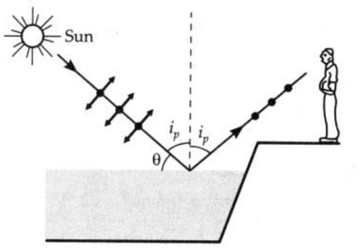
Q.7 The refractive index of water is 4/3 and that of glass 3/2. A beam of light travelling in water enters glass. For what angle of incidence the reflected light will be completely plane–polarized?

Q.8 Find the Brewstar angle for air–water surface for yellow light. Refractive index of water for yellow light = 1.33.

Q.9 A ray of light strikes a glass plate at an angle of incidence 57^o. If the reflected and refracted rays are perpendicular to each other, what is the refractive index of glass?

Q.10 When sunlight is incident on water at an angle of 53^o, the reflected light is found to be completely planepolarised. Determine (i) angle of refraction of light and (ii) refractive index of water.

Q.11 In figure, at what angle θ above the horizon should the sun be situated so that its light reflected from the surface of still water of the pond be totally polarized? Given : refractive index of water $\mu = 1.327$ and $\tan 53^o = 1.327$.



Q.12 The polarizing angle for a medium is 60^o. Determine (i) the refractive index of the medium and (ii) the refracting angle.

Q.13 A ray of light is incident on a glass plate of refractive index 1.54. If the reflected ray is completely plane polarized, find (i) angle of incidence (ii) angle of incidence (ii) angle of refraction and (iii) critical angle. Given tan 57^o = 1.54 and sin 40.5^o = 0.6439

Q.14 Yellow light is incident on a smooth surface of a block of dense flint glass for which the refractive index is 1.6640. Find the polarizing angle and the angle of refraction.

Q.15 A beam of light travelling in water falls on a glass plate immersed in water. When the incident angle is 51^o, the reflected beam of light is found to be completely plane polarized. Determine the refractive index of glass. Given refractive index of water = 4/3.

Q.16 A ray of light is incident on the surface of a glass plate of refractive index 1.536 at the polarising angle. Calculate the angle of refraction.

Q.17 The critical angle for a certain wavelength of light in glass is 40^o. Calculate the polarizing angle and the angle of refraction in glass corresponding to it.

Answers

1.	56.3^o	2.	31^o	3.	1.732
4.	53^o	5.	$36^o16'$	6.	53.74^o
7.	48^o22	8.	53^o	9.	1.54
10	(i) 37^o, (ii) 1.327	11.	37^o	12.	(i) 1.732 × (ii) 30^o
13.	(i) 57^o, (ii) 33^o, (iii) 40.5^o	14.	59^o, 31^o	15.	1.647
16.	$33^o4'$	17.	57.3^o, 32.7^o		

Polarisation by Scattering

Sunlight gets scattered (i.e., its direction is changed) when it encounters the molecules of the earth's atmosphere. The scattered light seen in a direction perpendicular to the direction of incidence is found to be plane polarized.

Explanation

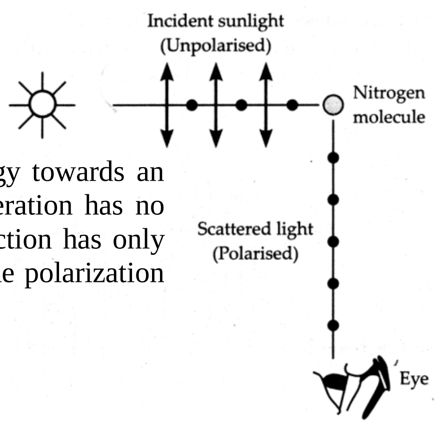


Figure shows the unpolarised light incident on a molecule. The dots show vibrations perpendicular to the plane of paper and double arrows show vibrations in the plane of paper. The electrons in the molecule begin to vibrate in both of these directions.

The electrons vibrating parallel to the double arrows cannot send energy towards an observer looking at 90^o to the direction of the sun because their acceleration has no transverse component. The light scattered by the molecules in this direction has only dots. It is polarized perpendicular to the plane of paper. This explains the polarization of light scattered from the sky.

NOTE

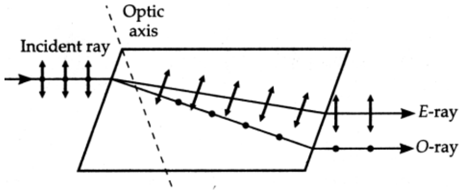
♦ Human eyes cannot distinguish between an unpolarised light and a polarized light. But the eyes of a bee can detect the difference. The bees can, not only, distinguish unpolarised light from polarized light but can also determine the direction of polarization.

Polarisation by Double Refraction: Nicol Prism

When an unpolarised ray passes through certain crystals like quartz or calcite, it splits up into two rays, as shown in figure. This phenomenon is called ***double refraction or birefringence.***

1. The one ray which obeys the ordinary laws of refraction and has vibrations perpendicular to the plane of incidence (dots) is called ***O–ray*** or ***ordinary ray.***

2. The other ray which does not obey the laws of refraction and has vibrations parallel to the plane of incidence is called ***E–ray*** or ***extraordinary ray.***



Optic axis

It is a particular direction in the crystal along which both the O– and E – rays have equal value of refractive index of the crystal and travel with the same velocity and hence there is no double refraction in this direction. Along this direction, the images due to O–and E–rays coincide.

Principal Section

Any plane which contains the optic axis and is perpendicular to the two opposite refracting faces of a crystal is called a principal section of the crystal.

Nicol Prism

It is an optical device based on the phenomenon of double refraction which is used for producing and analyzing plane polarized light. It was invented by *William Nicol.*

Principle

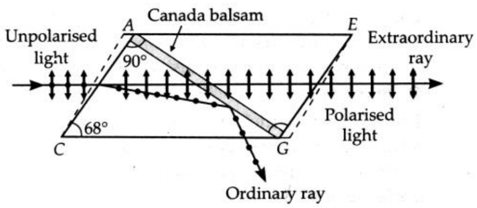
When a thin film of Canada balsam is placed between two calcite pieces, the O–rays of the unpolarised incidence light get eliminated through the phenomenon of total internal reflection while the E–rays are transmitted unaffected and emerge as a beam of plane polarized light.

Construction

The nicol prism consists of two calcite crystals cut at 68° angle with its principal axis joined by a glue called Canada balsam. Canada balsam has a refractive index of 1.55, while the refractive index of calcite for the O–rays is 1.658 and that for E–rays is 1.486. Thus, Canada balsam acts as a rarer medium for O–rays and a denser medium for E-rays.

Working

The principal section ACGE of a nicol prism. The diagonal AG represents the Canada balsam layer. When a ray of unpolarised light passes from a portion of the calcite crystal into the layer of Canada balsam, it passes from a denser to a rarer medium. When the angle of incidence is greater than the critical angle (≈ 69°), the O – ray is totally reflected and absorbed by a blackened surface.



The E–ray is not affected because it is travelling from rarer medium (calcite) to denser medium (Canada balsam). It gets transmitted through the nicol prism. Hence a ray of unpolarised light on passing through the nicol prism becomes plane polarized containing vibrations parallel to the principal section.

