Chapter -11

RAY OPTICS AND WAVE OPTICS

WE LEARN ABOUT

11.1.1 Introduction

(Mirror, reflection, refraction refraction through tens)

11.2.1 Combinations of lens and prism (Dispersion, Deviation)

11.3.1 Scattering of light

11.4.1 Microscope & telescope

11.5.1 Interference, Diffraction, polarisation of light wave

Brief introduction

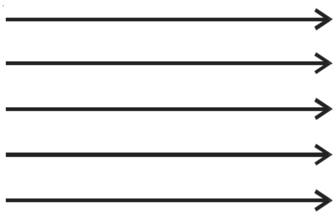
Sir James Chadwick, CH, FRS (20 October 1891 – 24 July 1974) was a British physicist who was awarded the 1935 Nobel Prize in Physics for his discovery of the neutron in 1932. In 1941, he wrote the final draft of the MAUD Report, which inspired the U.S. government to begin serious atomic bomb research efforts. He was the head of the British team that worked on the Manhattan Project during the Second World War. He was knighted in Britain in 1945 for his achievements in physics.

Chadwick graduated from the Victoria University of Manchester in 1911, where he studied under Ernest Rutherford (known as the "father of nuclear physics"). At Manchester, he continued to study under Rutherford until he was awarded his MSc in 1913. The same year, Chadwick was awarded an 1851 Research Fellowship from the Royal Commission for the Exhibition of 1851. He elected to study beta radiation under Hans Geiger in Berlin.

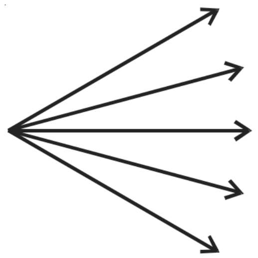
JAMES CHADWICK

11.1.1 Light rays and beams

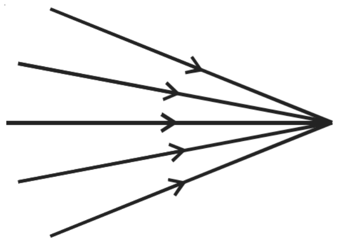
A ray of light is the direction along which the light energy travels. In practice a ray has a finite width and is represented in diagrams as straight lines. A beam of light is a collection of rays. A search light emits a parallel beam of light (Fig.a). Light from a lamp travels in all directions which is a divergent beam. (Fig.b). A convex lens produces a convergent beam of light, when a parallel beam falls on it (Fig.c).



(a) Parallel beam



(b) Divergent Beam



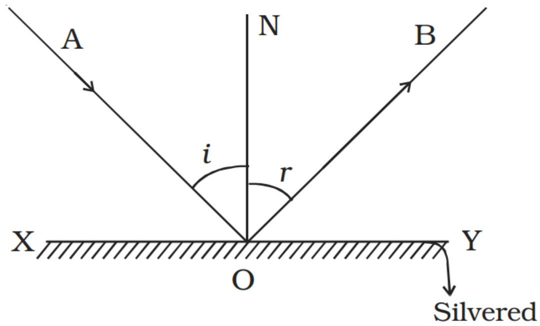
(c) Convergent Beam

Reflection of light

Highly polished metal surfaces reflect about 80% to 90% of the light incident on them. Mirrors in everyday use are therefore usually made of depositing silver on the backside of the glass. The largest reflector in the world is a curved mirror nearly 5 metres across, whose front surface is coated with aluminium. It is the hale Telescope on the top of Mount Palomar, California, U.S.A. Glass by itself, will also reflect light, but the percentage is small when compared with the case of silvered surface. It is about 5% for an air-glass surface.

Laws of reflection

Consider a ray of light, AO, incident on a plane mirror XY at O. It is reflected along OB. Let the normal ON is drawn at the point of incidence. The angle AON between the incident ray and the normal is called angle of incidence, i (Fig.) the angle BON between the reflected ray and the normal is called angle of reflection, r. Experiments show that :



(i) The incident ray, thereflected ray and the normal drawnto the reflecting surface at the pointof incidence, all lie in the same plane.

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

These are called the laws of reflection.

Deviation of light by plane mirror

Consider a ray of light, AO, incident on a plane mirror XY (Fig.) at O. It is reflected along OB. The angle AOX made by AO with XY is known as the glancing angle α with the mirror. Since the angle of reflection is equal to the angle of incidence, the glancing angle BOY made by the reflected ray OB with the mirror is also equal to α. The light has been deviated from a direction AO to a direction OB. Since angle COY = angle AOX, it follows that angle of deviation, d = 2α

So, in general, the angle of deviation of a ray by a plane mirror or a plane surface is twice the glancing angle.

Deviation of light by plane mirror

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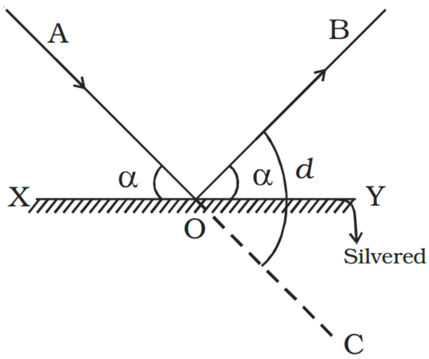
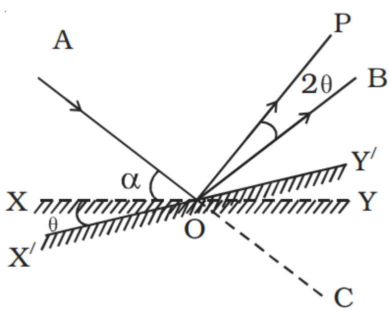


So, in general, the angle of deviation of a ray by a plane mirror or a plane surface is twice the glancing angle.

Deviation of light due to rotation of a mirror

Let us consider a ray of light AO incident on a plane mirror XY at O. It is reflected along OB. Let α be the glancing angle with XY (Fig.). We know that the angle of deviation COB = 2α.



Suppose the mirror is rotated through an angle θ to a position X′Y′. The same incident ray AO is now reflected along OP. Here the glancing angle with X′Y′ is (α + θ). Hence the new angle of deviation COP = 2 (α + θ). The reflected ray has thus been rotated through an angle BOP when the mirror is rotated through an angle θ.

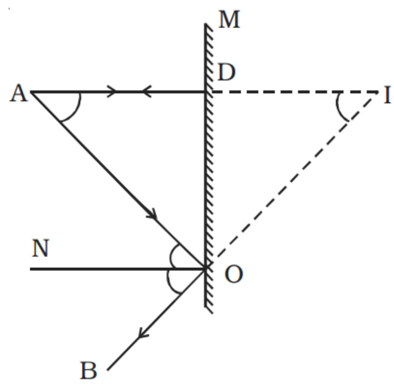
$$\angle BOP = \angle COP - \angle COB$$

$$\angle BOP = 2(\alpha + \theta) - 2\alpha = 2\theta$$

For the same incident ray, when the mirror is rotated through an angle, the reflected ray is rotated through twice the angle.

Image in a plane mirror

Let us consider a point object A placed in front of a plane mirror M as shown in the Fig. Consider a ray of light AO from the point object incident on the mirror and reflected along OB. Draw the normal ON to the mirror at O.



The angle of incidence AON = angle of reflection BON

Another ray AD incident normally on the mirror at D is reflected back along DA. When BO and AD are produced backwards, they meet at I. Thus the rays reflected from M appear to come from a point I behind the mirror. From the figure

$\angle AON = \angle DAO$ alternate angles and = $\angle BON = \angle DIO$, corresponding angles it follows that $\angle DAO = \angle DIO$.

The triangles ODA and ODI are congruent

∴ AD = ID

For a given position of the object, A and D are fixed points. Since AD = ID, the point I is also fixed. It should be noted that AO = OI. So the object and its image in a plane mirror are at equal perpendicular distances from the mirror.

Virtual and real images

An object placed in front of a plane mirror has an image behind the mirror. The rays reflected from the mirror do not actually meet through I, but only appear to meet and the image cannot be received on the screen, because the image is behind the mirror. This type of image is called an unreal or virtual image (Fig. a).

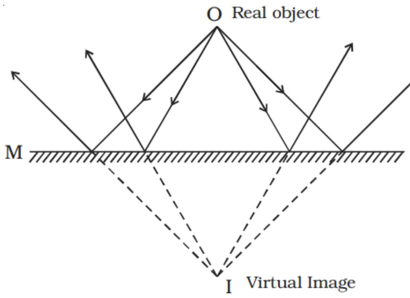


Fig. a Virtual image in a plane mirror

If a convergent beam is incident on a plane mirror, the reflected rays pass through a point I in front of M, as shown in the Fig.b. In the Fig.a, a real object (divergent beam) gives rise to a virtual image. In the Fig. b, a virtual object (convergent beam) gives a real image. Hence plane mirrors not only produce virtual images for real objects but also produce real images for virtual objects.

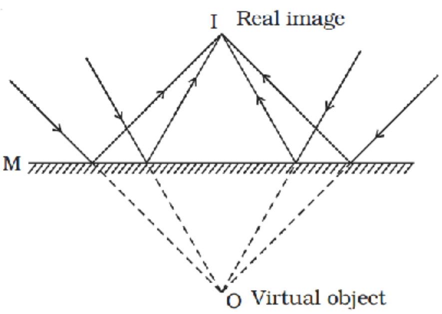


Fig.b Real image in a plane mirror

Characteristics of the image formed by a plane mirror

(i) Image formed by a plane mirror is as far behind the mirror as the object is in front of it and it is always virtual.

(ii) The image produced is laterally inverted.

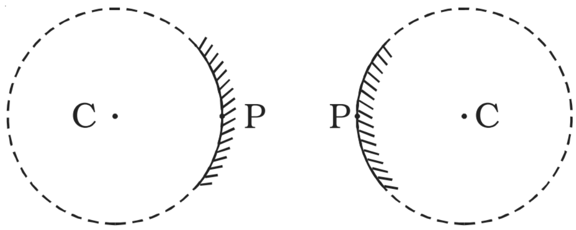
(iii) The minimum size of the mirror required to see the complete image of the object is half the size of the object.

(iv) If the mirror turns by an angle θ, the reflected ray turns through an angle 2θ.

(v) If an object is placed between two plane mirrors inclined at an angle θ, then the number of images formed is $n = 360^o/\theta - 1$

Reflection at curved surfaces

In optics we are mainly concerned with curved mirrors which are the part of a hollow sphere (Fig.). One surface of the mirror is silvered. Reflection takes place at the other surface. If the reflection takes place at the concave surface, (which is towards the centre of the sphere) it is called concave mirror. If the reflection takes place at the convex surface, (which is away from the centre of the sphere) it is called convex mirror. The laws of reflection at a plane mirror are equally true for spherical mirrors also.



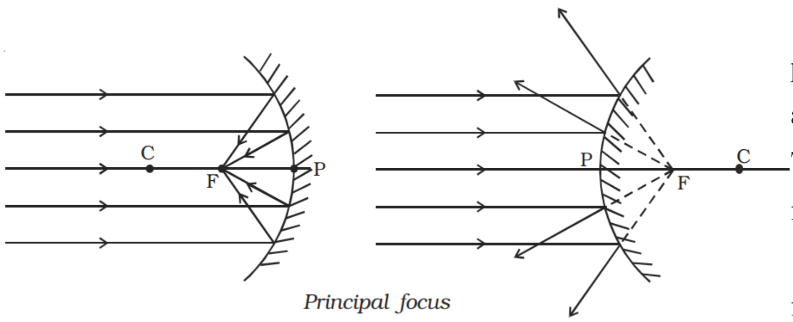
The centre of the sphere, of which the mirror is a part is called the centre of curvature (C).

The geometrical centre of the mirror is called its pole (P).

The line joining the pole of the mirror and its centre of curvature is called the principal axis.

The distance between the pole and the centre of curvature of the spherical mirror is called the radius of curvature of the mirror and is also equal to the radius of the sphere of which the mirror forms a part.

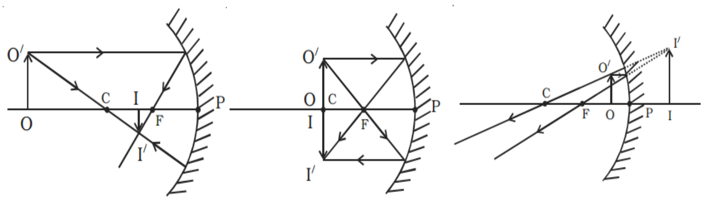
When a parallel beam of light is incident on a spherical mirror, the point where the reflected rays converge (concave mirror) or appear to diverge from the point (convex mirror) on the principal axis is called



the principal focus (F) of the mirror. The distance between the pole and the principal focus is called the focal length (f) of the mirror (Fig.)

Images formed by a spherical mirror

The images produced by spherical mirrors may be either real or virtual and may be either larger or smaller than the object. The image can be located by graphical construction as shown in Fig. by adopting any two of the following rules.

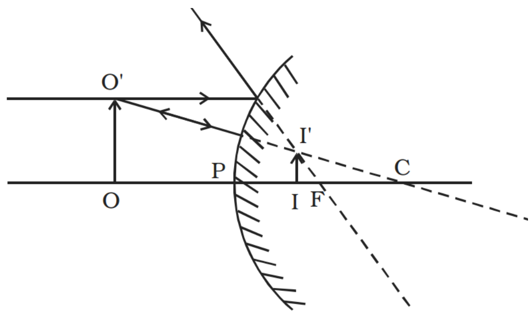


(i) A ray parallel to the principal axis after reflection by a concave mirror passes through the principal focus of the concave mirror and appear to come from the principal focus in a convex mirror.

(ii) A ray passing through the centre of curvature retraces its path after reflection.

(iii) A ray passing through the principal focus, after reflection is rendered parallel to the principal axis.

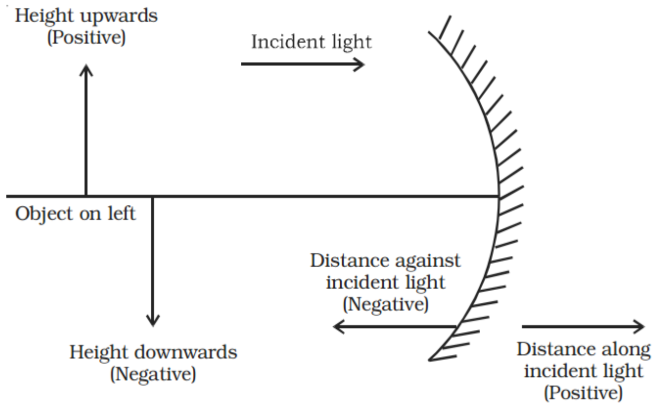
Image formed by a convex mirror



In a convex mirror irrespective of the position of the object, the image formed is always virtual, erect but diminished in size. The image lies between the pole and the focus (Fig.)

In general, real images are located in front of a mirror while virtual images behind the mirror.

Cartesian sign convention



The following sign conventions are used.

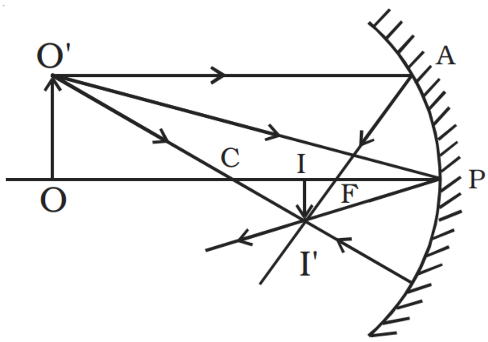
1. All distances are measured from the pole of the mirror (in thecase of lens from the optic centre).
2. The distances measured in the same direction as the incident light, are taken as positive.
3. The distances measured in the direction opposite to the direction of incident light are taken as negative.
4. Heights measured perpendicular to the principal axis, in the upward direction are taken as positive.
5. Heights measured perpendicular to the principal axis, in the downward direction are taken as negative.
6. The size of the object is always taken as positive, but image size is positive for erect image and negative for an inverted image.
7. The magnification is positive for erect (and virtual) image, and negative for an inverted (and real) image.

Relation between u, v and f for spherical mirrors

A mathematical relation between object distance u, the image distance v and the focal length f of a spherical mirror is known as mirror formula.

(i) Concave mirror – real image

Let us consider an object OO′ on the principal axis of a concave mirror beyond C. The incident and the reflected rays are shown in the Fig. A ray O′A parallel to principal axis is incident on the concave mirror at A, close to P. After reflections the ray passes through the focus F. Another ray O′C passing through centre of curvature C, falls normally on the mirror and reflected back along the same path. A third ray O′P incident at the pole P is reflected along PI′. The three reflected rays intersect at the point I′. Draw perpendicular I′I to the principal axis. II′ is the real, inverted image of the object OO′.