NOTE

♦ **Quarter–wave and half–wave planes:** For a double refracting crystal, the refractive indices for O–ray and E – ray are μ_0 & μ_e respectively. When these rays pass through a slab of thickness t, the path difference introduced between the two rays is

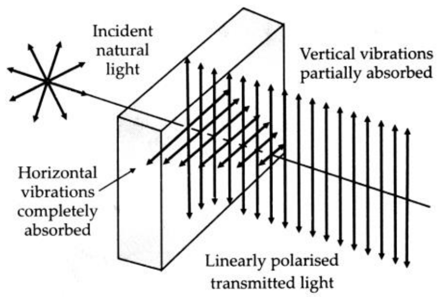
$$p = t\,(\mu_0 \sim \mu_e)$$

A plate which introduces a path difference of λ/4 between O–rays and E–rays is called a ***quarter wave plate.*** The thickness of a quarter wave plate is $t_{1/4} = \dfrac{\lambda}{4(\mu_0 \sim \mu_e)}$

A plate that introduces a path difference of $\lambda/2$ (or a phase difference of π) between O–rays and E–rays is called a ***half wave plate.*** The thickness of a half–wave plate is $t_{1/2} = \dfrac{\lambda}{2(\mu_0 \sim \mu_e)}$

Polarisation by Selective Absorption: Dichroism

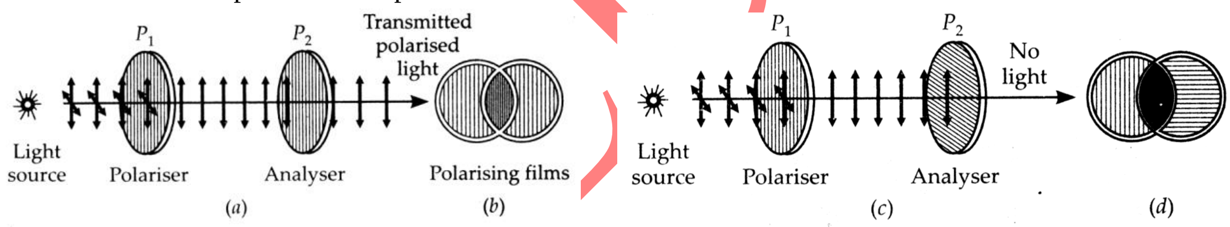
Certain doubly refracting crystals have the property of absorbing one of the doubly refracted beams to a greater extent than the other. The crystals showing this property are said to be *dichroic* and the phenomenon is known as *dichroism. Tourmaline* is a naturally occurring crystal which shows this phenomenon of selective absorption. As shown in figure, when unpolarised light is passed through a tourmaline crystal of sufficient thickness, the O–ray is completely absorbed while the E–ray is almost completely transmitted. So the emergent light is plane polarized.



Polaroids

Polaroids are thin commercial sheets which make use of the property of selective absorption to produce an intense beam of plane polarized light.

When a paste of quinine idosulphate made in nitrocellulose is squeezed out through a fine slit, the needle–shaped crystals of quinine idosulphate align themselves parallel to their optic axis. These crystals are highly dichroic. They absorb one of the doubly refracted beams completely. The thin polarizing sheet so obtained is enclosed between two thin glass plates for mechanical support and we get a polaroid. Each polaroid has a characteristic direction called polaroid axis (shown by parallel lines). A polaroid transmits only those vibrations which are parallel to its polaroid axis.



When a beam of unpolarised light falls on a polaroid P_1, it transmits only those vibrations which are parallel to its polaroid axis. It absorbs the vibrations in the perpendicular direction. Thus the transmitted light is plane–polarized. This can be examined by using a second polaroid P_2. When the polaroid axes of the two polaroids are parallel to each other (figure) and plane–polarized light transmitted by P_1 is also transmitted by P_2, when second polaroid is rotated through 90^o ***(cross polaroids),*** no light is transmitted by P_2.

NOTE:

- Improve polaroid films have been developed by using polymer materials. If a film of polyvinyl alcohol (PVA) is stretched to 3 to 8 times its original length, its molecules get oriented in the direction of stress and the film becomes doubly refracting.

  When the stretched film of PVA is impregnated with iodine, it becomes dichroic. The polaroid film so obtained is called ***H–polaroid.***

  If instead of impregnating with iodine, the stretched film is heated in the presence of a strong dehydrating agent, it becomes strongly dichroic and very stable. This polaroid is called ***K–polaroid.***

Uses of Polaroids

Polaroids have several uses in daily life:

1. ***In sunglasses and camera filters:*** *Sunglasses* and *camera filers* are made of polarizing sheets to reduce the glare of light produced by reflection from shiny surface such as water surface.

2. ***In wind screens:*** The wind screens and car head lights of motor cars are fitted with polaroid films with their axes inclined 45^{o} to the horizontal. When two cars approach each other from opposite directions, the transmission planes of their wind screens will be perpendicular to each other, so the glare of their head lights is completely eliminated. Each driver sees the road by the light sent by his own car.
3. ***In window panes of aeroplanes:*** One of the polaroids is fixed while the other can be rotated to control the amount of light coming in.
4. ***In photoelasticity:*** Glass and some plastic materials exhibit double refraction only when stressed. If polarized light is passed through them and then analysed, the bright coloured lines indicate the existence of strains. In engineering work, plastic models of structures are constructed and weaknesses are examined in the way.
5. ***In three–D movies:*** Three–D motion pictures are projected on screen by two projectors, each forming a slightly different image. One image is for one eye and other for the second eye so that the brain interprets this difference as depth or third dimension. Lights from each projector are plane polarized, but in mutually perpendicular directions. The two 3–D glasses are really polarizing glasses with their directions of polarization perpendicular to each other. So one eye sees one image and other sees a slightly different image.
6. ***In liquid crystal displays (LCDs):*** An important application of polarization is in liquid crystal displays or LCD's used in many watches, calculators and portable computers (lap tops). Liquid crystals have long molecules whose directions can be controlled by applying electric fields. This facts is used in rotating the plane of polarization is perpendicular to the axis of an analyser which cuts it out. These dark regions can be controlled with applied voltages and used to form letters and numbers.

Detection of Plane Polarised Light by Polaroids

The given light is passed through a polaroid and the polaroid is rotated about through a polaroid and the polaroid is rotated about the direction of incident light. The intensity of the emergent light is observed.

1. If on rotating the polaroid through one compete rotation, there is no change in the intensity of emergent light, then the given light is ***unpolarised.***
2. If the intensity of emergent light shows alternate rise and fall and becomes twice maximum and twice zero in one complete rotation of the polaroid, then the given light is ***plane –polarized*** or ***linearly polarized.***
3. If the intensity of emergent light becomes twice maximum and twice minimum (and not zero) in one complete rotation of the polaroid, then the given light is ***partially polarized.***

Doppler Effect of Light

When a source of sound travels towards an observer, the apparent frequency is higher than the frequency actually emitted by the source. When the source moves away, the apparent frequency is lower than the actual frequency. Doppler effect is a basic property of all waves and so occurs in case of light also.

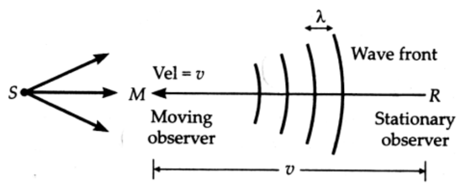
Whenever there is a relative motion between source of light and observer, the frequency of light received by the observer is different from the frequency actually emitted by the source. This phenomenon of the apparent change in the frequency of light is called ***Doppler effect*** *for light.*

Expression for the apparent frequency of light

Suppose a source of light emits waves of frequency v and wavelength λ. If c is the speed of light, t hen

$$\lambda = \frac{c}{v}$$

Suppose an observer moves towards the source with velocity v.



In one second, the source and observer come closer by a distance v.

$\therefore$ Apparent frequency
= No. of light waves emitted per second
by the source + No. of light waves contained in distance v

or $$v' = v + \frac{v}{\lambda} = v + \frac{v}{c/v} = v + v.\frac{v}{c}$$

or $$v' = v\left(1 + \frac{v}{c}\right) \quad .... (1)$$

Clearly, v' > v i.e., the apparent frequency increases when source and observer approach each other. When source and observer move away from each other, the apparent frequency can be obtained by replacing v by – v in the above equation. Then

$$v' = v\left(1 - \frac{v}{c}\right) \quad ... (2)$$

Clearly, v' < v i.e., the apparent frequency decreases when source and observer move away from each other.

Blue shift and red shift

Equation (1) and (2) can be combined together as

$$v' = v\left(1 \pm \frac{v}{c}\right) \quad \text{or} \quad v' - v = \pm \frac{v}{c}.v$$

The frequency change Δv = v' – v is called *Doppler shift*. Putting $v = \frac{c}{\lambda}$ and $v' = \frac{c}{\lambda'}$, we get

$$\frac{c}{\lambda'} - \frac{c}{\lambda} = \pm \frac{v}{c}.\frac{c}{\lambda} \quad \text{or} \quad \frac{\lambda - \lambda'}{\lambda'} = \pm \frac{v}{c}$$

But $$\frac{\lambda - \lambda'}{\lambda'} \approx \frac{\lambda - \lambda'}{\lambda}$$

$\therefore$ $$\frac{\lambda - \lambda'}{\lambda} = \pm \frac{v}{c} \quad \text{or} \quad \lambda - \lambda' = \pm \frac{v}{c}\lambda$$

(i) When source and observer approach each other, positive sign is taken. Then $\lambda - \lambda'$ is positive or $\lambda' - \lambda$, i.e., the wavelengths in the middle part of the visible spectrum shift towards the blue region. This is called **blue shift.**

(ii) When source and observer move away from each other, negative sign is taken. Then $\lambda - \lambda'$ is negative of $\lambda' - \lambda$, i.e., the wavelengths in the middle part of the visible spectrum shift towards the red region. This is called ***red shift.***

Applications of Doppler Effect:

1. Light received from stars and galaxies shows a red shift which indices that the universe is expanding.
2. By measuring Doppler shift in the e.m. wave reflected from an automobile, the speed of the automobile can be determined.
3. Doppler shift of light received from Saturn rings shows that the rings consists of a number of discontinuous satellites.
4. By meaning Doppler shift in the light received from eastern and western edges of the sun, the speed of rotation of the sun has been determined to be 2 km s^{-1} from east to west relative to the earth.

Assignment – XIV

Q.1 What speed should a galaxy move with respect to us so that the sodium line at 589.0 nm is observed at 589.6 nm?

Q.2 The spectral line for a given element in light received from a distant star is shifted towards longer wavelength side by 0.025%. Calculate the velocity of star in the line of light.

Q.3 The earth is moving towards a fixed start with a velocity of 30 km s^{-1}. An observer on the earth observes a shift of 0.58 Å in the wavelength of light coming from the star. Find the wavelength of light emitted by the star.

Q.4 A radar wave has frequency of 8.1×10^9 Hz. The reflected wave from an aeroplane shows a frequency difference of 2.7×10^3 Hz on the higher side. Deduce the velocity of aeroplane in the higher side. Deduce the velocity of aeroplane in the line of sight.

Q.5 Light from a galaxy, having wavelength of 6000 Å, is found to be shifted towards red by 50 Å. Calculate the velocity of recession of the galaxy.

Q.6 The spectral line in the spectrum of light from a star is found to be shifted by 0.032% from its normal position towards the red end of the spectrum. Compute the velocity of the star.

Q.7 A star is moving away from an observer with a speed of 500 kms^{-1}. Calculate the Doppler shift if the wavelength of light emitted by the star is 6000 Å.

Q.8 A star is moving towards the earth with a speed of 9.0×10^6 ms^{-1}. If the wavelength of a particular spectral line emitted by it is 6000 Å, then find t he apparent wavelength.

Answers

1.	-3.06×10^5 ms^{-1} = – 306 km/s	2.	-7.5×10^4 ms^{-1}
3.	5800 Å	4.	180 km h^{-1}
5.	2.5×10^6 ms^{-1}	6.	96 km s^{-1}
7.	Increase of 10 Å	8.	5820 Å

NCERT Exercise

1 Monochromatic light of wavelength 589 nm is incident from air on a water surface. What are the wavelength, frequency and speed of (i) reflected, and (ii) refracted light? Refractive index of water is 1.33.

2 What is the geometrical shape of the wavefront in each of the following cases:

(a) Light diverging from a point source

(b) Light emerging out of a convex lens when a point source is placed at its focus.

(c) The portion of the wavefront of light from a distant start intercepted by the earth.

3 (a) The refractive index of glass is 1.5. What is the speed of light in glass? Speed of light in vacuum is 3.0×10^8 ms^{-1}.

(b) Is the speed of light in glass independent of the colour of light? If not, which of the two colours (red and violet) travels slower in a glass prism?

4 In a Young's double – slit experiment, the slits are separated by 0.28 mm and the screen is placed 1.4m away. The distance between the central bright fringe and the fourth bright fringe is measured to be 1cm. Determine the wavelength of light used in the experiment.

5 In Young's double–slit experiment using monochromatic light of wavelength λ, the intensity of light at a point on the screen where path difference is λ is k units. What is the intensity of light at a point where path difference is $\lambda/3$?

6 A beam of light consisting of two wavelengths, 650 nm and 520 nm, is used to obtain interference fringes in a Young's double–slit experiment.

(a) Find the distance of the third bright fringe on the screen from the central maximum for wavelength 650 nm.

(b) What is the least distance from the central maximum where the bright fringes due to both the wavelengths coincide?

The distance between the two slits is 2 mm and the distance between the plane of the slits and the screen is 120 cm.

7 In a double–slit experiment the angular width of a fringe is found to be 0.2^o on a screen placed 1 m away. The wavelength of light used is 600 nm. What will be the angular width of the fringe if the entire experimental apparatus is immersed in water? Take refractive index of water to be 4/3.

8 What is Brewster transition? (μ for glass is 1.5)

9 Light of wavelength 5000 Å falls on a plane reflecting surface. What are the wavelength and frequency of the reflected light? For what angle of incidence is the reflected ray normal to the incident ray?