Right angled triangles, II ′P and OO′P are similar.

$$\therefore \frac{II'}{OO'} = \frac{PI}{PO} \qquad ...(1)$$

Right angled triangles II′F and APF are also similar (A is close to P ; hence AP is a vertical line)

$$\therefore \frac{II'}{AP} = \frac{IF}{PF}$$

AP = OO′. Therefore the above equation becomes,

$$\frac{II'}{OO'} = \frac{IF}{PF} \qquad ...(2)$$

Comparing the equations (1) and (2)

$$\frac{PI}{PO} = \frac{IF}{PF} \qquad ...(3)$$

But, IF = PI – PF

Therefore equation (3) becomes,

$$\frac{PI}{PO} = \frac{PI - PF}{PF} \qquad ...(4)$$

Using sign conventions, we have PO = – u,

PI = – v and PF = – f

Substituting the values in the above equation, we get $\frac{-v}{-u} = \frac{-v-(-f)}{-f}$ (or)

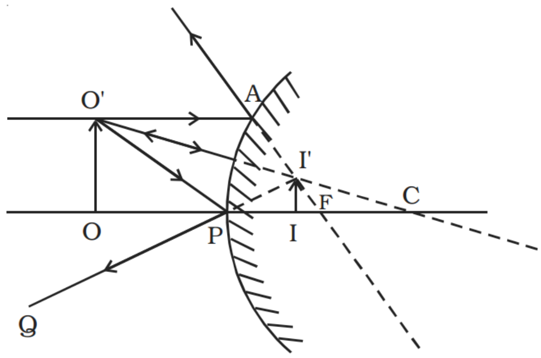
$$\frac{v}{u} = \frac{v-f}{f} = \frac{v}{f} - 1$$

Dividing by v and rearranging, $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

This is called mirror equation. The same equation can be obtained for virtual image also.

(ii) Convex mirror - virtual image

Let us consider an object OO′ anywhere on the principal axis of a convex mirror. The incident and the reflected rays are shown in the Fig. A ray O′A parallel to the principal axis incident on the convex mirror at A close to P. After reflection the ray appears to diverge from the focus F. Another ray O′C passing through centre of curvature C, falls normally on the mirror and is reflected back along the same path. A third ray O ′P incident at the pole P is reflected along PQ. The three reflected rays when produced appear to meet at the point I ′. Draw perpendicular II′ to the principal axis. II′ is the virtual image of the object OO′.



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Right angled triangles II′F and APF are also similar (A is close to P ; hence AP is a vertical line)

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AP = OO′. Therefore the above equation becomes,

$$\frac{II'}{OO'} = \frac{IF}{PF} \qquad \text{... (2)}$$

Comparing the equations (1) and (2)

$$\frac{PI}{PO} = \frac{IF}{PF} \qquad \text{... (3)}$$

Using sign conventions, we have

PO = – u, PI = +v and PF = +f.

Substituting the values in the above equation, we get

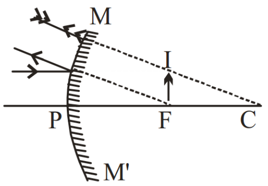
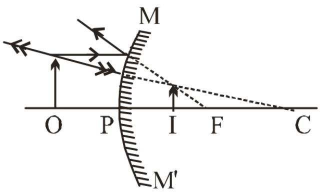
$$\frac{+v}{-u} = \frac{+f-(+v)}{+f} \quad \text{(or)} \quad -\frac{v}{u} = \frac{f-v}{f} = 1-\frac{v}{f}$$

Dividing by v and rearranging, $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

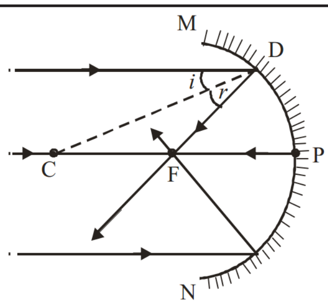
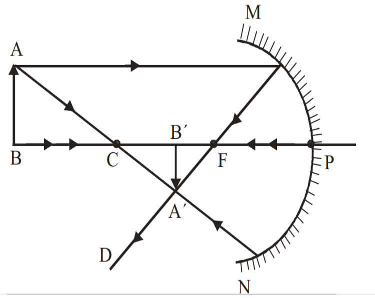
This is called mirror equation for convex mirror producing virtual image.

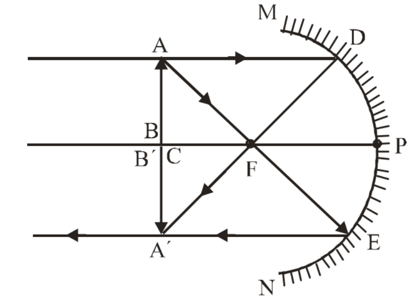
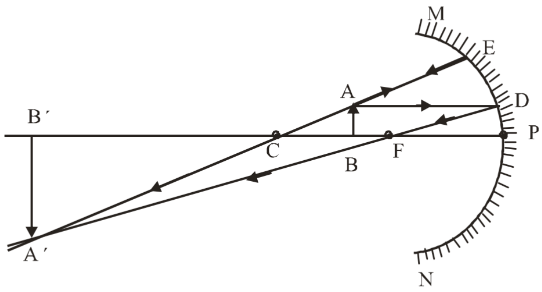
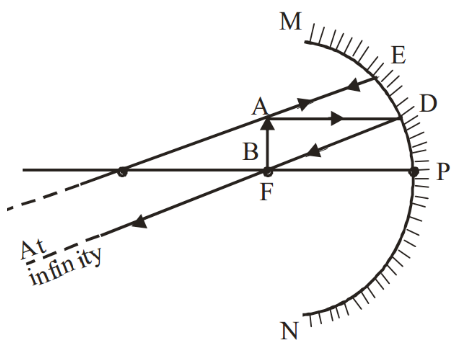
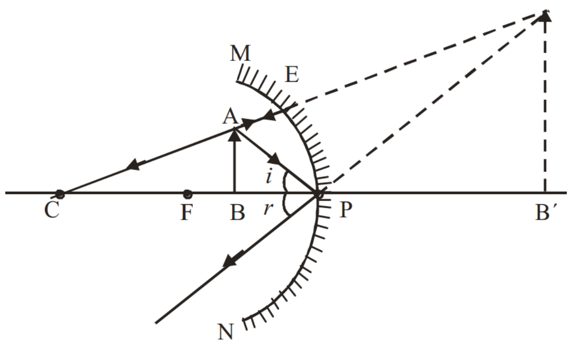
Image Formation By Spherical Mirrors:

a) Convex Mirror:

Position of the object	Ray diagram	Image details
At Infinity		Virtual, erect, very small at F
Infront of mirror		Virtual. erect, diminished between P and F

b) Concave Mirror:

At Infinity		Real, inverted, very small, at F
Between ∞ and C		Real, inverted, diminished, between F and C

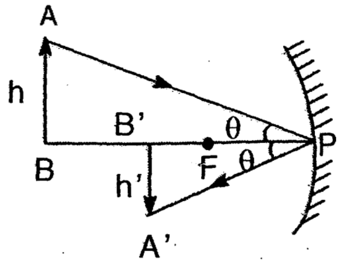
At C		Real, inverted, equal, at C
Between F and C		Real, inverted, enlarged, beyond C
At F		Real, inverted, very large, at infinity
Between F and P		Virtual, erect, enlarged, behing the mirror

Magnification

The size of the image relative to tire size of the object is another important quantity toconsider. Hence we define magnification. Note that magnification does not mean that the image is enlarged. The imageformed by optical system may be larger than, smaller than or of the same size of the object.

a) Lateral magnification:

The ratio of the transverse dimension of the final image formed by an optical system to the corresponding dimension of the object is defined as transverseor lateralorlinear magnification(m). Hence it is the ratio of the height of image (h') to the height of the object (h). From the Fig.



Lateral magnification $m = \frac{A'B'}{AB} = \frac{h'}{h}$

Here h and h' will be taken positive or negative in accordance with the accepted sign convention.

In triangles A'B'P and ABP, we have $\frac{B'A'}{BA} = \frac{B'P}{BP}$ with signconvention this becomes

$$\frac{-h'}{h} = \left(\frac{-v}{-u}\right) \text{ so that, } m = \frac{h'}{h} = -\frac{v}{u}$$

Here negative magnification implies that image is inverted with respect to object, While positive magnification means that image is erect with respect to object i.e., m is negative means for real object, real images is formed and for virtual object images is formed; m is positive means for real object, virtual image is formed and for virtual object real image is formed.

b): Longitudinal magnification:

If a one dimensional object is placed with its length along the principal axis, the ratio of length of image to length of object iscalled longitudinal magnification (m_L). Longitudinal magnification call can be expressed as

$$m_L = \frac{(v_2 - v_1)}{(u_2 - u_1)}$$

where v_1 and v_2 are image positions corresponding to u_1 and u_2 positions.

For small objects $m_L = -\frac{dv}{du}$

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

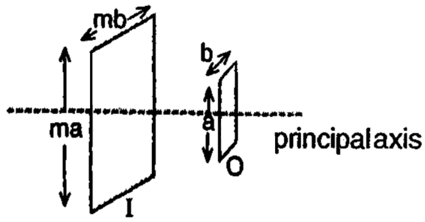
In case of small linear objects $-\frac{dv}{v^2} - \frac{du}{u^2} = 0$

$$\therefore m_L = -\frac{dv}{du} = \left[\frac{v}{u}\right]^2 = m^2$$

c) Areal magnification:

If a twodimensional object is placed with its plane perpendicular to principal axis, its magnification is called areal or superficial magnification.If m is the lateral magnification and m_A is the areal magnification.

$$m_A = \frac{\text{area of image}}{\text{area of object}} = \frac{(ma)(mb)}{ab} = m^2$$



d) Over – all magnification:

In case of more than one optical component, the image formed by first component will act as an objectfor the second and image of second acts as an object for third and soon, the product of all individual magnifications is called .over all magnification.

$$m_0 = \frac{I}{O} = \frac{I_1}{O_1} \times \frac{I_2}{O_2} \times ..... \frac{I_n}{O_n} = m_1 \times m_2 \times ..... \times m_n$$

Motion of object in front of mirror along the principle axis

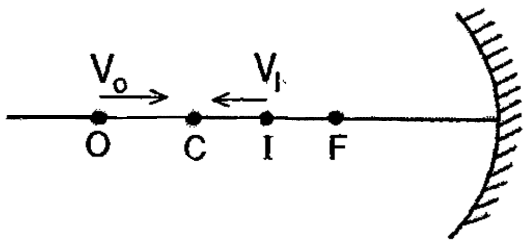
When the position of the object changes with time on the principal axis relative to the mirror, the image position also changes with time relative to the mirror. Hence to know the ralation between the mirror. hence to know the reltation between object and image speed we use the mirror equation

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

Differentiate with respect to time, we get

$$-\frac{1}{v^2} \cdot \frac{dv}{dt} - \frac{1}{u^2} \cdot \frac{du}{dt} = 0 \text{ (or) } \frac{dv}{dt} = -\left(\frac{v}{u}\right)^2 \cdot \frac{du}{dt}$$

$$\text{or } V_I = -\left(\frac{v}{u}\right)^2 . V_O$$

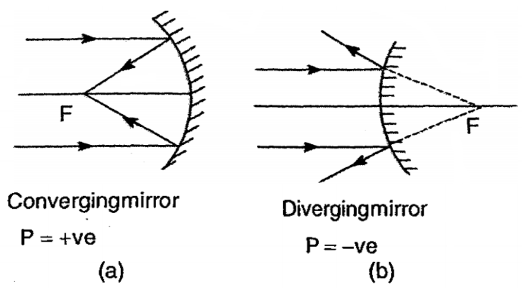


where V_I is velocity of image with respect to mirror and V_0 is the velocityof object with respect to mirror along the principal axis. Here negative sign indicates the object and image are always moving opposite toeach other. In concave mirror,depending on the position of the object, imagespeed may be greater orlesserorequal to the object speed.

(a)	$R < u < \infty$	$\|m\| < 1$	$V_I < V_0$
(b)	$u = R$	$\|m\| = 1$	$V_I = V_0$
(c)	$f < u < R$	$\|m\| > 1$	$V_I > V_0$
(d)	$u < f$	$\|m\| > 1$	$V_I > V_0$
(e)	$u = 0$	$\|m\| \approx 1$	$V_I \approx V_0$

Relation between object and image velocity given above is also valid for convex mirror. In convex mirror, speed of image is slower than the object, whatever the position of the object may be. Above relationis not trueincase of acceleration of object and image.

POWER OF CURVED MIRROR



Every optical instrument has power, It is the ability of optical instrument todeviate the path of rays incident on it. If the instrument converges the rays parallel to principal axis, its power is said to be positive and if it diverges, its power is said to be negative.

For a mirot

$$\text{Power 'P'} = -\frac{1}{f(\text{metre})}$$

(or) $$P = -\frac{100}{f(\text{cm})}$$

S.I. unit of power is dioptre (D) = m^{-1}

For concave mirror (converging mirror), power is positive and for convex mirror(diverging mirror power is negative

Example: 1

A 2.0 cm tall objects is placed 15 cm from a concave mirrot of focal length 10 cm. Find the position, size and nature of the image.

Solution:

$u = -15$ cm; $f = -10$ cm; $O = 2.0$ cm

Using mirror formula, we have,

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} \text{ (or)}$$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-10} - \frac{1}{-15} = -\frac{1}{10} + \frac{1}{15} = -\frac{1}{30}$$

$\therefore$ $v = -30$ cm

$$\text{Magnification, } m = \frac{I}{O} = -\frac{v}{u} = -\frac{-30}{-15} = -2$$

$\therefore$ $I = -2 \times O = -2 \times 2 = -4$ cm (invered)

Thus the image is real nd inverted w.r.t. object, 4 cm in length and is formed at a distance of 30 cm from the mirror on the same side as the object.

Example: 2

An object is placed 10 cm in front of a concave mirror of focal length 15 cm. Find the (i) image position and (ii) magnification.

Solution:

(i) Using mirror formula, $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

Here, $u = -10$ cm; $f = -15$ cm

$\therefore$ $\frac{1}{-10} + \frac{1}{v} = -\frac{1}{15}$ (or) $v = 30$ cm

Since v is positive in sign, the image s virtual and erect w.r.t. object and is formed 30 cm behind the mirror.

(ii) Magnification $m = -\frac{v}{u}$

Here $v = 30$ cm; $u = -10$ cm

$\therefore$ $m = -\frac{(30)}{(-10)} = 3.$

Therefore, the image (erect w.r.t. object) is three times as high as the object.

Example: 3

The image of an object in a convex mirror is 4 cm from the mirror. If the mirror has a radius of curvature of 24 cm, find (i) object position and (ii) the magnification.

Solution:

The image in convex mirror is always virtual and is formed behind the mirror. Therefore, v = +4 cm. The focal length of the mirror = R/2 = 24/2 = 12 cm. Since it is a convex mirror, f = +12 cm.

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

(or) $\frac{1}{u}+\frac{1}{4}=\frac{1}{12}$ $\therefore$ u = – 6 cm

Since u is negative, the object is in front of the mirror.

(ii) Magnification, $m=-\frac{v}{u}=-\left(\frac{4}{-6}\right)=\frac{2}{3}$

Hence the image is two – thirds as high as the object.

Example: 4

An erect image three times the size of the object is obtained with a concave mirror of radius of curvature 36 cm. What is the position of the object?

Solution:

An erect image w.r.t object is obtained with a concave mirror only when the image is virtual. Therefore, images is formed behind the mirror and magnification is positive. If x is the distance of the object from the mirror, then,

u = – x; v = + 3x and f = – R/2 = – 36/2 = –18 cm

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

or $\frac{1}{-x}+\frac{1}{3x}=-\frac{1}{18}$

or $\frac{-2}{3x}=-\frac{1}{18}$

$\therefore$ x = + 12 cm i.e., u = – 12 cm

Thus the object is 12 cm in front of the mirror.

Example: 5

A convex mirror of radius of curvature 20 cm forms an image which is half the size of the object. Locate the position of object and its image.

Solution:

Fot convex mirror, R = +20 cm

$\therefore$ f = R/2 = 20/2 = 10 cm

Magnification, $m=-\frac{v}{u}=+\frac{1}{2}$ $\therefore$ = –u/2

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

(or) $\frac{1}{u}+\frac{-2}{v}=\frac{1}{10}$ $\therefore$ u = –10 cm

$v=-\frac{u}{2}=-\left(\frac{-10}{2}\right)=+5$ cm

Example: 6

A square wire of side 3.0 cm is placed 25 cm away from a concave mirror of focal langth 10 cm. WHat is the area encloswd 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.

Solution:

h_1 = 3.0 cm; u = – 25 cm; f = – 10 cm

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

$=\frac{1}{-10}-\frac{1}{-25}=-\frac{1}{10}+\frac{1}{25}=-\frac{3}{50}$

v = – 50/3 cm

Now $m=\frac{h_2}{h_1}=-\frac{v}{u}$

or $\frac{h_2}{3.0}=-\frac{50/3}{-25}$

$\therefore$ $h_2=3.0\times-\frac{2}{3}=-2.0$ cm

$\therefore$ Side of the image of the square wire is 2 cm.