10 Estimate the distance for which ray optics is a good approximation for an aperture of 4 mm and wavelength 400 nm.

11 The 6563 Å H_α line emitted by hydrogen in a start is found to be red shifted by 15 Å. Estimate the speed with which the star is receding from the earth.

12 Explain how Newton's corpuscular theory predicts that the speed of light in a medium, say water, is greater than the speed of light in vacuum. Is the prediction confirmed by experimental determination of the speed of light in water? If not, which alternative picture of light is consistent with experiment?

13. You have learent in the text how Huygen's principle lends to the laws of reflection and refraction. Use the same principle to deduce directly that a point object placed in front of a plane mirror produces a virtual image whose distance from the mirror is equal to the object distance from the mirror?

14. Let us list some of the factors which could possibly influence the speed of wave propagation:

(i) nature of the source (ii) direction of propagation

(iii) motion of the sources and / or observer (iv) wavelength (v) intensity of the wave

On which of these factors, if any, does

(a) the speed of light in vacuum

(b) the speed of light in a medium (say glass or water) depend?

15. For sound waves, the Doppler formula for frequency shift differs slightly between the two situations : (i) source at rest ; observer moving and (ii) source moving : observer at rest. The exact Doppler formulas for the case of light waves in vacuum are, however, strictly identical for these situations. Explain why this should be so. Would you expect the formulas to be strictly identical for the two situations in case of light travelling in a medium?

16. In double–slit experiment using light of wavelength 600 nm, the angular width of a fringe formed on a distant screen is 0.1^o. What is the spacing between the two slits?

17. Answer the following questions :

(a) In a single–slit diffraction experiment, the width of the slit is made double the original width. How does this affect the size and intensity of the central diffraction band?

(b) In what way is diffraction from each slit related to the interference pattern in a souble–slit experiment?

(c) When a tiny circular obstacle is placed in the path of light from a distant source, a bright spot is seen at the centre of the shadow of the obstacle. Explain why?

(d) Two students are separated by a 7m partition wall in a room 10 m high. If both light and sound waves can bend around obstacles, how is it that the students are unable to see each other even though they can converse easily?

(e) Ray optics is based on the assumption that light travels in a straight line. Diffraction effects (observed when light propagates through small apertures/slits or around small obstacles) disprove this assumption. Yet the geometrical optics assumption is so commonly used in understanding location and several other properties of images in optical instruments. What is the justification?

18. Two towers on the top of two hills are 40 km apart. The line joining them passes 50m above a hill half way between the towers. What is the longest wavelength of radiowaves which can be sent between the towers without appreciable diffraction effects?

19. A parallel beam of light of wavelength 500 nm falls on a narrow slit and the resulting diffracgtion pattern is observed on a screen 1m away. It is observed that the first minimum is at a distance of 2.5 mm from the centre of the screen. Find the width of the slit.

20. Answer the following questions :

(a) When a low–flying aircraft passes overhead, we sometimes notice a light shaking of the picture on our TV screen. Suggest a possible explanation.

(b) As you have learnt in the text, the principle of linear superposition of wave displacements is basic to understanding intensity distributions in diffraction and interference patterns. What is the justification of this principle?

21. In deriving the single slit diffraction pattern, it was stated that the intensity is zero at angles of $\frac{n\lambda}{a}$. Justify this by suitably dividing the slit to bring out the cancellation.

Answers

1. (i) 5.09×10^{14} Hz, (ii) 444 nm
2. (a) Spherical wavefront, (b) Plane wavefront, (c) Plane wavefront

3.	(a) 2.0×10^8 ms^{-1}, (b) No	4.	6000 Å	6.	(a) 1.17 m, (b) 1.56 mm
7.	0.6^o	8.	56.3^o	9.	45^o
10.	40 m	11.	-6.86×10^5 ms^{-1}	12.	$v < c$
16.	3.44×10^{-4} m	18.	12.5 cm	19.	0.2 mm

IIT Entrance Exam.

Multiple choice Questions with one correct answer

1. Two coherent monochromatic light beams of intensities I and $4I$ are superposed. The maximum and minimum possible intensities in the resulting beams are

(a) $5I$ and I (b) $9I$ and I (c) $5I$ and $3I$ (d) $9I$ and $3I$

2. Two beams of light having intensities I and $4I$ interfere to produce a fringe attern on a screen. The phase difference between the beams is $\pi/2$ at point A and π at point B. Then the difference between the resultant intensities at A and B is

(a) $2I$ (b) $4I$ (c) $5I$ (d) $7I$

3. In Young's double slit experiment, the separation between the slits is halved and distance between the slits and screen is doubled. The fringe width is

(a) unchanged (b) halved (c) doubled (d) quadrupled

4. In a Young's double slit experiment, 12 fringes are observed to be formed in a certain segment of the screen, when light of wavelength 600 nm is used. If the wavelength of light is changed to 400 nm, number of fringes observed in the same segment of the screen is given by

(a) 12 (b) 18 (c) 24 (d) 30

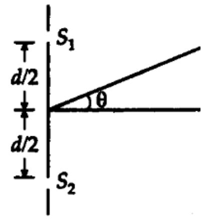
5. In a double slit experiment, instead of taking slits of equal widths, one slit is made twice as wide as the other. Then, in the interference pattern,

(a) the intensities of both the maxima and the minima increase
(b) the intensity of the maxima increases and the minima have zero intensity
(c) the intensity of the maxima decreases and that of the minima increases
(d) the intensity of the maxima decreases and the minima have zero intensity

6. In an ideal double–slit experiment, when a glass plate (refractive index 1.5) of thickness t is introduced in the path of one of the interfering beams (wavelength λ) the intensity at the position where the central maximum occurred previously remains unchanged. The minimum thickness of the glass plate is

(a) 2λ (b) $2\lambda/3$ (c) $\lambda/3$ (d) λ

7. In an interference arrangement similar to Young's double slit experiment, the slits S_1 and S_2 are illuminated with coherent microwaves sources, each of frequency 10^6 Hz. The source are synchronized to have zero phase difference. the slits are separated by a distance d = 150.0m. The intensity $I(\theta)$ is measured as a function of θ, where θ is defined as shown. If I_0 is the maximum intensity, then $I(\theta)$ for $0 \le \theta \le 90°$ is given by



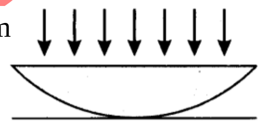
(a) $I(\theta) = I_0/2$ for $\theta = 30°$ (b) $I(\theta) = I_0/4$ for $\theta = 90°$

(c) $I(\theta) = I_0$ for $\theta = 0°$ (d) $I(\theta)$ is constant for all values of θ

8. In a Young's double slit experiment, bi-chromatic light of wavelengths 400 nm and 560 nm are used. The distance between the slits is 0.1 nm and the distance between the plane of the slits and the screen is 1 m. The minimum distance between two successive regions of complete darkness is

(a) 4 mm (b) 5.6 mm (c) 14 mm (d) 28 mm

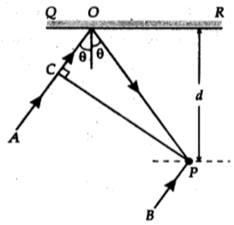
9. A thin slice is cut out of a glass cylinder along a plane parallel to its axis. The slice is placed on a flat glass plate as shown in figure. The observed interference fringes from this combination shall be



(a) straight (b) circular (c) equally spaced

(d) having fringe spacing, which increases as we go outwards

10. In the figure, CP represents a wavelength and AO and BP, the corresponding two rays. Find the condition on θ for constructive interference at P between the ray BP and the reflected ray OP.