Area enclosed by the image of the wire

= 2 × 2 = 4 cm^2

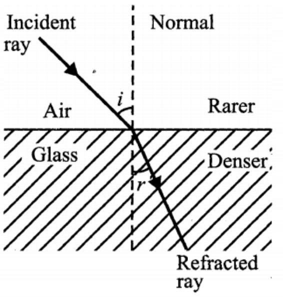
11.1.2. Refraction

When light travels in homogeneous medium,it follows a striaght line path. But as light passes obliquely from one transparent medium to another, it deviates from its original path. This bending of light (i.e. change in the path of light) is called refraction of light. The deviation of light occurs because light travels at different speeds in the different media. The medium in which the speed of light is less is called denser medium (or optically denser medium) while the medium in which the speed of light is more is called rarer medium (or optically rarer medium). In this cahapeter, we shall deal with various aspects of refraction of light.

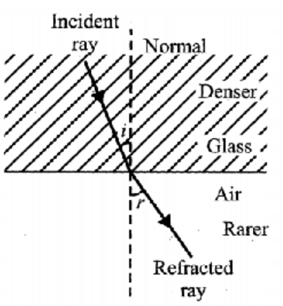
REFRACTION OF LIGHT:

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

When a ray of light goes from a rarer medium (where speed of light is more) to a denser medium (where speed of light is less), it bends towards the normal as shown in Fig. (*i*). Clearly, in this case, angle of refraction (r) is less than the angle of incidence (*i*) i.e. $\angle r > \angle i$. When a ray of light goes from a denser medium to a rarer medium, it bends away from the normal as shown in Fig. (*ii*). Clearly, in this case, $\angle r > \angle i$.



(*i*)



(*ii*)

In each of the above two cases, there is a change in the path of light as it goes from one medium to another. This is called refraction of light. The basic cause o f refraction is that the speed of light changes as it goes from one medium to another.

* No refraction takes place if the ray enters from one medium to another normally (i.e. at right angles to the surface of separation of the two media).

Discussion. The following points are worth noting:

(i) When a light goes from one medium to another, the frequency of light does not change.However, the speed of light and wavelength of light change.

(ii) The intensity of the refracted ray is less than that of the incident ray. It is because there is partial reflection and absorption of light at the surface.

LAWS OF REFRACTION

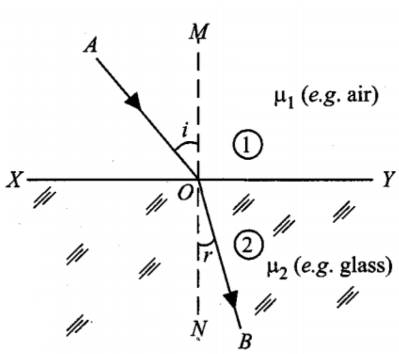
The phenomenon of refraction of light takes place according to the following three laws:

1. The incident ray, the normal at the point of incidence and the refracted ray all lie in the same plane.
2. When light goes from one medium to another, the frequency of light does not change However, the velocity and wavelength of light change.
3. The ratio of the sine of angle o f incidence to the sine of angle of refraction is constant for the two media i.e.

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

This constant (${}^1\mu_2$) is called refractive index of medium 2 (in which refracted ray travels) w.r.t. medium 1 (in which incident ray travels). Eq. (i) is known as Snell's law and holds good for all angles of incidence.

If medium 1 has refractive index μ_1 and medium 2 has refractive index as shown in Fig., then,



$${}^1\mu_2 = \frac{\mu_2}{\mu_1}$$

From eq.(*i*), $$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$$

or $\mu_1 \sin i = \mu_2 \sin r$

$\therefore$ $\mu \sin i = \text{Constant}$ (ii)

Eq. (ii) is a useful form of Snell's law which may be stated as under:

If a ray of light goes from medium 1 to medium 2, the product of refractive index of medium 1 and sine of angle of incidence is equal to the product of refractive index of medium 2 and sine of angle of refraction.

Thus, referring to Fig., if $i = 60°, \mu_1 = 1.33$ and $\mu_2 = 1.5$, then angle of refraction r is given by:

$$1.33 \sin 60° = 1.5 \sin r$$

or $$\sin r = \frac{1.33 \sin 60^0}{1.5} = 0.7679 \quad r = 50.2°$$

Refractive index

The refractive index of a medium is a measure of the velocity of light in the medium. The greater the refractive index of a medium, the smaller is the velocity of light in that medium and vice-versa. A medium that has higher refractive index is called optically denser medium and the one that has smaller refractive index is said to be optically rarer medium.

The refractive index (μ) of a medium is defined as :

$$\text{Refractive index}, \mu = \frac{\text{Velocity of light in vacuum (c)}}{\text{Velocity of light in medium (v)}}$$

For example, the refractive index of ordinary glass is 1.5. Therefore, velocity of light in ordinary glass given by ;

$$\mu = \frac{\text{Velocity of light in vacuum (c)}}{\text{Velocity of light in glass (v)}}$$

or $$1.5 = \frac{3 \times 10^8}{v}$$

$\therefore$ Velocity of light in glass,

$$v = \frac{3 \times 10^8}{1.5} = 2 \times 10^8 \text{ ms}^{-1}$$

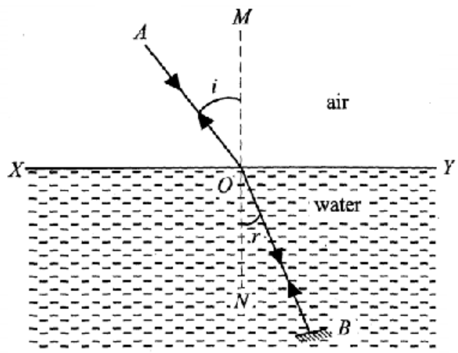
Note:

The refractive index of most common glasses used in optical instruments lies between 1.46 and 1.96. There are very few substances having indices greater than 1.96, diamond being one with an index of 2.47.

Principle of reversibility of light

According to principle of *reversibility of light, if a reflected or refracted ray is reversed in direction, it will retrace its original path.

Fig. illustrates the principle of reversibility of light. Here refraction of light takes place at the plane surface XY which separates two transparent media viz. air and water. A ray of light AO is incident at point O on air-water surface at an angle of incidence i. At point O, refraction takes place and the refracted ray follows the path OB; r being the angle of refraction. If a plane mirror is placed normal to the path of the refracted ray, then the ray is reversed in direction and retraces the original path. Now r becomes the angle of incidence in water and i the angle of refraction in air.



An important result. This useful principle has more than a purely geometrical foundation. Let us apply it to Fig. When ray of light AO travels from air to water, then according to Snell's law,

$${}^a\mu_w = \frac{\sin i}{\sin r} \quad ...(i)$$

When the path of light is reversed, the ray of light BO travels from water to air. Now r is the angle of incidence and i is the angle of refraction. According to Snell's law,

$${}^w\mu_a = \frac{\sin r}{\sin i} \quad ...(ii)$$

* For reflection, $\angle i = \angle r$; For refraction, $\mu_1 \sin i = \mu_2 \sin r$.

The symmetry of these relations shows the validity of principle of reversibility of light.

Multiplying eqs. (i) and (ii), we get,

$$^{a}\mu_{w} \times {}^{a}\mu_{w} = \frac{\sin i}{\sin r} \times \frac{\sin r}{\sin i} = 1$$

$$\therefore \quad {}^{a}\mu_{w} = \frac{1}{{}^{w}\mu_{a}}$$

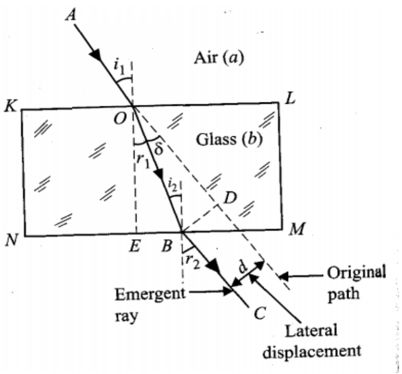
Hence the refractive index of denser medium w.r.t. rarer medium is equal to the reciprocal of the refractive index of rarer medium w.r.t. denser medium.

Thus if the refractive index from air to glass ($^{a}\mu_{g}$) is 1.5, then refractive index from glass to air ($^{g}\mu_{a}$) = 1/1.5 = 0.67. Similarly, if refractive index from air to water ($^{a}\mu_{w}$) is 4/3, then refractive index from water to air ($^{w}\mu_{a}$) is 3/4.

Refraction through rectangular glass slab

When a ray of light passes through a rectangular glass slab, the emergent ray is parallel to the incident ray, although there is lateral displacement.

Consider a rectangular glass slab KLMN as shown in Fig. A ray of light AO in air (medium 'a') is incident on the glass surface KL (medium 'b') at point O. The ray bends towards the normal and follows the path OB. At point B, again refraction takes place and the ray bends away from the normal, emerging out of glass following path BC. It will be shown that the emergent ray BC is parallel to the incident ray AO.



At point O, $\quad \frac{\sin i_1}{\sin r_1} = {}^{a}\mu_{b} \quad$ ...(i)

At point B, $\quad \frac{\sin i_2}{\sin r_2} = {}^{b}\mu_{a} \quad$ ...(ii)

Multiplying eqs. (*i*)and (*ii*), we get

$$^{a}\mu_{b} \times {}^{b}\mu_{a} = \frac{\sin i_1}{\sin r_1} \times \frac{\sin i_2}{\sin r_2}$$

But $\quad {}^{a}\mu_{w} \times {}^{a}\mu_{w} = 1$

$$\therefore \quad \frac{\sin i_1}{\sin r_1} \times \frac{\sin i_2}{\sin r_2} = 1$$

Now $\quad r_1 = i_2 \quad$ ...alternate angles

$$\therefore \quad \frac{\sin i_1}{\sin r_2} = 1$$

or $\quad \sin i_1 = \sin r_2$

or $\quad i_1 = r_2$

Thus when a ray of light passes through a parallel-sided glass slab, the emetgent ray is parallel to the incident ray. However, it is laterally displaced. The lateral displacement d is shown in Fig.

Expression for lateral displacement: The perpendicular distance between the incident and emergent rays is called lateral displacement d.

In Fig. draw BD $\perp$ AO produced.

$\therefore$ Lateral displacement = BD = d

Let $\angle$BOD = δ = Deviation on refraction at first surface KL

In Δ BOD, $\quad \sin\delta = \frac{BD}{OB}$

$\therefore \quad BD = OB \sin\delta \quad$ (*iii*)

In Δ OEB, $\quad \cos r_1 = \frac{OE}{OB}$

$$OB = \frac{OE}{\cos r_1} = \frac{t}{\cos r_1}$$

where OE = t = Thickness of glass slab

From eq.(iii), $BD = \frac{t}{\cos r_1}\sin\delta = \frac{t\sin(i_1 - r_1)}{\cos r_1}$

($\because \delta = i_1 - r_1$)

$\therefore$ Lateral displacement, $d = BD = \frac{t\sin(i_1 - r_1)}{\cos r_1}$

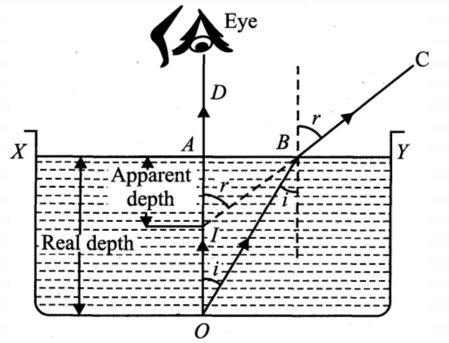
It may be noted that lateral displacement increases with (i) increase in thickness of glass slab (ii) increase in the value of angle of incidence and (iii) increase in the refractive index of slab.

It can be shown that lateral displacement will be maximum when $i_1 = 90°$.

Real depth and apparent depth

An object placed in a denser medium (e.g. water) when viewed from a rarer medium (e.g. air) appears to be at a lesser depth than its real depth. This is on account of refraction of light.

Consider a point object O at the bottom of a beaker filled with water as shown in Fig. Suppose XY is the surface that separates air and water. A ray OA from O perpendicular to the surface XY passes straight through into the air along AD. A ray OB very close to ray OA is refracted at point B into the air away from the normal in a direction BC. When viewed from above, the rays will appear to come from point I which is the point of intersection of OD and BC produced backward. Thus a virtual image of O is formed at I. Therefore, the depth of the object will appearto be AI. The depth AO is the real depth of the object and depth AI is called its apparent depth Clearly, apparent depth AI is smaller than the real depth AO.



As light is travelling from denser medium (water) to rarer medium (air),

∴ $^{w}\mu_{a} = \frac{\sin i}{\sin r} = \frac{\sin BOA}{\sin AIB} = \frac{AB/BO}{AB/BI}$

or $^{w}\mu_{a} = BI/BO$

If point B is very close to point A (i.e. when viewed from vertically above O), then,

BI = AI and BO = AO

∴ $^{w}\mu_{a} = AI/AO$

or $^{a}\mu_{w} = \frac{AO}{AI} = \frac{\text{Real depth}}{\text{Apparent depth}}$

As $^{a}\mu_{aw} = \frac{4}{3}$ ∴ $\frac{4}{3} = \frac{AO}{AI}$

or $AI = \frac{3}{4} \text{ x } AO$

i..e. Apparent depth = $\frac{3}{4}$ x Real depth

Therefore, the apparent depth is (3/4)th of the real depth of the beaker of water.

Apparent normal shift The height through which an object appears to be raised in a denser medium when viewed vertically above from a rarer medium is called apparent normal shift(d).

Apparent normal shift, d = Real depth - Apparent depth

$= AO - AI = AO - \frac{AO}{\mu} = AO\left(1 - \frac{1}{\mu}\right)$

∴ $d = t\left(1 - \frac{1}{\mu}\right)$

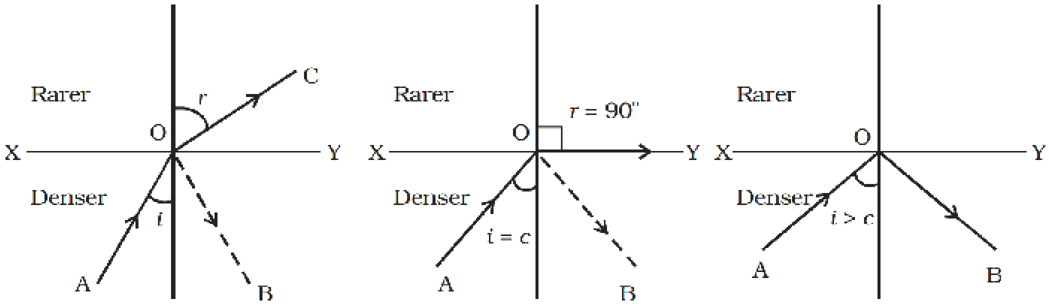
where t - AO = real depth of the object and μ is the refractive index of denser medium w.r.t. rarer medium.

Note that apparent shift depends upon (i) real depth (t) of the object and (ii) refractive index (μ) of the denser medium w.r.t. the rarer medium

11.1.3 Total internal reflection

When a ray of light AO passes from an optically denser medium to a rarer medium, at the interface XY, it is partly reflected back into the same medium along OB and partly refracted into the rarer medium along OC (Fig.).

If the angle of incidence is gradually increased, the angle of refraction r will also gradually increase and at a certain stage r becomes 90^o. Now the refracted ray OC is bent so much away from the normal and it grazes the surface of separation of two media. The angle of incidence in the denser medium at which the refracted ray just grazes the surface of separation is called the critical angle c of the denser medium. If i is increased further, refraction is not possible and the incident ray is totally reflected into the same medium itself. This is called total internal reflection.



If µd is the refractive index of the denser medium then, from Snell's Law, the refractive index of air with respect to the denser medium is given by,

$$_d\mu_a = \frac{\sin i}{\sin r}$$

$$\frac{\mu_a}{\mu_d} = \frac{\sin i}{\sin r}$$

$$\frac{1}{\mu_d} = \frac{\sin i}{\sin r} (\because \mu_a = 1 \text{ for air})$$

$$\text{If } r = 90^0, i = c$$

$$\frac{\sin c}{\sin 90^0} = \frac{1}{\mu_d} \text{ (or) } \sin c = \frac{1}{\mu_d} \text{ or } c = \sin^{-1}\left(\frac{1}{\mu_d}\right)$$

If the denser medium is glass, $c = \sin^{-1}\left(\frac{1}{\mu_g}\right)$

Hence for total internal reflection to take place (i) light must travel from a denser medium to a rarer medium and (ii) the angle of incidence inside the denser medium must be greater than the critical angle i.e. $i > c$.

11.1.4 Applications

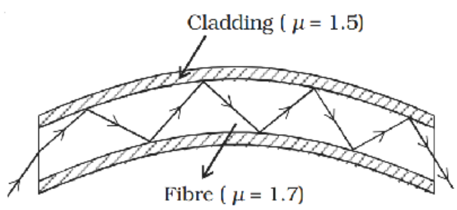
(i) Diamond

Total internal reflection is the main cause of the brilliance of diamonds. The refractive index of diamond with respect to air is 2.42. Its critical angle is 24.41^o. When light enters diamond from any face at an angle greater than 24.41^o it undergoes total internal reflection. By cutting the diamond suitably, multiple internal reflections can be made to occur.

(a)

(ii) Optical fibres

The total internal reflection is the basic principle of optical fibre. An optical fibre is a very thin fibre made of glass or quartz having radius of the order of micrometer (10–6m). A bundle, of such thin fibres forms a 'light pipe' (Fig.a).



(b)

Fig.b shows the principle of light transmission inside an optical fibre. The refractive index of the material of the core is higher than that of the cladding. When the light is incident at one end of the fibre at a small angle, the light passes inside, undergoes repeated total internal reflections along the fibre and finally comes out. The angle of incidence is always larger than the critical angle of the core material with respect to its cladding. Even if the fibre is bent or twisted, the light can easily travel through the fibre.

Light pipes are used in medical and optical examination. They are also used to transmit communication signals.

Example: 7

Calculate the critical angle for glass – water surface. The refractive indices of glass and water are 1.5 and 1.33 respectively.

Solution:

Refractive index of glass w.r.t. water is

$$ {}^{w}\mu_g = \frac{{}^{a}\mu_g}{{}^{a}\mu_w} = \frac{1.5}{1.33} = 1.1278 $$

Now $\quad {}^{w}\mu_g = \frac{1}{\sin C} \quad$ or $\sin C = \frac{1}{{}^{w}\mu_g} = \frac{1}{1.1278}$

$$ = 0.8867 $$

$\therefore \quad C = 62.46^0$

Example: 8

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 liquid into the air, calculate the value of critical angle.

Solution:

Here, $v = 1.5 \times 10^8$ ms^{-1}; $c = 3 \times 10^8$ ms^{-1} ; $C = ?$

Refractove index of liquid w.r.t. air is

$$ \therefore \quad \sin C = \frac{v}{c} = \frac{1.5 \times 10^8}{3 \times 10^8} = 0.5 \quad \therefore \quad C = 30^0 $$

Refraction of light

When a ray of light travels from one transparent medium into another medium, it bends while crossing the interface, separating the two media. This phenomenon is called refraction.

Image formation by spherical lenses is due to the phenomenon of refraction. The laws of refraction at a plane surface are equally true for refraction at curved surfaces also. While deriving the expressions for refraction at spherical surfaces, we make the following assumptions.

(i) The incident light is assumed to be monochromatic and

(ii) the incident pencil of light rays is very narrow and close to the principal axis.

Cartesian sign convention

The sign convention followed in the spherical mirror is also applicable to refraction at spherical surface. In addition to this two more sign conventions to be introduced which are:

(i) The power of a converging lens is positive and that of a diverging lens is negative.

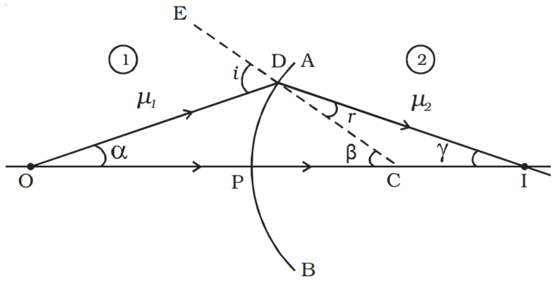
(ii) The refractive index of a medium is always said to be positive.

If two refractions are involved, the difference in their refractive index is also taken as positive.

11.1.5 Refraction at a spherical surface

Let us consider a portion of a spherical surface AB separating two media having refracting indices μ_1 and μ_2 (Fig.). This is symmetrical about an axis passing through the centre C and cuts the surface at P. The point P is called the pole of the surface. Let R be the radius of curvature of the surface.

Consider a point object O on the axis in the first medium. Consider two rays OP and OD originating from O. The ray OP falls normally on AB and goes into the second medium, undeviated. The ray OD falls at D very close to P. After refraction, it meets at the point I on the axis, where the image is formed. CE is the normal drawn to the point D. Let *i* and r be the angle of incidence and refraction respectively.



Let $\angle DOP = \alpha, \angle DCP = \beta, \angle DIC = \gamma$,

Since D is close to P, the angles α, β and γ are all small. From the Fig.

$\tan\alpha = \frac{DP}{PO}$, $\tan\beta = \frac{DP}{PC}$ and $\tan\gamma = \frac{DP}{PI}$

$\therefore \alpha = \frac{DP}{PO}$, $\beta = \frac{DP}{PC}$ and $\gamma = \frac{DP}{PI}$

From the ΔODC, $i = \alpha + \beta$ ...(1)

From the ΔDCI, $\beta = r + \gamma$ or $r = \beta - \gamma$ ...(2)

From Snell's Law, $\frac{\mu_2}{\mu_1} = \frac{\sin i}{\sin r}$ and for small angles of i and r, we can write, $\mu_1 i = \mu_2 r$ ...(3)

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

we get

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

or $\mu_1\alpha + \mu_2\gamma = (\mu_2 - \mu_1)\beta$ ... (4)

Substituting the values of α, β and γ in equation (4)

$$\mu_1\left(\frac{DP}{PO}\right) + \mu_2\left(\frac{DP}{PI}\right) = (\mu_1 - \mu_2)\frac{DP}{PC}$$

$$\frac{\mu_1}{PO} + \frac{\mu_2}{PI} = \left(\frac{\mu_2 - \mu_1}{PC}\right) \quad ...(5)$$

As the incident ray comes from left to right, we choose this direction as the positive direction of the axis. Therefore u is negative, whereas v and R are positive substitute PO = –u PI = +v and PC = +R in equation (5), $\frac{\mu_1}{-u} + \frac{\mu_2}{v} = \frac{\mu_2 - \mu_1}{R}$

$$\frac{\mu_2}{v} + \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$

Equation (6) represents the general equation for refraction at a spherical surface.

If the first medium is air and the second medium is of refractive index μ, then

$$\frac{\mu}{v} - \frac{1}{u} = \frac{\mu - 1}{R} \quad ...(7)$$

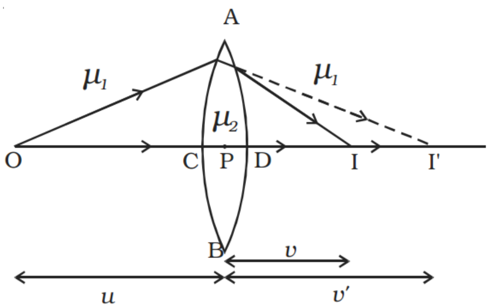
11.1.6 Refraction through thin lenses

A lens is one of the most familiar optical devices. A lens is made of a transparent material bounded by two spherical surfaces. If the distance between the surfaces of a lens is very small, then it is a thin lens.

As there are two spherical surfaces, there are two centres of curvature C_1 and C_2 and correspondingly two radii of curvature R_1 and R_2. The line joining C_1 and C_2 is called the principal axis of the lens. The centre P of the thin lens which lies on the principal aixs is called the optic centre.

Lens maker's formula and lens formula

Let us consider a thin lens made up of a medium of refractive index μ_2 placed in a medium of refractive index μ_1 . Let R_1 and R_2 be the radii of curvature of two spherical surfaces ACB and ADB respectively and P be the optic centre.



Consider a point object O on the principal axis. The ray OP falls normally on the spherical surface and goes through the lens undeviated. The ray OA falls at A very close to P. After refraction at the surface ACB the image is formed at I′. Before it does so, it is again refracted by the surface ADB. Therefore the final image is formed at I as shown in Fig.

The general equation for the refraction at a spherical surface is given by

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R} \quad ... (1)$$

For the refracting surface ACB, from equation (1) we write

$$\frac{\mu_2}{v'} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R_1} \quad ... (2)$$

The image I′ acts as a virtual object for the surface ADB and the final image is formed at I. The second refraction takes place when light travels from the medium of refractive index μ_2 to μ_1.

For the refracting surface ADB, from equation (1) and applying sign conventions, we have

$$\frac{\mu_1}{v} - \frac{\mu_2}{v'} = \left(\frac{\mu_2 - \mu_1}{-R_2}\right) \quad \text{... (3)}$$

Adding equations (2) and (3)

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

Dividing the above equation by μ_1

$$\frac{1}{v} - \frac{1}{u} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \quad \text{...(4)}$$

If the object is at infinity, the image is formed at the focus of the lens.

Thus, for u = ∞, v = f. Then the equation (4) becomes.

$$\frac{1}{f} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \quad \text{...(5)}$$

If the refractive index of the lens is μ and it is placed in air, μ_2 = μ and μ_1 = 1. So the equation (5) becomes

$$\frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \quad \text{...(6)}$$

This is called the lens maker's formula, because it tells what curvature will be needed to make a lens of desired focal length. This formula is true for concave lens also.

Comparing equation (4) and (5)

we get

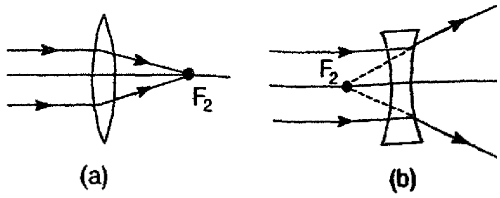
$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \quad \text{... (7)}$$

which is known as the lens formula.

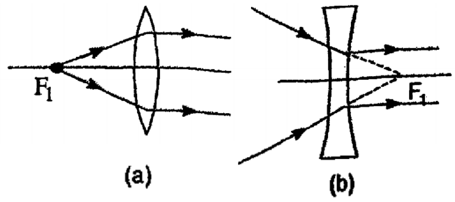
Rules for image formation:

In order to locate the image ad its nature by a lens graphically, the following rules are adopted.

(i) A ray parallel to the principal axis, after refraction,passes through the principal focus or appears to diverge from it.



(ii) A ray passing through the first focus F_1 become parallel to the principal axis after refraction.



(iii) A ray through the optical centre O passes undeviated because the middle of the lens acts like a thin parallel sided slab.

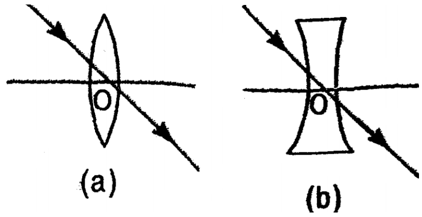
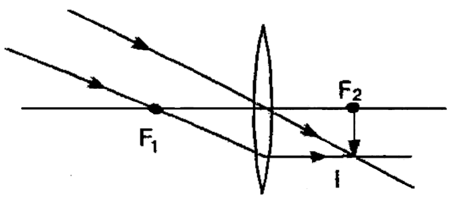
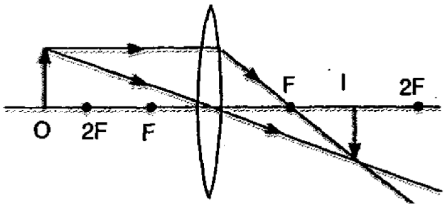
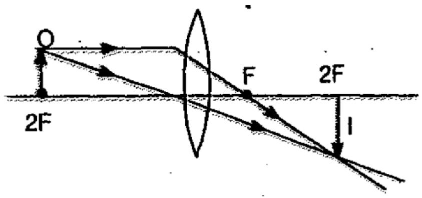
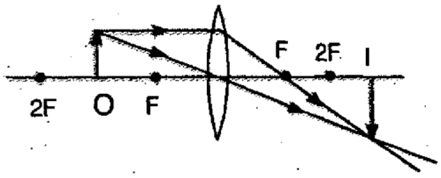
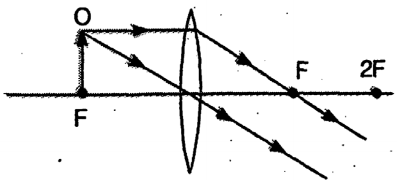
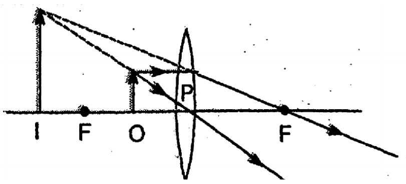


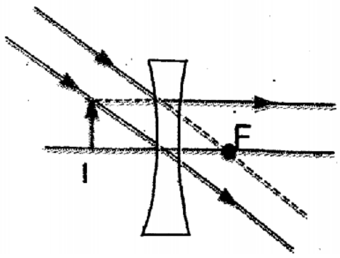
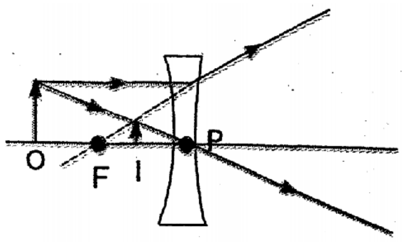
Image Formation by Lens

a) Convex lens:

Position of the object	Ray diagram	Image details
At infinity		Real, inverted, diminished at F

Between ∞ and 2F		Real, inverted, diminished between F and 2F
At 2F		Real, inverted, equal, at 2F
Between 2F and F		Real, inverted, enlarged between 2F and infinity
At F		Real, inverted, enlarged, at infinity
Between F and P		Virtual, erect, enlarged betweeen and object on same side

b) Concave lens:

Position of the object	Ray diagram	Image details
At infinity		Virtual, erect, diminished at F
In front of lens		Virtual, erect, diminished between F and P

a) Regarding convex lens:

(i) A convex lens will form a real image for a|curved surface,real object when the object is placed beyond focus.

(ii) When the objectc on with in the focus, then a virtual image is formed forthereal object.

(iii) The real image formed is always inverted while virtual image isaiways erect

b) Regardingconcave lens:

(i) A concave lens always forms virtual image for a real object.

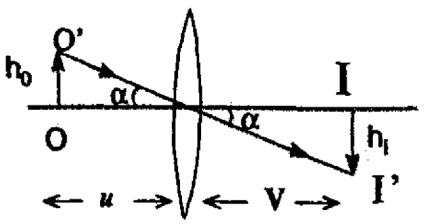
(ii) The image formed by a concave lens is always erect and diminished in size.

(iii) A concave lens can forma real image as well as virtual image if the object is virtual.

Magnification

a) Lateral magnification:

Magnification produced by a lens is defined astheratioof thesizeof imagetothat of the object. Here the sizes are measured perpendicular to principal axis



$$m = \frac{II'}{OO'} = \frac{h_i}{h_o} = \frac{v}{u}$$

When we apply the sign convention, for erect (and virtual) image formed by a convex orconcave lens 'm' is positive, and for an inverted (and real) image, m is negative.

b) Longitudinal magnification:

Longitudinal magnification is defined as the ratioof infinitesimal axial length(dv) in theregion of the image to the corresponding length (du) in the region of the object.

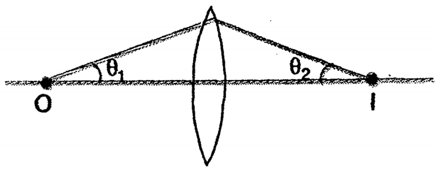
Longitudinal magnification (m_L) = dv/du

On differentiating equation $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

we get $m_L = -m^2$.

c) Angular magnification of lens

The ratio of the slopes of emergent ray and corresponding incident ray with principal axis is called the angular magnification.



Angular magnification (γ) = $\frac{\tan \theta_2}{\tan \theta_1}$

It shoud note be that

(i) longitudinal magnification isproportional to the square of the lateral magnification.

(ii) When several lenses or mirrors are used co-axially, the total magnification

$$m = m_1 \times m_2 \times \text{..........} \times m_n$$

Example:

What is the refractive index of material of a plano-convex lens, if the radius of curvature of the convex surface is 10 cm and focal length of the lens is 30 cm?

Solution:

According to lens – maker's formula,

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

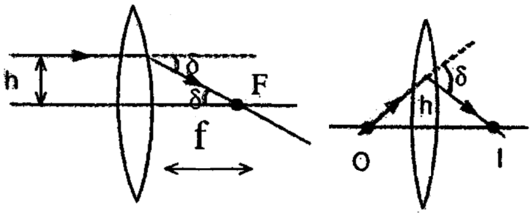
Here f = 30 cm, R_1 = 10 cm and $R_2 = \infty$

so $\frac{1}{30} = (\mu - 1)\left[\frac{1}{10} - \frac{1}{\infty}\right]$

i.e., $3\mu - 3 = 1$ or $\mu = (4/3)$

11.1.7 Power of a lens

As we said earlier in mirrors, the power of a lens is the measure of its ability to produce convergence or divergence of a parallel beam of light The power P of a lens is defined as the tangent of the angle by which it converges or diverges a beamof light falling at unit distant from the optical centre.



(a) (b)

tan δ = h/f   if h = 1, tan δ = 1/f

As per definition, power (P) = tan δ = 1/f.