(a) $\cos\theta = 3\lambda/2d$ (b) $\cos\theta = \lambda/4d$

(c) $\sec\theta - \cos\theta = \lambda/d$ (d) $\sec\theta - \cos\theta = 4\lambda/d$

11. In young's double slit experiment, the intensity at a point is (1/4) of the maximum intensity. Angular position of this point is

(a) $\sin^{-1}(\lambda/d)$ (b) $\sin^{-1}(\lambda/2d)$ (c) $\sin^{-1}(\lambda/3d)$ (d) $\sin^{-1}(\lambda/4d)$

12. Consider Fraunhoffer diffraction pattern obtained with a single slit illuminated at normal incidence. At the angular position of the first diffraction minimum, the phase difference (in radians) between the wavelets from the opposite edges of the slit is.

(a) $\pi/4$ (b) $\pi/2$ (c) 2π (d) π

13. Yellow light is used in a single slit diffraction experiment with slit width of 0.6 mm. If yellow light is replaced by X-rays, then the observed pattern will reveal

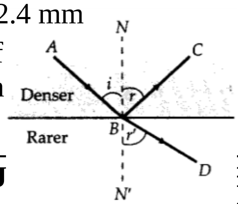
(a) that the central maximum is narrower (b) more number of fringes

(c) less number of fringes (d) no diffraction pattern

14. A beam of light of wavelength 600 nm from a distant source falls on a single slit 1.00 mm wide and the resulting diffraction pattern is observed on a screen 2 m away. The distance between the first dark fringes on either side of the central bright fringe is

(a) 1.2 cm (b) 1.2 mm (c) 2.4 cm (d) 2.4 mm

15. A ray of light from denser medium strikes a rarer medium at an angle of incidence i. The reflected and refracted rays make an angle 90^{o} with each



other. The angles of reflection and refraction are r and r' as shown in the figure. The critical angle is

(a) $\sin^{-1}(\tan r)$ (b) $\sin^{-1}(\tan i)$ (c) $\sin^{-1}(\tan r')$ (d) $\tan^{-1}(\sin i)$

Multiple choice questions with one or more than one correct answers.

16. In the Young's double slit experiment, the interference pattern is found to have an intensity ratio between bright and dark fringes as 9. This implies that

(a) the intensities at the screen due to two slits are 5 units and 4 units respectively

(b) the intensities at the screen due to slits are 4 units and 1 unit respectively

(c) the amplitude ratio is 3 (d) the amplitude ratio is 2

17. White light is used to illuminate the two slits in a Young's double slit experiment. The separation between the slits is b and the screen is at a distance d ($>b$) from the slits. At a point on the screen directly in front of one of the slits, certain wavelengths are missing. Some of these missing wavelengths are

(a) $\lambda = \frac{b^2}{d}$ (b) $\lambda = \frac{2b^2}{d}$ (c) $\lambda = \frac{b^2}{3d}$ (d) $\lambda = \frac{2b^2}{3d}$

18. In a Young's double slit experiment, the separation between the two slits is d and the wavelength of the light is λ. The intensity of light falling on slit 1 is four times the intensity of light falling on slit 2. Choose the correct choice (s).

(a) If $d = \lambda$, the screen will contain only one maximum.

(b) if $\lambda < d < 2\lambda$, at least one more maximum (besides the central maximum) will be observed on the screen

(c) If the intensity of light falling on slit 1 is reduced so that it becomes equal to that of slit 2, the intensities of the observed dark and bright fringe will increase.

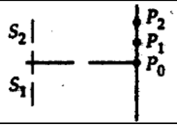
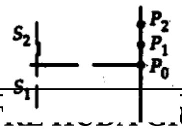
(d) If the intensity of light falling on slit 2 is increased so that it becomes equal to that of slit 1, the intensities of the observed dark and bright fringes will increases.

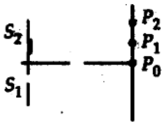
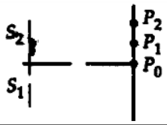
19. A parallel monochromatic beam of light is incident normally on a narrow slit. a diffraction pattern is formed on a screen placed perpendicular to the direction of the incident beam. At the first minimum of the diffraction pattern, the phase difference between the rays coming from the two edges of the slit is

(a) 0 (b) $\pi/2$ (c) π (d) 2π

Match–matrix type :

20. **Column I :** Shows four ituations of standard Young's double slit arrangement with the screen placed far away from the slits S_1 and S_2. In each of these cases $S_1P_0 = S_2P_0$, $S_1P_1 - S_2P_1 = \lambda/4$ and $S_1P_2 - S_2P_2 = \lambda/3$, where λ is the wavelength of the light used. In the case B, C and D a transparent sheet of refractive index μ and thickness t is pasted on slit S_2. The thicknesses of the sheets are different in different cases. The phase difference between the light waves reaching a point P on the screen from the two slits is denoted by $\delta(P)$ and the intensity by $I(P)$. Match each situation given in **Column I** with the statement(s) in **Column II** valid for that situation.

Column – I	Column – II
(a) 	(p) $\delta(P_0) = 0$
(b) $(\mu - 1)t = \lambda/4$ 	(q) $\delta(P_1) = 0$

(c)	$(\mu-1)t=\lambda/2$ 	(r)	$I(P_1)=0$
(d)	$(\mu-1)t=3\lambda/4$ 	(s)	$I(P_0)>I(P_1)$
		(t)	$I(P_2)>I(P_1)$

Answers

1.	B	**2.**	B	**3.**	D	**4.**	B	**5.**	A	**6.**	A	**7.**	C	**8.**	D
9.	A	**10.**	B	**11.**	C	**12.**	C	**13.**	D	**14.**	C	**15.**	A	**16.**	B,D
17.	A,C	**18.**	A,B	**19.**	D										

20. (a) $\to$ p, s ; (b) $\to$ q ; (c) $\to$ t ; (d) $\to$ r, s, t

AIEEE

1. To demonstrate the phenomenon of interference, we require two sources, which emit radiation of
(a) nearly the same frequency (b) the same frequency (c) different wavelength
(d) the same frequency and having definite phase relationship

2. A Young's double slit experiment uses a monochromatic source. The shape of the interference fringes formed on a screen is
(a) hyperbola (b) circle (c) straight line (d) parabola

3. The maximum number of possible interference maxima for slit separation equal to twice the wavelength in Young's double–slit experiment is
(a) infinite (b) five (c) three (d) zero