If lens is placed in a medium other than air, of refractive index μ, then power P = μ/f

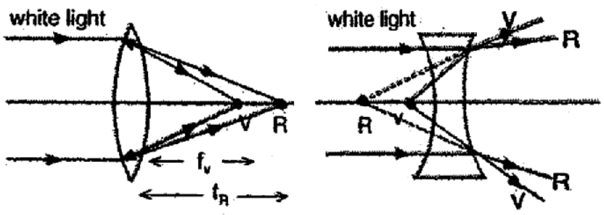
The S.I. unit of power is dioptre (D) and 1 D = 1 m^{-1}

i.e., $P = \frac{1}{f(\text{in m})} = \frac{100}{f(\text{in cm})} D$

For of concave mensiscus with $R_1 = R_2$, f = ∝ and P = 0.

The deviation produced by a lens is independent of the position of the object whatever may be the direction of incidence. All the year rays sufer the same deviation in refraction through the lens. Clearly a lens with shorter focal length devides the incident light more. A convex lens converge the incident rays. Due to this reason, that power of a convex lens is taken as positive. On theother hand, aconcavelens divergetheincident rays.Therefore its power is taken as negative.

- Every part of a lens forms complete image even if a portion is obstructed,but intensity of the image decreases. Also if a lens is painted with black Strips and a green page is seen through it, the green page will notappear with black strips but will remain green with reduced intensity.
- The minimum distance between a real object and its real image formed by a single lens is 4f.

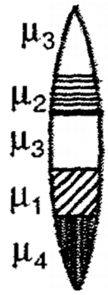


(a) (b)

- As focal length of a lens depends on its of refractive index i.e. 1/f ∝ (μ – 1), the focal length of a given lens is different for different wavelengths and maximum for red and minimum for violet whatever the nature of the lens as shown in the figure.

Since, on change temperature of the medium refractive index changes, at different temperatures focal length ofalens is different.

- If a lens made of a number of layers of different refractive indicesas shown in figure,for a given wavelength of light it will have many focal lengths as 1/f ∝ (μ – 1). Hence it will form as many images as there are different μ's.

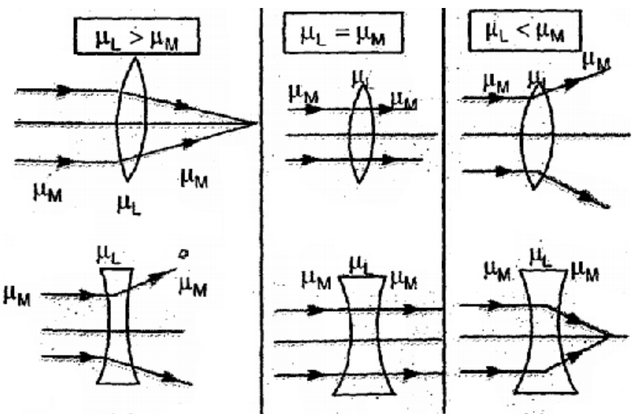


According to given Fig., number of images formed by lens is 4

- If a lens is shifted from one medium to an other, depending on therefractiveindex of the lens and the surrounding medium, its focal length as well its nature may change.

As $\mu_r = \frac{\mu_L}{\mu_M}$ and 1/f ∝ (μ_r – 1)

When μ_L & μ_M change such that



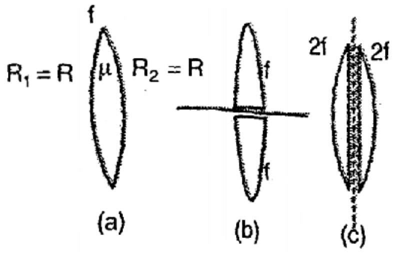
(a) (b) (c)

Case (i) If μ_r > 1, focal length changes, but nature remain same.

Case (ii) If μ_r = 1 , focal length become infinite, the lens will neither converge nor diverge but will behave as a plane glass plate.

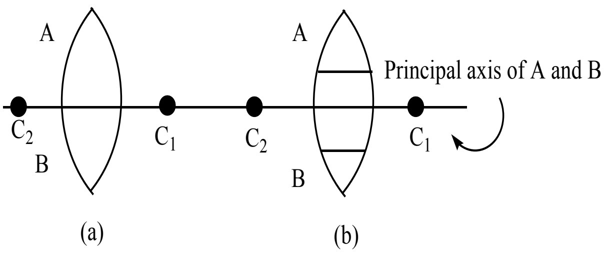
Case (iii) If $\mu_r < 1$, focal length, and nature of the lens changes.

- If the two radii of curvatures of a thin lens are not equal, the focal length remain unchanged, whether the light is incident on first face or the other.
- If a equi convex lens of focal length 'f' is cut into two equal parts along its principal axis, as shown in Fig(b) then none of μ, R_1 and R_2 will change, the focal length of each part will be equal to that of initial lens, but intensity of image formed by each part will reduce to half.

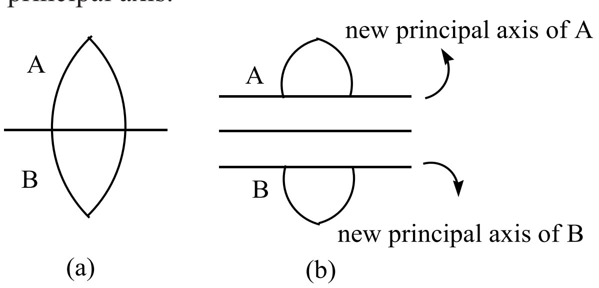


However if the same lens is cut in to two equal parts transverse to principal axis, as shown in Fig.(c) the focal length of each part will become double of initial value, but intensity of image remains same.

- (a) On removing a part of lens without disturbing remaining part, the principal axis position of the remaining part is same asearlier



- (b)If a lens is cut along the principal axis and the separation between them increased in a direction transverse to principal axis, each part has own principal axis.



To a lens $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

Therefore $-\frac{1}{v^2}\cdot\frac{dv}{dt} + \frac{1}{u^2}\cdot\frac{dv}{dt} = 0 \text{ (or) } V_I = \left(\frac{v}{u}\right)^2 V_0$

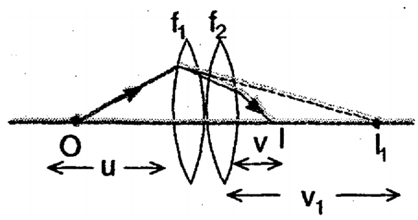
where V_I = velocity of image with respect to lens, V_0 = velocity of object with respect to lens.

i.e. $V_I = m^2.V_0 = \left[\frac{f}{u+f}\right]^2.V_0$

If an object is moved at constant speed towards a convex lens from infinity to focus,the image will move other side of the lens slower in the beginning and faster later on away from the lens. If the object moves from F to optical point, die images moves with greater speed same side of object from infinity towards lens.

11.2.1 Combination of lenses

In case of two thin lenses in contact, if the first lens of focal length f_1 forms the image I_1 at a distance v_1 from it



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

Now the image I_1 will act as an object for second lens. If the second lens forms image I at a distance 'v' from it, then

$$\frac{1}{v} - \frac{1}{v_1} = \frac{1}{f_2} \quad ....(2)$$

So adding (1) and (2) equations we have

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2} \text{ (or) } \frac{1}{v} - \frac{1}{u} = \frac{1}{F}$$

$$\text{with } \frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

i.e., the combination behaves as a single lens of equivalent focal length 'F' given by

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

This derivation is valid for any number of thin lenses in contact co – axially.

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} ---+\frac{1}{f_n}$$

In terms of power

$P_{net} = P_1 + P_2 + P_3 + ----- + P_n$

It is worthy to note that:

1. Here focal length values are to be substituted with sign.
2. If the two thin lenses are sepatrated by a distance 'd', then $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$

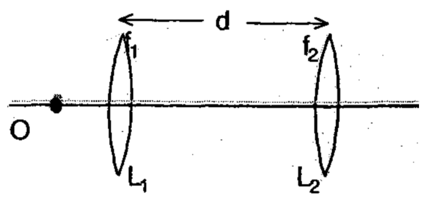
   So $P_{net} = P_1 + P_2 - dP_1P_2$
3. If the medium on either side of the lenses is air and the medium between the lenses is one having refractive index 'μ', we can imagine that the rays emerginf from the first lens are incident on the second lens as if they have traversed a thickness d/μ in air.

   Hence n $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{(d/\mu)}{f_1 f_2}$

   $\therefore \quad P = p_1 + p_2 - \left(\frac{d}{\mu}\right) p_1 p_2$
4. If two thin lenses of equal focal length but of opposite nature are put in contact, the resultant focal length of the combinations will be

   $\frac{1}{F} = \frac{1}{f} + \left(-\frac{1}{f}\right) = 0$

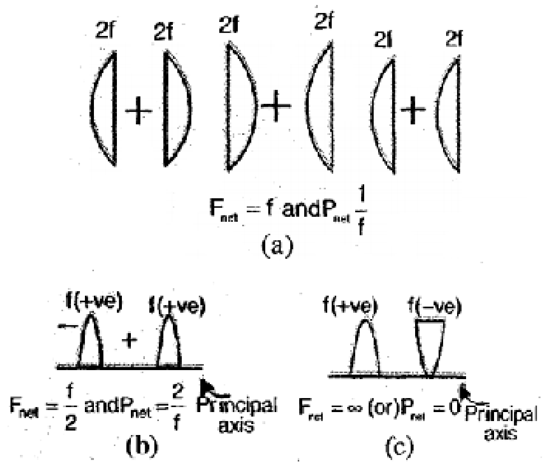
   i.e., $F = \infty$ and $P = 0$
5. If f_1 and f_2 are focal lengths of two lenses (L_1 and L_2) are separated by a distance 'd' on common principal axis and 'F' is the equivalent focal length of the system.



Then (i) the distance of equivalent lens from second lens I_2 is Fd/f_1 towards the object if the value is positive and away from the object if the value is negative

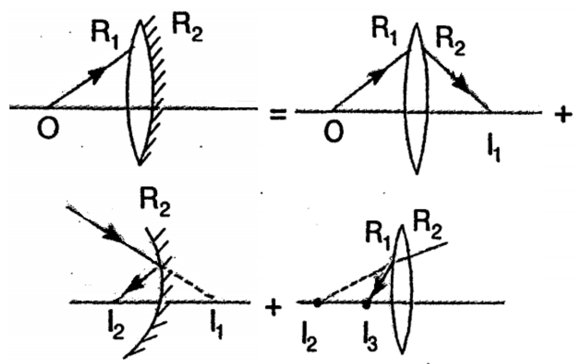
Note that F, f_1 and f_2 are to be substituted according to sigh convenction.

6. If a lens of focal length 'f' is divided into two equal parts, and if these parts are put in contact in different combination as shown in Fig. Then



LENS WITH ONE SILVERED SURFACE

If the back surface of a lens is silvered and an object is placed in front of it, then the rays are first refracted by lens, then reflected from the silvered surface and finally refracted by lens, so that we get two refractions and one reflection.



In the Fig, if f_l and f_m are respective focal lengths of lens and mirror, then

$$\frac{1}{F} = \frac{1}{f_l} + \frac{1}{f_m} + \frac{1}{f_l} = \frac{2}{f_l} + \frac{1}{f_m}$$

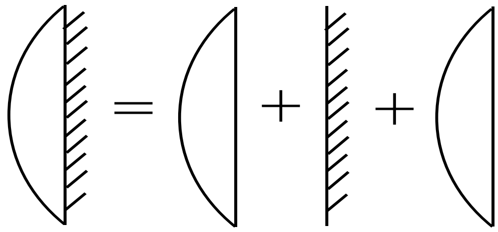
$P = P_l + P_m + P_l = 2P_l + P_m$

with $\quad P_l = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ and $P_m = \frac{2}{R_2}$

Here P_l and P_m are substituted with sign. The system will behave as a concave mirror if 'P' is positive and as a convex mirror if 'P' is negative. The rplacement with the mirror is due to overall reflection of given rays.

Example:

When the plane surface of a plano convex lens is slivered.

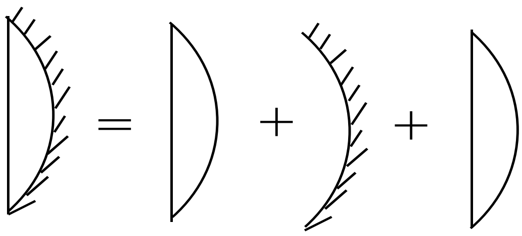


$P = 2P_l + P_m$. $P = 2.\left(\frac{\mu - 1}{R}\right) + 0 = \frac{2(\mu - 1)}{R}$

Since μ > 1, pPp is positive, the system behaves as a concave mirror with focal length $\frac{R}{2(\mu - 1)}$.

Example:

When curved surface of a plano convex lens is slivered.



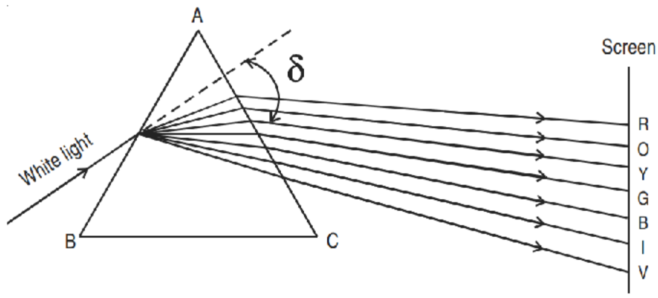
$P = 2P_l + P_m$. $P = \frac{2(\mu - 1)}{R} + \frac{2}{R} = \frac{2\mu}{R}$

Since μ > 1, pPp is positive, the system behaves as a concave mirror with focal length $\frac{R}{2\mu}$.

11.2.2 Dispersion of Light

When white light passes through a prism it splits up into different component colours. This phenomenon is called dispersion and arises due to the fact that refractive index of prism is different for different wavelengths.So different wavelengths in passing through a prism are deviated through different angles and as $\delta \alpha (\mu - 1)$, violet is deviated most whilered least giving rise to display of colours known as spectrum. The spectrum consistsof visible and invisible regions

In visible spectrum the deviation and the refractive index for the yellow ray are taken as the mean values. If the dispersion ina medium takes place in the order given by " VIBGYOR" it is called normal dispersion. If, however, the dispersiondoes not follow the rule 'VIBGYOR',it is said to be anomalous dispersion.



A medium which brings about dispersion is called dispersive medium. Prism that separate light according to wavelength are known as dispersive prisms. Dispersive prism are mainly used in spectrometers to separate closely adjacent spectral lines. Prisms made of glass are used in the visible region for dispersion. Dispersion can alsooccur in U.V and I.R regions, but materials used for the dispersion are different.

11.2.3 Angular Dispersion

The difference in the angles of deviations of any pair of colours iscalled angular dispersion (θ) for those two colours. Let the refractive indices of violet, red and yellow be indicated by μ_v , μ_R and μ_y.The deviation δ_y corresponding to yellow colour is taken as mean deviation. The deviations δ_v ,δ_R and δ_y can be written as

$\delta_v = (\mu_v - 1)A$ and $\delta_R = (\mu_R - 1)A$ and $\delta_y = (\mu_y - 1)A$.

Angular dispersion for violet and red

$\theta = (\delta_v - \delta_R) = (\mu_v - \mu_R)A$

Thus the angular dispersion depends on the nature of the material of prism and upon the angle of the prism, In general, the angular dispersion refer to angular dispersion of violet and red i.e., the total angle through which the visiblespectrum is spread out.

Dispersive power .

Dispersive power indicates the ability of the material of the prism to disperse the light rays. It is defined as the ratio of the angular dispersion to the mean deviation.

i.e. Dispersive power: $\omega = \frac{\theta}{\delta_y} = \frac{\delta_v - \delta_R}{\delta_y}$

where δ_y = deviation for yellow light.

$$\omega = \frac{\mu_v - \mu_R}{(\mu_y - 1)} = \frac{d\mu}{(\mu - 1)}$$

It is seen that the dispersive power is independent of the angle of prism and angle of incidence, but depends on material of the prism.

The dispersive power is more precisely expressed with reference to C,D and F, Fraunhoffer's lines in the solar spectrum. The C, D and F lines lie in the red, yellow and blue regions of the spectrum and thie wavelengths are 6563Å , 5893 Å and 4861 Å respectively.

$$\omega = \frac{\mu_F - \mu_C}{\mu_D - 1}$$

Note that a single prism produces both deviation and dispersion simultaneously. However, if two prisms (crown and flint)) are combined together, we can get deviation without dispersion or dispersion without deviation. The dispersive power of flint glass prism is greater than that of crown glass prism for same refracting angle, i.e., the angular separation of spectral colours in flint glass is more than that of crown glass. If two prisms of prism angles A and A' and refractive indices μ and μ' are placed together,

Total deviation

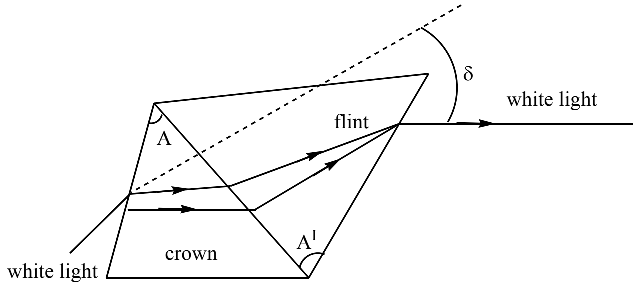
$\delta = \delta_1 + \delta_2 = (\mu_y - 1)A + (\mu'_y - 1)A'$ and

Total dispersion

$\theta = \theta_1 + \theta_2 = (\mu_v - \mu_R)A + (\mu'_v - \mu'_R)A'$.