4. In Young's double slit experiment, the intensity at a point where path difference is $\lambda/6$ (λ being the maximum intensity, then I'. If I_0 denotes the maximum intensity, then I'/I_0 is equal to
(a) $\frac{3}{4}$ (b) $\frac{1}{\sqrt{2}}$ (c) $\frac{\sqrt{3}}{2}$ (d) $\frac{1}{2}$

5. If I_0 is the intensity of the principal maximum in the single slit diffraction pattern, then what will be its intensity when the slit width is doubled?
(a) $2I_0$ (b) $4I_0$ (c) I_0 (d) $I_0/2$

6. Two point white dots are 1mm apart on a black paper. They are viewed by eye of pupil diameter 3 mm. Approximately, what is the maximum distance at which these dots can be resolved by the eye? [Take wavelength of light = 500 nm.]
(a) 5m (b) 1 m (c) 6 m (d) 3m

7. Wavelength of light used in an optical instrument are λ_1 = 4000Å and λ_2 = 5000 Å, then ratio of their respective resolving powers (corresponding to λ_1 and λ_2) is
(a) 16 : 25 (b) 9 : 1 (c) 4 : 5 (d) 5 : 4

8. When an unpolarised light intensity I_0 is incident on a polarizing sheet, the intensity of the light which does not get transmitted is
(a) $I_0/2$ (b) $I_0/4$ (c) zero (d) I_0

9. The angle of incidence at which reflected light is totally polarized for reflection from air to glass (refractive index μ) is
(a) $\sin^{-1}\mu$ (b) $\sin^{-1}(1/\mu)$ (c) $\tan^{-1}(1/\mu)$ (d) $\tan^{-1}\mu$

10. A mixture of light, consisting of wavelength 590 nm and an unknown wavelength, illuminates Young's double slit and gives rise to two overlapping interference patterns on the screen. The central maximum of both lights coincide. Further, it is observed that the third bright fringe of known light coincides with the 4^{th} bright fringe of the unknown light. From this data, the wavelength of the unknown light is
(a) 393.4 nm (b) 885.0 nm (c) 442.5 nm (d) 776.8 nm

Answers

1.	D	**2.**	A	**3.**	B	**4.**	A	**5.**	C
6.	A	**7.**	D	**8.**	A	**9.**	D	**10.**	C

DCE and G.G.. Indraprastha University Engineering entrance Exam

1. Which among the following, is a form of energy?
(a) Light (b) Pressure (c) Momentum (d) Power

2. The rectilinear propagation of light in a medium is due to
(a) its short wavelength (b) its high frequency
(c) its high velocity (d) the relative index of medium

3. Select the right option in the following :
(a) Christian huyges, a contemporary of Newton's established the wave theory of light by assuming that light waves were transverse.
(b) Maxwell provided the theoretical evidence that light is tranverse wave
(c) Thomas Young experimentally proved the wave behaviopur of light and Huygens assumption
(d) All the statements given above, correctly answer the question "What is light?"

4. Which of the following cannot be explained on the basis of wave nature of light?
(i) Polarization (ii) Optical activity (iii) Photoelectric effect (iv) Compton effect
(a) (iii) and (iv) (b) (ii) and (iii) (c) (i) and (iii) (d) (ii) and (iv)

5. The transverse nature of light is shown by
(a) interference (b) refraction (c) polarization (d) dispersion

6. The wavefront of distant source of unknown shape is approximately
(a) spherical (b) cylindrical (c) elliptical (d) plane

7. The coherence of two light sources means that the light waves emitted have

(a) same frequency (b) same intensity (c) constant phase difference (d) same velocity

8. Two coherent light beams of intensity *I* and 4*I* are superposed. the maximum and minimum possible intensities in the resulting beam are

(a) 9*I* and *I* (b) 9*I* and 3*I* (c) 5*I* and *I* (d) 5*I* and 3*I*

9. In a Young's double slit experiment, the slit separation is 0.;2 cm, the distance between the screen and slit is 1m. Wavelength of the light used is 5000Å. The fringe width (in mm) is

(a) 0.25 (b) 0.26 (c) 0.27 (c) 0.28

10. In a Young's double slit experiment, the slit separation is 1mm and the screen is 1m from the slit. For a monochromatic light of wavelength 500 nm, the distance of 3^{rd} minima from the central maxima is

(a) 0.50 mm (b) 1.25 mm (c) 1.50 mm (d) 1.75 mm

11. In a double slit experiment, the distance between slits is increased ten times whereas their distance from screen is halved, then what is the fringe width?

(a) if remains same (b) becomes 1/10 (c) becomes 1/20 (d) becomes 1/90

12. In Young's double slit experiment the wavelength of light was changed from 7000Å to 3500 Å. While doubling the separation between the slits which of the following is not true for this experiment?

(a) the width of the fringes changes (b) the colour of bright fringes changes

(c) the separation between successive bright fringes changes

(d) the separation between successive dark fringes remains unchanged

13. If a transparent slab of refractive index $\mu = 1.5$ and thickness $t = 2.5 \times 10^{-5}$m is inserted in front of one of the slits of Young's double slit experiment, how much will be the shift in the interference pattern? The distance between the slits is 0.5 mm and that between slits and screen is 100 cm.

(a) 5 cm (b) 2.5 cm (c) 0.25 cm (d) 0.1 cm

14. The angular fringe width does not depend upon

(a) wavelength (λ) (b) distance between slits

(c) distance between slits and screen (D) (d) ration λ/d

15. In Young's double slit experiment distance between two sources is 0.1 mm. The distance of screen from the source is 20 cm. Wavelength of light used is 5460 Å. Then, angular position of the first dark FRINGE IS

(A) 0.08° (b) 0.16° (c) 0.20° (d) 0.313°

16. The colours seen in the reflected white light from a thin oil film are due to

(a) diffraction (b) interference (c) polarization (d) dispersion

17. In diffraction from a single slit, the angular width of the central maxima does not depend on

(a) λ of light used (b) width of slit

(c) distance of slits from screen (d) ratio of λ and slit width

18. The width of the diffraction band varies

(a) inversely as the wavelength (b) directly as the width of the slit

(c) directly as the distance between the slit and the screen

(d) inversely as the size of the source from which the slit is illuminated

19. A beam of light of wavelength 600 nm from a distant source falls on a single slit 1mm wide and the resulting diffraction pattern is observed on a screen 2m away. The distance between the first dark fringes on either side of the central bright fringe is

(a) 1.2 cm (b) 1.2 mm (c) 2.4 cm (d) 2.4 mm

20. In the phenomenon of diffraction of light, when blue light is used in the experiment instead of rod light, then

(a) fringes will become narrower (b) fringes will become broader
(c) no change in fringe width (d) none of the above

21. A single slit of width *d* is illuminated by violet light of wavelength 400 nm and the width of the diffraction pattern is measured as *y*. When half of the slit width is covered and other half illuminated by yellow light of wavelength 600nm, the width of the diffraction pattern is
(a) the pattern vanishes and the width is zero (b) $\frac{y}{3}$ (c) $3y$ (d) None of the above

22. A laser beam is used for locating distant objects because
(a) It is monochromatic (b) it is coherent
(c) It is not absorbed (d) it has small angular spread