11.2.4 Deviation without dispersion or a chromatism:

An achromatic prism is a combination of two appropriate prisms so constructed that it shows no colours. Flint glasses have higher dispersive power than crown glass. Hence, it is possible to combine two prisms of different materials and specified angles such that ray of white light may pass through the combination without dispersion, thought may suffer deviation. Such a combination is called achromatic combination.



i.e., $\delta \neq 0$ and $\theta = 0$

$\therefore \quad (\mu_v - \mu_R)A + (\mu'_v - \mu'_R)A' = 0$

$$\frac{(\mu_v - \mu_R)A}{(\mu_y - 1)}(\mu_y - 1) + \frac{(\mu'_v - \mu'_R)A}{(\mu'_y - 1)}(\mu'_y - 1) = 0$$

i.e., $\quad \omega_c\delta_c + \omega_f\delta_f = 0$

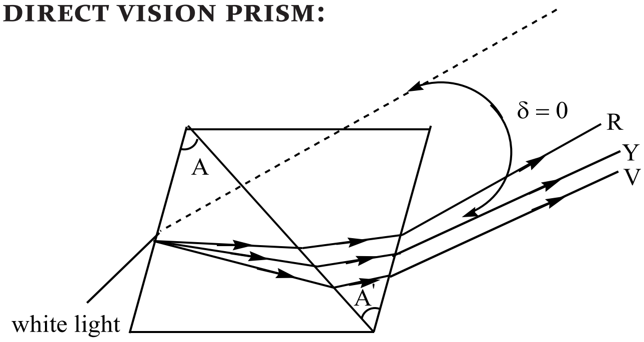
Since the deviation produced by flint prism here is opposite to crown prism, that of the net deviation $\delta = \delta_c + \delta_f$

$$\delta = (\mu_y - 1)A + (\mu'_y - 1)A'$$

$$\delta = \frac{(\mu_y - 1)}{(\mu_v - \mu_R)}(\mu_v - \mu_R)A - \frac{(\mu'_y - 1)}{(\mu'_v - \mu'_R)}(\mu'_v - \mu'_R)A'$$

$$\delta = \frac{\theta_c}{\omega_c} - \frac{\theta_f}{\omega_f}$$

11.2.5 Dipersion – without deviation or direct vision prism:



If the angles of the crown and flint glass prism are so adjusted that the deviation produced for the mean rays by the first prism is equal and opposite to that produced by the second prism, then the final beam will be parallel to the incident beam. Such combination of two prisms will produce dispersion of the incident beam without deviation i.e., $\delta = 0$ and $\theta \neq 0$

$\therefore \quad (\mu_y - 1)A + (\mu'_y - 1)A' = 0$

$$\frac{(\mu_y - 1)}{(\mu_v - \mu_R)}(\mu_v - \mu_R)A + \frac{(\mu'_y - 1)}{(\mu'_v - \mu'_R)}(\mu'_v - \mu'_R)A' = 0$$

i.e., $\quad \frac{\theta_c}{\omega_c} + \frac{\theta_f}{\omega_f} = 0$

Since the deviation produced by flint glass prism here is opposite to that of crown prism, the net angular dispersion $\theta = \theta_c + \theta_f$

$$\theta = (\mu_v - \mu_R)A + (\mu'_v - \mu'_R)A' \quad \text{(or)}$$

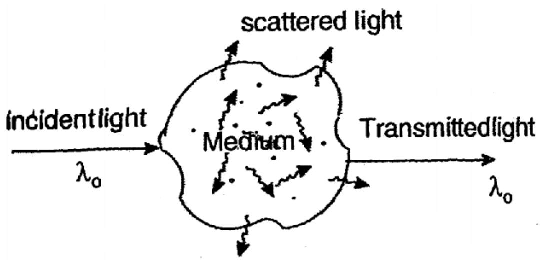
$$\theta = \frac{(\mu_v - \mu_R)A}{(\mu_y - 1)}(\mu_y - 1) - \frac{(\mu'_v - \mu'_R)A}{(\mu'_y - 1)}(\mu'_y - 1)$$

$$\theta = \omega_c\delta_c - \omega_f\delta_f$$

11.3.1 Scattering of Light

If the molecules of a medium after absorbing incoming radiations (light) emit them in all possible directions, this process is called scattering.

In scattering if the wavelength of radiation remain unchanged, the scattering is called elastic, otherwise inelastic.



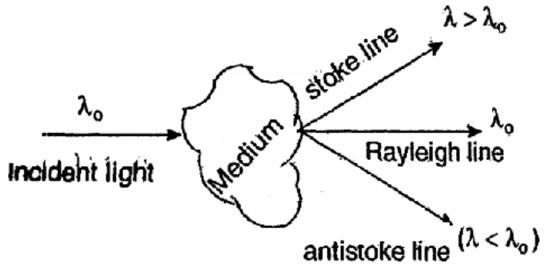
According to Rayleigh, in case of elastic scattering of light by the molecules, the amount of light scattered depends on both nature of molecules and wavelength of light. Light of shorter wavelength is scattered much more than light of longer wavelength.

Intensity of scattered light $\alpha \ \frac{1}{\lambda^4}$

Therefore blue wavelength are scattered most while red least. Rayleight scattering takes place when the size of the scatter (say a), is much less than the wavelength of light (λ). i.e., $a << \lambda$. At large scattering objects (dust or water) all wavelengths are scattered nearly equally.

Regarding scattered light

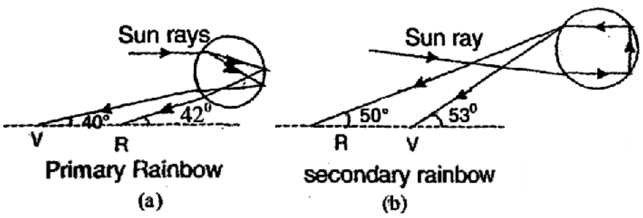
1. Visibility of an object from alll directions is due to scattering light.
2. Scattered light is plane polarized.
3. Under specific conditions, light can also suffer inelastic scattering from molecules (particles like dust and water droplets) in which its wavelength changes. This effect is called Raman – effect.
4. Scattering explains the blue of sky. When white light from the sun enters the erath's atmosphere, scattering takes place and as scattered intensy is proportional to $\left(\frac{1}{\lambda^4}\right)$, blue is scattered most. When we look at the sky we receive scattered light which is rich in blue and the sky, appears blue.
5. At sunset or sunrise, the sun rays have to pass through a large distance in the atmosphere. Most of the blue and other shorter wavelengths are removed by scattering. Tge least scattered light reaching our eyes, therefore, is red. This explains the reddish appearance of the sun and full moon near the horizon.



Inelastic scattering

Ranibow:

Rainbows are formed by dispersion of sun light falling on rain drops. We can observe the rainbow in a direction facing against the sun. Some times two rainbows are seen. The common rainbow known as the primary rainbow is a colourled band, having red on the outside and violet on the inner side. It is formed due to two refractions and one reflection of light falling on the raindrops. The other rainbow called the secondary rainbow is a coloured band, having violet on the outside and red on the inner side. It is formed due to two refractions and two reflections of the sun light falling on the raindrops. It is due to four step process. The intensity of light is reduced at the second reflection and hence the secondary rainbow is fainter than the primary rainbow. The rainbows are visible only when the altitude the sun is less than 42^0. A complete rainbow can be seen in an areaoplane flying at high altitudes.



11.3.2. Tyndal scattering

When light passes through a colloidal solution its path is visible inside the solution. This is because, the light is scattered by the particles of solution. The scattering of light by the colloidal particles is called Tyndal scattering.

Raman effect

In 1928, Sir C.V. Raman discovered experimentally, that the monochromatic light is scattered when it is allowed to pass through a substance. The scattered light contains some additional frequencies other than that of incident frequency. This is known as Raman effect.

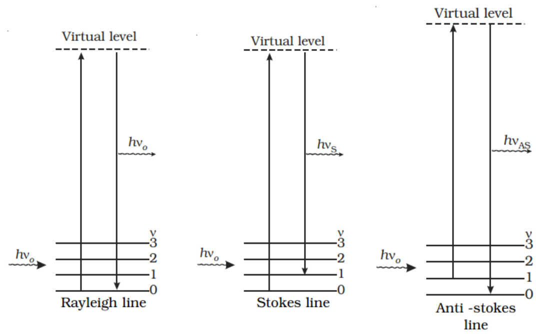
The lines whose frequencies have been modified in Raman effect are called Raman lines. The lines having frequencies lower than the incident frequency are called Stoke's lines and the lines having frequencies higher than the incident frequency are called Anti−stokes lines. This series of lines in the scattering of light by the atoms and molecules is known as Raman Spectrum.

The Raman effect can be easily understood, by considering the scattering of photon of the incident light with the atoms or molecules. Let the incident light consist of photons of energy $h\nu_o$.

1. If a photon strikes an atom or a molecule in a liquid, part of the energy of the incident photon may be used to excite the atom of the liquid and the rest is scattered. The spectral line will have lower frequency and it is called stokes line.
2. If a photon strikes an atom or a molecule in a liquid, which is in an excited state, the scattered photon gains energy. The spectral line will have higher frequency and it is called Anti−stoke's line.
3. In some cases, when a light photon strikes atoms or molecules, photons may be scattered elastically. Then the photons neither gain nor lose energy. The spectral line will have unmodified frequency.

If ν_o is the frequency of incident radiation and νs the frequency of scattered radiation of a given molecular sample, then Raman Shift or Raman frequency Δν is given by the relation $\Delta\nu = \nu_o - \nu_s$.

The Raman shift does not depend upon the frequency of the incident light but it is the characteristic of the substance producing Raman effect. For Stoke's lines, Δν is positive and for Anti–stoke's lines Δν is negative.



(v = 0, 1, 2 .... are the vibration levels of the ground electronic state.)
Raman Spectrum

The intensity of Stoke's line is always greater than the corresponding Anti−stoke's Line. The different processes giving rise to Rayleigh, Stoke's and Anti-stokes lines are shown in Fig.

When a system interacts with a radiation of frequency ν_o, it may make an upward transition to a virtual state. A virtual state is not one of the stationary states of the molecule. Most of the molecules of the system return back to the original state from the virtual state which corresponds to Rayleigh scattering. A small fraction may return to states of higher and lower energy giving rise to Stoke's line and Antistoke's line respectively.

Applications of Raman Spectrum

(i) It is widely used in almost all branches of science.

(ii) Raman Spectra of different substances enable to classify them according to their molecular structure.

(iii) In industry, Raman Spectroscopy is being applied to study the properties of materials.

(iv) It is used to analyse the chemical constitution

11.4.1 Microscopes

A microscope is an optical instrument which forms a magnified image of very small objects held close to the eye.

Very small objects subtend small visual angle at the naked eye due to their smallness. We can increase the visual angle by bringing these objects closer to the eye. But the object cannot be brought closer to D (= 25 cm = least distance of distinct vision) otherwise the image formed will be blurred. However, if we place a suitable converging lens (convex lens) close to the eye, we can move the object closer than D (= 25 cm). The virtual image of the object formed by the lens is far from the eye and thus can be seen comfortably. This virtual image subtends a large visual angle at the eye and hence the tiny object appears large. A microscope is based on this principle. We shall discuss the following two microscopes :

(i) Simple microscope or Magnifying glass

(ii) Compound microscope.

11.4.2 Simple m icroscope or m agnifying glass

A simple microscope consists of a convex lens of small focal length and is used magnified images of the tiny objects placed close to the eye.

With naked eye (i.e. unaided eye), the tiny object subtends a small visual angle at the eye. However, when the tiny object held close to the eye is viewed through a simple microscope, the image of the tiny object subtends a large visual angle at the eye. Therefore, the object looks bigger.

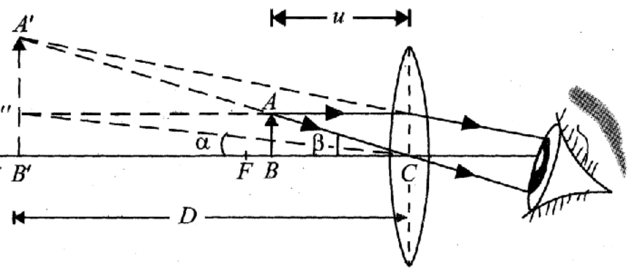
Principle. A simple microscope is based on the fact that when an object is placed between the optical centre and focus (or at the focus) of a convex lens, a magnified, virtual and erect image of the object is formed on the same side of the lens as the object. For this reason, a simple microscope is also called a magnifying glass.

Theory. The tiny object to be seen is placed between the lens and its focus (or at focus) and the eye is placed just behind the lens. Then eye sees a magnified, virtual and erect image of the object. The position of the image depends upon the position of the object relative to that of the lens. We discuss two situations.

(i) When image is formed at the near point. This situation is shown in Fig. The object AB is placed within the focus of the lens. A virtual, erect w.r.t. object and magnified image A'B' is formed behind the object. The lens is adjusted so that the image is at the near point. The image is seen most clearly when it is at the near point. This is the normal use of the microscope.

Magnifying power. The magnifying power (or angular magnification) 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 o f distinct vision from the eye i.e.

β *



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* Note that when object is placed at the near point of the eye, it subtends an angle α at the eye. However when the object is placed inside the near point and viewed through the magnifier, the image subtends a larger angle β at the eye.

where

β = angle subtended at the eye by the image at the near point

α = angle subtended at the unaided eye by the object at the near point

Thus referring to Fig., we have,

$\tan\beta = \frac{A'B'}{D}$ and $\tan\alpha = \frac{A''B'}{D} = \frac{AB}{D}$ Since the angles usually encountred in such situations are small, the tangents can be replaced by the angles themselves.

$$\therefore \quad \beta = \frac{A'B'}{D} \quad \text{and} \quad \alpha = \frac{AB}{D}$$

$$\therefore \quad M = \frac{\beta}{\alpha} = \frac{A'B'}{D} \times \frac{D}{AB} = \frac{A'B'}{AB}$$

Note that in this case, angular magnification is equal to the linear magnification. Now A'B'/AB is the linear magnification produced and is equal to v/u i.e. A'B'/AB = v/u.

$$\therefore \quad M = \frac{A'B'}{AB} = \frac{v}{u}$$

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

Multiplysing both sides by v, we get,

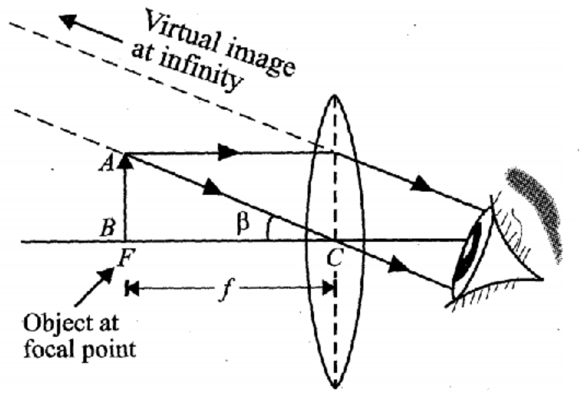
$$\frac{v}{v} - \frac{v}{u} = \frac{v}{f}$$

$$or \quad 1 - M = \frac{v}{f}$$

$$or \quad 1 - M = -\frac{D}{f} \quad (\because v = -D)$$

$$\therefore \quad M = 1 + \frac{D}{f}$$

This is the expression for the magnifying power of a simple microscope when the image is formed at the near point. It is clear that shorter the focal length of the convex lens, the greater is the magnifying power.



(ii) When the image is formed at infinity: This situation is shown in Fig. In this case, the object is placed at the focus of the concex lens.

Magnifying power, $M = \frac{\beta}{\alpha}$

where

β = angle subtended at the eye by the image at infinity

α = angle subtended at the unaided eye by the object when it is placed at the *near point.

Referring to Fig. , $\tan\beta = \frac{AB}{f}$ and $\tan\alpha = \frac{AB}{D}$. Since angles β and α are small, tan β ≃ and tan α ≃ α.

$$\therefore \quad \beta = \frac{AB}{f} \text{ and } \alpha = \frac{AB}{D}$$

$$\therefore \quad M = \frac{\beta}{\alpha} = \frac{AB}{f} \times \frac{D}{AB} = \frac{D}{f}$$

$$or \quad M = \frac{D}{f}$$

This is the expression for the magnifying power of a simple microscope when the image is formed at infinity.

Note that in this case, magnification is only 1 less than the magnification when the image is formed at the near point. But viewing is quite comfortable because the eye is focussed at infinity.

Note. In a microscope, when viewing an object at the near point, the eye is fully accommodated and is, therefore, under most strain. The effects of eye strain over longer periods of viewing can be considerable. Therefore, a person will often view the image at infinity because it is more comfortable.

Uses of magnifying glass

(i) Jewellers and watch makers use the magnifying glass to obtain a magnified view of tiny parts of jewellery and watch parts.

(ii) In science laboratories, a magnifying glass is used for reading vernier scales etc.

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* An object is best seen when it is at the near point. Therefore, in case of microscopes, it is meaningful to specify α as being the angle subtended by the object when it is at the near point.

11.4.3 Compound Microscope

A compound microscope consists of two convex lenses of suitable focal lengths and forms highly magnified images of tiny objects. A good quality compound microscope can produce magnification of the order of 1000.

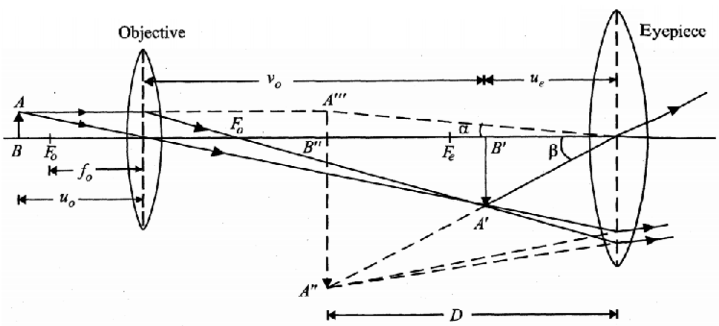
Principle. A compound microscope is based on the principle that a convex lens can form magnified images in the following two ways :

(a) When the object is inside the focal length of a convex lens, a magnified, virtual and erect image of the object is formed as in a simple microscope.

(b) When the object is between the focal length f and 2f from the convex lens, the image formed is magnified, real and inverted.

In a compound microscope, both these effects are used to produce a highly magnified image of a tiny object.

Construction. A compound microscope consists of two convex lenses fitted co-axially at the free ends of a long metallic tube. One convex lens called objective lens O is of small focal length f_0 and small aperture and faces the object to be magnified. The other convex lens called Eyepiece E has moderate focal length f_e and aperture greater than that of the objective lens. The final image is viewed through the eyepiece. The distance between the objective lens and the eyepiece can be adjusted with the help of rack and pinion arrangement.



(i) When final image is formed at near point. The small object AB is placed slightly beyond the focus F_0 of the objective lens as shown in Fig. The objective lens forms a magnified, real and inverted,imageA'B' of the object AB on the other side of the lens.The image A'B' acts as an object for the eyepiece.

The separation between the objective lens and eyepiece is so adjusted that A'B' lies within the focus F_e of the eyepiece (See Fig.). The magnified image A'B' is further magnified by the eyepiece acting as a simple microscope. The adjustments are so made that the final image A"B" is formed at the near point i.e. at the least distance of distinct vision from the eye. Note that the final image A"B" is inverted w.r.t. the object AB.

Magnifying power. The magnifying power of a compound microscope is defined as the ratio of the angle subtended at the eye by the final image to the angle subtended at the eye by the object when both (final image and object) are at the least distance of distinct vision from the eye i.e.

Magnifying power, $M = = \dfrac{\beta}{\alpha}$

where

β = angle subtended at the eye by the final image A"B"

α = angle subtended at the unaided eye by the object AB when it is at the near point

Thus referring to Fig., we have,

$$\tan\beta = \frac{A''B''}{D} \text{ and } \tan\alpha = \frac{A'''B''}{D} = \frac{AB}{D}.$$

Since the angles usually encountered in such situations are small, the tangents can be replaced by the angles themselves.

$$\therefore\ \beta = \frac{A''B''}{D} \text{ and } \alpha = \frac{A'''B''}{D} = \frac{AB}{D}$$

$$\therefore\ M = \frac{\beta}{\alpha} = \frac{A''B''}{D} \times \frac{D}{AB} = \frac{A''B''}{AB}$$

$$\text{or}\quad M = \frac{A''B''}{A'B'} \times \frac{A'B'}{AB}$$

Here A'B' is the height of the intermediate image formed by the objective lens.

$$\therefore\qquad M = M_e \times M_0$$

where

$M_e = \frac{A''B''}{A'B'}$, the magnification produced by the eyepiece.

$M_0 = \frac{A'B'}{AB}$, the magnification produced by the objective lens.

Value of M_e : The focal length of eyepiece is f_e and it forms final image A"B" of the inter mediate image A'B' at the least distance of distinct vision (D).

As the eyepiece act!as a simple microscope,

$$\therefore \quad M_e = 1 + \frac{D}{f_e}$$

Value of M_0. The distance of the object AB from the objective lens is $-u_0$ and the distance of the intermediate image A'B' formed by the objective is v_0 from it.

$$\therefore \quad M_0 = \frac{A'B'}{AB} = \frac{v_0}{-u_0}$$

$$\therefore \quad M = \frac{v_0}{-u_0}\left(1 + \frac{D}{f_e}\right) \qquad ...(i)$$

In this case, the length of microscope, $L = v_0 + u_e$.

Since the focal length of the objective lens is very small, $u_0 \simeq f_0$. Also the focal length f_e is small so that $v_0 \simeq L$ where L is the length of the microscope.

Putting $u_0 = f_0$. and $v_0 = L$ in eq, (i), we have,

$$M = \frac{L}{-f_0}\left(1 + \frac{D}{f_e}\right)$$

Clearly, the magnifying power M of a compound microscope will be large if f_0 (= focal length of objective) and f_e (= focal length of eyepiece) are small. Note that magnification of a compound microscope is negative i.e. final image formed is inverted w.r.t. the object.

(ii) When final image is formed at infinity. When the intermediate image A'B' is ADJUSTED to lie at the focus F_e of the eyepiece, the final image A"B" is formed at infinity.

Now $\qquad M = M_e \times M_0$

As shown above, $M_0 = \frac{v_0}{-u_0}$ or $M_0 = \frac{L}{-f_0}$

When image is formed at infinity,

$Me = \frac{D}{f_e}$ ... as for a simple microscope

$$\therefore \quad M = \frac{v_0}{-u_0} \times \frac{D}{f_e}$$

$$Also \quad M = \frac{L}{-f_0} \times \frac{D}{f_e}$$

In this case, length of microscope = $v_0 + f_e$.

Discussion. The following points are worth noting about a compound microscope :

(a) We take f_0 smaller than f_e so that field of view may be increased.

(b) Since the apertures of both the lenses are small, spherical aberration (i.e. distortion of image) is minimised.

(c) In order to minimise chromatic aberration, both objective lens and eyepiece are formed by a number of lenses.

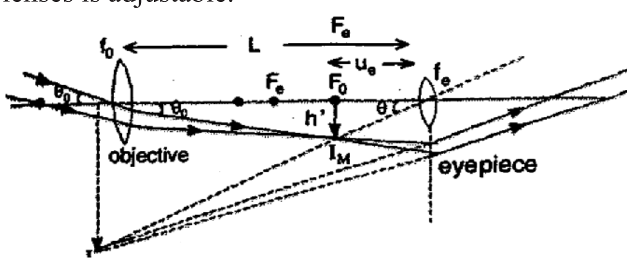
11.4.4 TELESCOPES:

A microscope is used to view the objects placed close to it. To look at distant objects such as a star, a planet or a diff etc, we use another optical instrum ent called telescope, which increases the visual angle of distant object. The telescope that uses a lens as an objective is called refracting telescope. However, many telescopes use a curved mifror as an objective; such telescopes are known as reflecting telescopes. There are three types of refracting telescopes in use.

(i) Astronomical telescope
(ii) Terrestrial telescope ?
(iii) Galilean telescope

ASTRONOM ICAL TELESCOPE

Fig. shows the construction and working of an astronomical telescope. It consists of two converging lenses. The one facing the object is called objective or field lens and has larger focal length and aperture while the other facing eye called eyepiece or ocular has small focal length and aperture. The distance between the two lenses is adjustable.



When the object is between infinity and $2F_o$ of objective and hence image (I_M) formed by objective is real, invited and diminished and is between F_o and $2F_o$ on the other side of it This image(I_M) acts as an eyepiece and it is within the focus F_e. So final image (I) with respect to I_M is erect, virtual, enlarged and at a distance D to infinity from theeye. This in turn implies that final image (I) with respect to object is inverted.

As per definition of magnifying power of telescope, from figure.

$$M = \frac{\theta}{\theta_0} = \frac{(h'/u_e)}{(h'/f_0)} = -\frac{f_0}{u_e},$$

with length of tube $L = f_0 + u_e$

Here the angles θ_0 and θ are formed on j opposite sides of the axis. Hence their signs are opposite and θ_0/θ is negative Now there are two possibilities.

(i) If the image is at infinity (far point):

Here $u_e = f_e$

Hence $M_\infty = -\frac{f_0}{f_e}$ and $L_\infty = f_0 + f_e$

Usually a telescope is operated in this mode unless stated other wise. In this mode u_e is maximum, hence magnifying power is minimum, while length of tube is maximum.

(ii) If the image is at D (Near Point):

In this situation for eyepiece $v_e = -D$

$$\frac{1}{-D} - \frac{1}{-u_e} = \frac{1}{f_e} \text{ i.e., } \frac{1}{u_e} = \frac{1}{f_e}\left[1 + \frac{f_e}{D}\right]$$

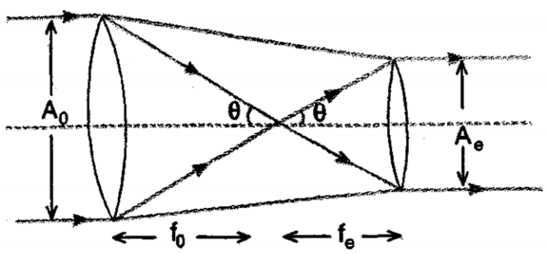
$$M_D = \frac{-f_0}{f_e}\left[1 + \frac{f_e}{D}\right] \text{ with } L_D = f_0 + \frac{f_e D}{f_e + D}$$

In this situation u_e is minimum , hence magnifying power is maximum while the length of the tube is minimum and eye is most strained.

Note that (i) In case of telescope, if object and final image are at infinity and total light entering the telescope leaves it parallel to its axis as shown.

$$\text{Magnifying power} = \frac{f_0}{f_e} = \frac{A_0}{A_e}$$

Where A_0 and A_e are the apertures of objective and eyepiece.



(ii) As magnifying power is negative, the image seen in astronomical telescope is truly inverted i.e., left is turned right with upside down simultaneously. However as most of theastronomical objects are symmetrical, this
inversion does not effect the observations.

(iii) In a telescope, if field and eye lens are interchanged, magnifying power will change from $\frac{f_0}{f_e}$ to $\frac{f_e}{f_0}$

(iv) Larger aperture of objective helps in improving the brightness of image by gathering more light from the distant object. However it increases aberrations, particularly spherical.

COMPARISION BETWEEN MICROSCOPE AND TELESCOPE:

S.No	Microscope	Telescope
1.	It is used to see very small objects.	It is used to see distant objects
2.	Its objective is of small focal length and of small aperture	Its objective is of large focal length and of large aperture
3.	It produces linear magnification and size of the image is lager than that of the object.	It produces angular magnification and the image is near to the eye, but the size does not increase.

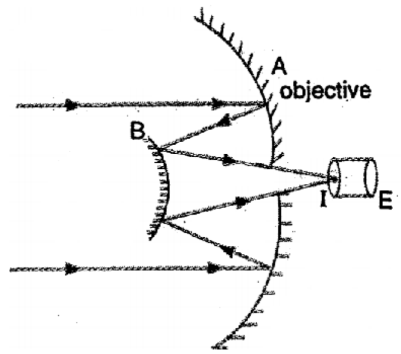
S.No	Compound microscope	Astronomical telescope
1.	It is used to increase visual angle of nearby tiny objects.	It is used to increase visual angle of distant larg objects
2.	Both lens are convergent, of shorter focal length and aperture.	Both lens are convergent, field lens is of large focal length and aperture, while eye lens o f short focal length and aperture.
3.	Final image is inverted, virtual and enlarged at a distance D to infinity from the eye.	Same as microscope
4.	Magnifying power does not change varies appreciably if field and eye lens are interchanged.	Magnifying power becomes tim es its initial $1/m^2$ value if the field and eye lens are interchanged.
5.	Magnifying power is increased by decreasing the focal length of both the lenses.	Magnifying power is increased by increasing the focal length of field lens and by decreasing the focal length of eye piece.

Reflecting telescope

The telescope in which the objective is a curved mirror is called reflecting telescope. In large telescopes this has many advantages. To get fine image the objective of the telescope should have a large aperture. But objective of very large aperture cannot be manufactured, therefore in very large telescopes the objective is a paraboloidal or spherical mirror instead of converging lens. Mirrors are inherently free from chromatic and spherical aberration. Mirror weighs much less than lens of equivalent optical quality. So mechanical support is much less problem. The objective mirror focuses light into the telescope tube. So the eye piece and observer must be there obstructing some light. This is rectified in Cassegrain's telescope.

11.4.5 Cassegrain's telescope

It has a large spherical mirror A, having an aperture in the centre as shown in Fig The rays from the distant star after reflection from the mirror 'A' fall on the convex mirror B and are allowed to converge at I. The final image can be viewed through the eye. piece (E). The main advantage is it has a large focal length in a short telescope.



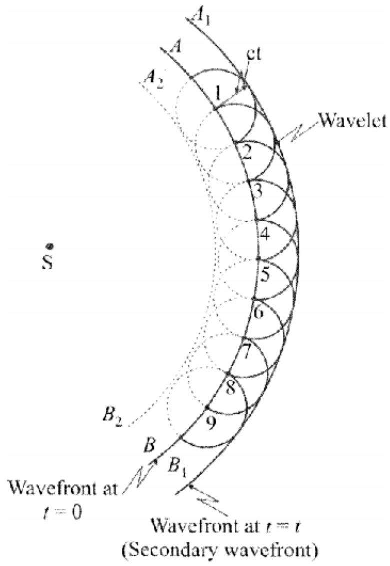
There are many points in favour of reflecting telescopes:

1. There is no absorption of light as in lenses.
2. The m irrors are free from chrom atic aberration.
3. In the case of paraboloidal mirror, there is no spherical aberration for beams parallel to the axis.
4. Mirrors can be constructed with considerably large diameters than lenses.
5. Mirrors can be easily mounted whereas lenses can be mounted only on the edges or rim

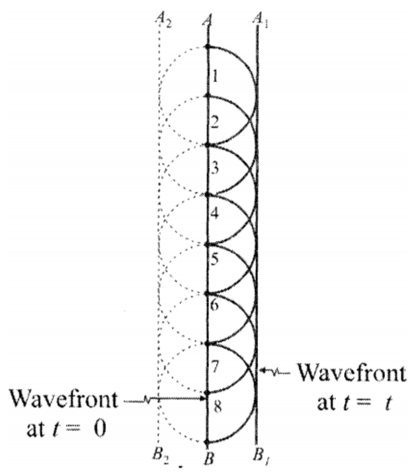
Wave Optics: An Introduction:

In geometrical optics, we have represented light as rays which travel in straight lines in a homogeneous medium. By doing this, we have studied a variety of phenomenon involving mirrors and lenses. The phenomenon like interference and diffraction can not be explained on the bases of particle nature of light. These phenomenon can only be explained on the basis of wave nature of light. This part of optics is called physical optics.

The wave theory of light was presented by Christiaan Huygens in 1678. During that period Newton's corpuscular theory had satisfactorily explained the phenomenon of reflection, refraction and rectilinear propagation of light. So scientist believed in the corpuscular theory; no one really believed in Huygen's wave theory. The wave characteristics of light was not really accepted until the interference experiments of Young in 1801. It should be pointed out that Huygens did not know whether the light waves were longitudinal or transverse and also how they propagate through vacuum. It was then explained by Maxwell by introducing electromagnetic wave theory in nineteenth century.



(a) Spherical wavefront.



(b) Plane wavefront.

11.5.1 Huygens' principle

Huygens principle provides a geometrical method which allows us to determine the shape of the wavefront at any time, if the shape of the wavefront at an earlier time is known. A wave front is the locus of the points which are in the same phase. Huygens' principle can be stated as follows :

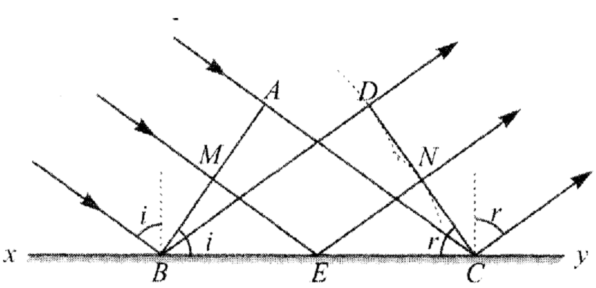
(i) Each point of a given wavefront is a source of new disturbance which is called secondary disturbance. The wavelets originated from these points spread out in all directions with the speed of light.