23. Resolving power of a micropower depends upon
(a) wavelength of light used (direct proportional)
(b) wavelength of light used (insversely proportional)
(c) frequency of light used (d) focal length of objective

24. Which one of the following can measure the position of a particle most accurately?
(a) polarized light (b) light with high wavelength
(c) light with low wavelength (d) none of the above

25. At Kavalur in India, the astronomers using a telescope whose objective had a diameter of one metre started using telescope of diameter 2.54m. This resulted in
(a) the increase in the resolving power by 2.54 times for the same λ
(b) the increase in the limiting angle by 2.54 times for the same λ
(c) decrease in the resolving power (d) no effect on the limiting angle

26. The resolving power of a reflecting telescope depends
(a) on the intensity of light used (b) directly on wavelength of the light used
(c) on the focal length of objective lens (d) directly on the diameter of objective lens

27. We can obtain polarized light with the help of which of the following instrument?
(a) Nicol prism (b) Biprism (c) Polarimeter (d) none of the these

28. An unpolirised beam of intensity I_0 is incident on a pair of nicols making an angle of 60^o with each other. The intensity of light emerging from the pair is
(a) I_0 (b) $I_0/2$ (c) $I_0/4$ (d) $I_0/8$

29. When unpolarised light beam is incident from air onto glass (n = 1.5) at the polarizing angle,
(a) reflected beam is polarized 100 per cent.
(b) reflected and refracted beams are partially polarized
(c) the reason for (*a*) is that almost all the light is reflected (d) None of the above

30. An optically active compound
(a) rotates the plane polarised light (b) changes the direction of polarized light
(c) does not allow plane polarized light to pass through (d) none of the above

31. Specific rotation of sugar solution is 0.5 deg m^2/kg 200 kg–m^3 of impure sugar solution is taken in a sample polarimeter tube of length 20cm and optical rotation is found to be 19^o. The percentage of purity of sugar is
(a) 20% (b) 80 % (c) 95% (d) 89%

32. If in Young's double slit experiment of light, interference is performed in water, which of the following is correct?
(a) fringe width will decrease (b) fringe width will increase
(c) there will be no fringe (d) fringe width will remain unchanged

33. A ray of light strikes a material's slab at an angle of incidence 60°. If the reflected and refract ted rays are perpendicular to each other, the refractive index of the material is

(a) $\frac{1}{\sqrt{3}}$ (b) $\frac{1}{\sqrt{2}}$ (c) $\sqrt{2}$ (d) $\sqrt{3}$

Answers

1.	A	**2.**	A	**3.**	B	**4.**	A	**5.**	C	**6.**	D	**7.**	C	**8.**	A
9.	A	**10.**	B	**11.**	C	**12.**	D	**13.**	B	**14.**	C	**15.**	B	**16.**	B
17.	C	**18.**	C	**19.**	D	**20.**	A	**21.**	B	**22.**	D	**23.**	B	**24.**	C
25.	A	**26.**	D	**27.**	A	**28.**	D	**29.**	A	**30.**	A	**31.**	C	**32.**	A
33.	D														

AIIMS Entrance Exam

1. According to Huygen's principle, light is a form of

(a) particle (b) rays (c) wave (d) none of the above

2. Light propagates rectilinearly, because of its

(a) frequency (b) wavelength (c) velocity (d) wave nature

3. Light appears to travel in a straight line, because

(a) its velocity is very large (b) it is not absorbed by surrounding
(c) its wavelength is very small (d) it is reflected by surrounding

4. Interference occurs in which of the following waves?

(a) longitudinal (b) transverse (c) electromagnetic (d) all of these

5. Ratio of intensities of two waves is 9 : 1. If these waves are superimposed, what is the ratio of maximum and minimum intensities?

(a) 9 : 1 (b) 3 : 1 (c) 4 : 1 (d) 5 : 3

6. Two waves of intensities I and $4I$ superpose. Then, the maximum and minimum intensities are

(a) $5I$ and $3I$ (b) $9I$ and I (c) $9I$ and $3I$ (d) $5I$ and I

7. What is the path difference for destructive interference?

(a) $n\lambda$ (b) $n(\lambda + 1)$ (c) $(2n+1)\lambda/2$ (d) $(n+1)\lambda/2$

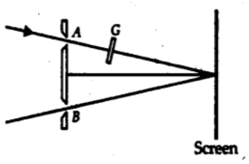
8. A monochromatic beam of light is used for the formation of fringes on the screen by illuminating the two slits in the Young's double slit interference experiment. When a thin film of mica is interposed in the path of one of the interfering beams, then

(a) the fringe width increases (b) the fringe width decreases
(c) the fringe width remains the same but the pattern shifts (d) the fringe pattern disappears

9. A double slit experiment is performed with light of wavelength 500 nm. A thin film of thickness 2 μm and refractive index 1.5 is introduced in the path of the upper beam. The location of the central maximum will

(a) remain unshifted (b) shift downward by nearly two fringes
(c) shift upward by nearly two fringes (d) shift downward by ten fringes

10. In Young's experiment, the monochromatic light is used to illuminate two slits A and B as shown. Interference fringes are observed on a screen placed in front of the slits. Now if a thin glass plate is placed normally in the path of beam coming from the slit A, then



(a) fringes will disappear (b) fringe width will increase
(c) fringe width will decrease (d) there will be no change in fringe width

11. What happens, if the monochromatic light used in Young's double slit experiment is replaced by white light?
(a) No fringes are observed (b) All bright fringes become white
(c) All bright fringes have colours between violet and red
(d) Only the central fringe is white and all other fringes are coloured
12. When exposed to sunlight, thin films of oil on water often exhibit brilliant colours due to the phenomenon of
(a) interference (b) diffraction (c) dispersion (d) polarization

13. When a compact disc is illuminated by a source of white light, coloured lines are observed. This is due to
(a) dispersion (b) diffraction (c) interference (d) refraction.
14. When a beam of light is used to determine the position of an object, the maximum accuracy is achieved, if the light is
(a) polarized (b) of longer wavelength
(c) of shorter wavelength (d) of high intensity
15. An astronaut is looking down on earth's surface from a space shuttle at an altitude of 400 km. Assuming that the astronaut's pupil diameter is 5 mm and the wavelength of visible light is 500 nm, the astronaut will be able to resolve linear objects of the size of about
(a) 0.5 m (b) 5m (c) 50 m (d) 500 m
16. In case of linearly polarised light, the magnitude of the electric field vector
(a) is parallel to the direction of propagation (b) does not change with time
(c) increase and decrease linearly with time (d) varies periodically with time
17. In an elliptically polarised light, the amplitude of vibrations.
(a) changes in magnitude only (b) changes in direction only
(c) remains constant (d) both (a) and (b)
18. At what angle of incidence will the light reflected from glass (= 1.5) be completely polarised?
(a) 40.3^o (b) 51.6^o (c) 56.3^o (d) 72.8^o
19. Golden view of sea shell is due to
(a) diffraction (b) dispersion (c) polarisation (d) reflection

Answers

1.	C	**2.**	D	**3.**	C	**4.**	D	**5.**	C	**6.**	B	**7.**	C	**8.**	C
9.	C	**10.**	D	**11.**	D	**12.**	A	**13.**	B	**14.**	C	**15.**	C	**16.**	D
17.	A	**18.**	C	**19.**	C										

CBSE PMT Prelims Exam

1. Which one of the following phenomena is not explained by Huygens′ construction of wavefront?
(a) refraction (b) reflection (c) diffraction (d) origin of spectra
2. The frequency of a light wave in a material is 2×10^{14} Hz and wavelength is 5000Å. The refractive index f material will be
(a) 1.50 (b) 3.00 (c) 1.33 (d) 1.40

3. A ray of light travelling in air has wavelength λ, frequency v, velocity v and intensity I. If this ray enters into water, then these parameters are λ', v', v' and I' respectively. Which of the following relation is correct?

(a) $\lambda = \lambda'$ (b) v = v′ (c) $v = v'$ (d) $I = I'$

4. An electromagnetic radiation of frequency n wavelength λ, travelling with velocity v in air enters a glass slab of refractive index μ. The frequency, wavelength and velocity of light in the glass slab will be respectively,

(a) n, 2λ and $\frac{v}{\mu}$ (b) $\frac{2n}{\mu}, \frac{\lambda}{\mu}$ and v (c) $\frac{n}{\mu}, \frac{\lambda}{\mu}$ and $\frac{v}{\mu}$ (d) $n, \frac{\lambda}{\mu}$ and $\frac{v}{\mu}$

5. Light travels through a glass plate of thickness t and having a refractive index μ. If c is the velocity of light in vacuum, the time taken by the light to travel this thickness of glass is

(a) $t\mu c$ (b) tc/μ (c) $\mu c/t$ (d) $\mu t/c$

6. Time taken by sunlight to pass through a window of thickness 4mm whose refractive index is 3/2 is

(a) $2\times10^{-4}\ s$ (b) $2\times10^{8}\ s$ (c) $2\times10^{-11}\ s$ (d) $2\times10^{11}\ s$

7. Ratio of intensities of two waves are given by 4 : 1. Then ratio of the amplitudes of two waves is

(a) 2 : 1 (b) 1 : 2 (c) 4 : 1 (d) 1 : 4

8. Interference is possible in

(a) light waves only (b) sound waves only
(c) both light and sound waves (d) neither light nor sound waves

9. Interference was observed in interference chamber, when air was present. Now, the chamber is evacuated and if the same light is used, a careful observer will see

(a) no interference (b) interference with bright bands (c) interference with dark bands
(d) interference, in which width of the fringe will be slightly increased

10. If yellow light emitted by sodium lamp in Young's double slit experiment is replaced by mono–chromatic blue of light of the same intensity, then

(a) fringe width will decrease (b) fringe width will increase
(c) fringe width will remain unchanged (d) fringes will be comes less intense

11. In a Young's double slit experiment, the fringe width is found to be 0.4mm. If the whole apparatus is immersed in water of refractive index 4/3 without disturbing the geometrical arrangement, the new fringe width will be

(a) 0.3 mm (b) 0.4 mm (c) 0.53 mm (d) 540 microns

12. In a Young's experiment, two coherent sources are placed 0.9mm apart and the fringes are observed 1m away. If it produces the second dark fringe at a distance of 1mm from the central fringe, the wavelength of monochromatic light used would be

(a) 60×10^{-4} cm (b) 10×10^{-4} cm (c) 10×10^{-5} cm (d) 6×10^{-4} cm

13. In Young's double slit experiment carried out with light of wavelength (λ) = 5000 Å, the distance between the slits is 0.2mm and the screen is at 200 cm from the slits. The central maximum is at $x = 0$. The third maximum (taking the central maximum as zeroth maximum) will be at x equal to

(a) 1.67 cm (b) 1.5 cm (c) 0.5 cm (d) 5.0 cm

14. The Young's double slit experiment is performed with blue and with green light of wavelength 4360Å and 5460 Å respectively. If x is the distance of 4^{th} maximum from the central one, then

(a) x(blue) = x(green) (b) x(blue) > x (green) (c) x(blue) < x (green) (d) $\frac{x(\text{blue})}{x(\text{green})} = \frac{5460}{4360}$

15. In a Fresnel biprism experiment, the two positions of lens give separation between the slits as 16 cm and 9 cm respectively. What is the actual distance of separation?
(a) 12.5 cm (b) 12 cm (c) 13 cm (d) 14 cm

16. Colours appear on a thin soap film and soap bubbles due to the phenomenon of
(a) interference (b) scattering (c) diffraction (d) dispersion

17. The frequency of e.m. wave which is best suited to observe a particle of radius 3×10^{-6} m, is of the order of
(a) 10^{15} (b) 10^{13} (c) 10^{14} (d) 10^{12}

18. A parallel beam of monochromatic light of wavelength 5000Å is incident normally on a single narrow slit of width 0.001 mm. The light is focused by a convex lens on a screen placed in focal plane. The first minimum will be formed for the angle of diffraction equal to
(a) 0^o (b) 15^o (c) 30^o (d) 50^o

19. A telescope has an objective lens of 10 cm diameter and is situated at a distance of 1 km from two objects. The minimum distance between these two objects, which can be resolved by the telescope, when the mean wavelength of light is 5000 Å, is of the order of
(a) 0.5 m (b) 5 m (c) 5 mm (d) 5 cm

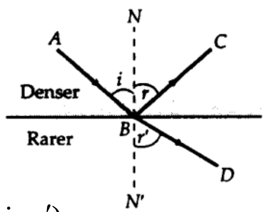
20. Diameter of hyman eyelens is 2mm. What will be the minimum distance between two points to resolve them, which are situated at a distance of 50m from eye? The wavelength of light is 5000Å.
(a) 2.32 mm (b) 4.28 mm (c) 1.25 cm (d) 12.48 cm

21. The angular resolution of a 10 cm diameter telescope at a wavelength of 5000 Å is of the order of
(a) 10^6 rad (b) 10^{-2} rad (c) 10^{-4} rad (d) 10^{-6} rad

22. Which of the phenomenon is not common to sound and light waves?
(a) interference (b) diffraction (c) coherence (d) polarisation

23. Which one of the following statements is true?
(a) both light and sound waves can travel in vacumm
(b) both light and sound waves in air are trans narrow verse
(c) the sound waves in air are longitudinal, while the light waves are transverse
(d) both light and sound waves in air are longitudinal

24. A ray of light from a rarer medium strikes a denser medium as shown in figure. The reflected and refracted rays make an angle of 90° with each other. The angles of reflection and refraction are critical angle would be r and r'. The critical angle would be



(a) $\sin^{-1}(\tan r)$ (b) $\tan^{-1}(\sin r)$ (c) $\sin^{-1}(\tan r')$ (d) $\tan^{-1}(\sin r')$

Answers

1.	D	**2.**	B	**3.**	B	**4.**	D	**5.**	D	**6.**	C	**7.**	A	**8.**	A
9.	D	**10.**	A	**11.**	A	**12.**	D	**13.**	B	**14.**	C	**15.**	B	**16.**	A
17.	C	**18.**	C	**19.**	C	**20.**	C	**21.**	C	**22.**	D	**23.**	C	**24.**	A