(ii) The envelope of these wavelets in the forward direction gives the shape and position of the new wavefront at any subsequent time.

To understand this consider a spherical wave front AB as shown in figure. Every point such as 1, 2, . etc. on AB becomes the source of secondary spherical wavelets. After time t the radius of each wavelet will be ct, where c is the speed of the light. Thus from the points 1, 2, 3,.... etc draw spheres of radii equal to ct. These spheres represent the secondary wavelets. According to Huygens the common envelope A ^ in forward direction gives the position of new wavefront (see.Fig.).

Proof of law of reflection

Let xy be a reflecting surface. AMB is a plane wavefront incident at an angle i. All the particles on AB vibrate in same phase.



In the time the disturbance at A reaches C, the secondary waves from B will travel a distance BD such that BD -A C . With the point B as centre and radius equal to AC draw an arc. From the point C, draw the tangent CD.

In triangles BAC and BDC; BC is common and BD = AC

$\angle BAC = \angle BDC = 90°$

∴ The two triangles are congruent, and so

$\angle ABC = \angle BDC$

or i = r.

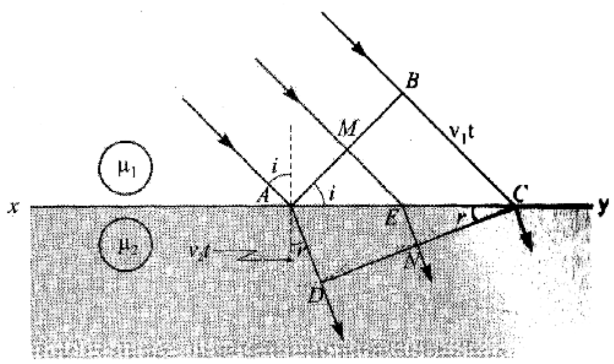
Thus angle of incidence is equal to angle of reflection. This proves the law of reflection.

Proof of law of refraction

Let xy is the interface between two media 1 and 2 of refractive indexes μ_1 and μ_2 respectively. Suppose v_1 and v_2 are the velocities of light in two media. The second medium is optically denser than first and so $v_2 < v_1$. AMB is the plane wavefront incident at an angle i. In the time disturbance at B reaches C, the secondary waves fromA will travel a distance AD = v_2t, where t is the time taken by the waves to travel the distance BC.

Thus $BC = v_1t$

and $AD = v_2t$.



With A as the centre and radius AD draw an arc. Then draw a tangent CD to the arc. CD represents the refracted wavefront, r be the angle of refraction. We have

$$\frac{BC}{AD} = \frac{v_1 t}{v_2 t} = \frac{v_1}{v_2} \qquad ....(i)$$

In triangles ABC and ACD, we have

$$\frac{\sin i}{\sin r} = \frac{BC/AC}{AD/AC} = \frac{BC}{AD} \qquad ....(ii)$$

From equations (i) and (ii), we have

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$

Since $\frac{v_1}{v_2} = \frac{\mu_2}{\mu_1}$

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$$

or $\mu_1 \sin i = \mu_1 \sin r$

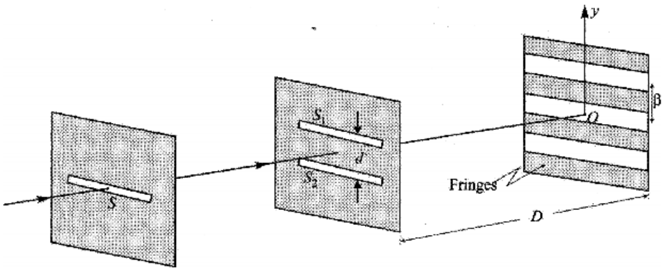
This proves the law of refraction, which is called Snell's law.

11.5.2 INTERFERENCE:

When two or more coherent waves superimpose, the resultant intensity in the region of superposition is different from the intensity of individual waves. This modification in the distribution of intensity in the region of superposition is called interference.

Young's double slit experiment (YDSE)

Thomas Young in 1801 devised an ingenious method of producing coherent sources. In this method a single wavefront is divided into two; these two split wavefronts act as if they originated from two sources having a constant phase relationship and therefore, when they were allowed to interfere, a stationary interference pattern was obtained. In the experiment light from a source S fell on a cardboard which contained two pinholes (or slits) S_1 and S_2 which were very close to one another. The spherical waves originating from S_1 and S_2 were coherent and so beautiful interference fringes or bands were obtained on the screen.



Coherent sources

Two sources of light are said to be coherent if they emit light waves of same frequency and having constant phase difference (may be zero). It means the two sources must emit waves of the same wavelength. In practice it is not possible to have two independent sources which are coherent and so for practical purposes, two virtual sources formed from a single source can act as coherent sources. Young's double slits arrangement, Fresnel's biprism method, Llyod's mirror arrangement are the methods of producing two coherent sources from a single source.

NOTE:

1. Two independent laser sources o f equal wavelengths can be coherent Because they can maintained the constant phase difference for long time.
2. Two ordinary sources can not maintain the constant phase difference so they can not be coherent and hence w ill not interfere.

Analytical treatment of interference

Consider a monochromatic source of light S emitting light waves of wavelength λ and two narrow slits S_1 and S_2. S_1 and S_2 are separated a distance d and equidistance from S. S_1 and S_2 then becomes two virtual coherent sources of light waves. Let ϕ is the phase difference between the two waves reaching at point P. The equation of wave for any fixed position (say screen at x = 0) can be written as :$y = a \sin(\omega t - kx)$, where x = 0 and so, we get $y = a \sin \omega t$. Thus for two coherent waves, we can write

$$y_1 = a_1 \sin \omega t$$

and $$y_2 = a_2 \sin(\omega t + \phi)$$

By principle of superposition, we have

$$y = y_1 + y_2$$
$$= a_1 \sin \omega t + a_2 \sin(\omega t + \phi)$$
$$= a_1 \sin \omega t + a_2 [\sin \omega t \cos \phi + \cos \omega t \sin \phi]$$
$$= (a_1 + a_2 \cos \phi) \sin \omega t + a_2 \sin \phi \cos \omega t]$$

Substituting $a_1 + a_2 \cos \phi = R \cos \theta$ ...(i)

and $a_2 \sin \phi = R \sin \theta$. we get ...(ii)

$$y = R \cos\theta \sin \omega t + R \sin \theta \cos \omega t$$

or $$Y = R \sin(\omega t + \theta) \quad ...(1)$$

This shows that the resultant wave at any point P is simple harmonic of amplitude R. The amplitude R can be obtained as : Squaring equations (i) and (ii), we have

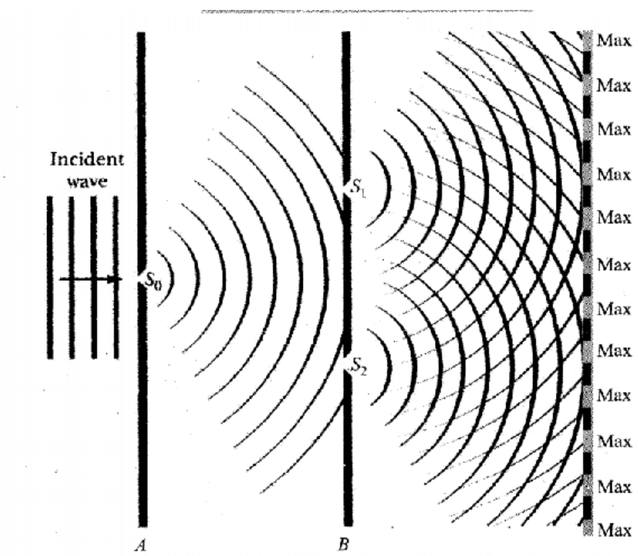
$$R^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos \phi \quad ....(2)$$

As intensity I of wave is proportional to square of the amplitude, and so

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \phi \quad ...(3)$$

Also dividing equation (ii) by (i), we get

$$\tan \theta = \frac{a_2 \sin \phi}{a_1 + a_2 \cos \phi} \quad ...(4)$$



In Young's interference experiment, incident monochro matic light is diffracted by slit S_0, which then acts as a point source of light that emits semicircular wavefronts. As that light reaches screen B, it is diffracted by slits S_1 and S_2, which then act as two point sources of light. The light waves traveling from slits

S_1 and S_2, overlap and undergo interference, forming an interference pattern of maximam and minimam on viewing screen C.

Depending on the phase difference ϕ between the two waves, the intensity of resulting wave may be minimum or maximum. Accordingly there are two types of interference.

These are:

(i) Constructive interference (bright point)

The intensity I will be maximum, when

$$\cos \phi = +1,$$

or $\phi = 2\pi n$, n =0,1,2,.,

As path difference $\Delta x = \frac{\lambda}{2\pi}\phi$

$\therefore$ $\Delta x = n\lambda$

Now $I_{max} = R^2_{max} = a_1^2 + a_2^2 + 2a_1a_2$

or $I_{max} = R^2_{max} = (a_1 + a_2)^2$ ...(5)

(ii) Destructive interference (dark point)

The intensity I will be minimum, when

$$\cos \phi = -1$$

$\phi = (2n - 1)\pi$, n = 1,2,3,....

Also $\Delta x = (2n - 1)\frac{\lambda}{2}$

Now $I_{min} = R^2_{min} = a_1^2 + a_2^2 - 2a_1a_2$

or $I_{max} = R^2_{max} = (a_1 - a_2)^2$ ...(6)

Thus

$$\frac{I_{max}}{I_{min}} = \frac{R^2_{max}}{R^2_{min}} = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2} \quad ...(7)$$

Special cases : When two identical waves interfere,

$$a_1 - a_2 = a$$

$\therefore$ $I_{max} = 4a^2$ and $I_{min} = 0$

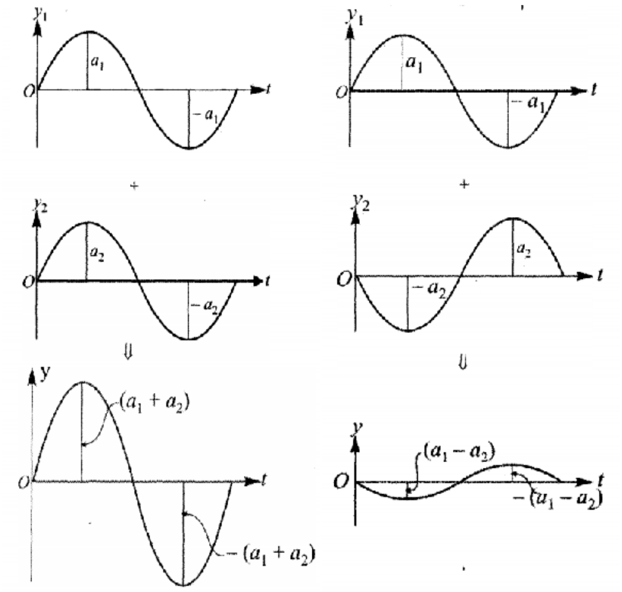
Also $I = a_2 + a_2 + 2aa\cos\phi$

$= 2a^2(1 + \cos\phi)$

$= 2a^2 \times 2\cos^2\frac{\phi}{2}$

$= 4a^2\cos^2\frac{\phi}{2}$

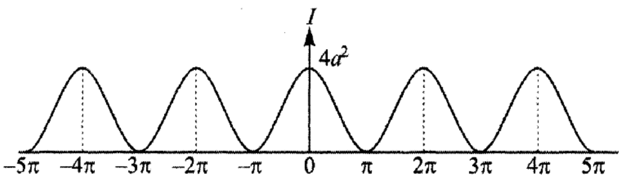
or $I = I_{max}\cos^2\frac{\phi}{2}$ ...(8)



Interference between two waves with $\phi = 0$. Interference between two waves with $\phi = \pi$.

Intensity distribution

It has been obtained that intensity at bright points is $4a^2$ and at dark points is zero. According to law of conservation of energy, the energy of the intefering waves as a whole remains constant. Thus the energy from points of minimum intensity transfers to the points of maximum intensity. The intensity variation with phase difference is shown in fig.

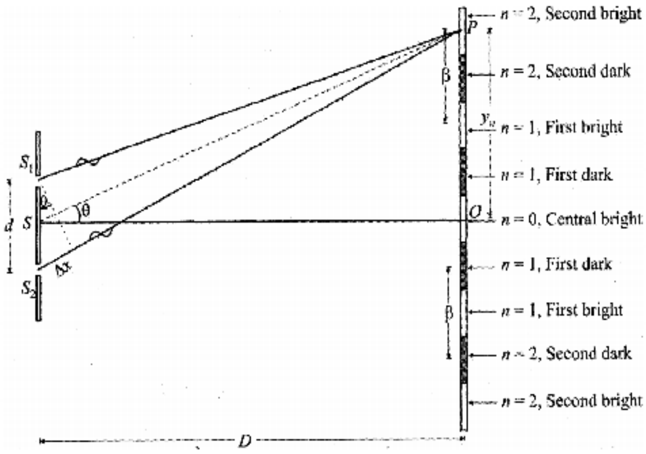


Variation of I with ϕ.

FRINGE WIDTH

Consider two sources S_1 and S_2 emitting monochromatic light of wavelength λ. The separation between them is d. The interference fringes are obtained on a screen placed at a distance D from the sources. The fringes are of equal width and alternatively bright and dark. The centre to centre distance between two consecutive bright or dark fringes is called fringe width β.

Consider a point P on the screen at a distance yn from the centre of the screen O. The angular position of the point P is 0 from the centre of the sources (see fig.).



The path difference between the waves on arriving at point P, is $S_2P - S_1P$ which is equal to Δx. From the figure Δx = d sin θ. For small θ, we can write sin θ $\simeq$ tan θ. Thus

$$\Delta x \simeq d \tan\theta.$$

From the triangle SOP, $\tan\theta = \frac{y_n}{D}$

$$\therefore \qquad \Delta x = \frac{dy_n}{D} \qquad \text{...(i)}$$

Bright fringes

There will be bright fringe at P, when Δx = nλ. Thus path difference

$$\frac{dy_n}{D} = n\lambda$$

or $$y_n = \frac{nD\lambda}{d}; \qquad n = 0, 1, 2...... \qquad \text{...(9)}$$

Equation (9) represents the position of n^{th} bright fringe. The $(n-1)^{th}$ fringe will be at a distance

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

∴ Fringe width $\beta = y_n - y_{n-1}$

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

or $$\beta = \frac{D\lambda}{d} \qquad \text{...(10)}$$

(ii) Dark fringes

There will be dark fringe at P, when

$\Delta x = (2n-1)\frac{\lambda}{2}$.Thus

$$\frac{dy_n}{D} = (2n-1)\frac{\lambda}{2} \qquad \text{...(i)}$$

or $$y_n = \frac{(2n-1)}{2}\frac{D\lambda}{d} \qquad n = 1,2,..... \qquad \text{...(11)}$$

Equation (11) represents the position of nth dark fringe. The $(n-1)^{th}$ fringe will be at a distance

$$y_{n-1} = \left[\frac{2(n-1)-1}{2}\right]\frac{D\lambda}{d}$$

∴ Fringe width $\beta = y_n - y_{n-1}$

$$= \left[\frac{2n-1}{2}\right]\frac{D\lambda}{d} - \left[\frac{2(n-1)-1}{2}\right]\frac{D\lambda}{d}$$

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

It shows that the fringe width is equal for bright and dark fringe.

NOTE:

The maximum path difference $\Delta x_{max} = d$, when sinθ = 1. If n are the number of brights fringes on one side of the central bright, then d = nλ or n = d/λ. Thus total number of fringes that can be on the screen are = 2n + 1, including central central fringe.

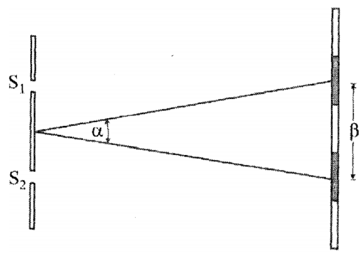
Angular fringe width

Sometime it is required to represent fringe width in terms of angle subtended at the centre of the sources. If a is the angular fringe width, then

$$\alpha = \beta/D$$

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

or $$\alpha = \frac{\lambda}{d} \text{ radian.}$$



Special case : I[illegible] and observer is in air, then fringe width

$$\beta_{water} = \frac{D\lambda_{water}}{d}$$

As $$\lambda_{water} = \frac{\lambda_{air}}{\mu_\omega}$$

$$\therefore \qquad \beta_{water} = \frac{1}{\mu_\omega}\left[\frac{D\lambda_{air}}{d}\right] = \frac{\beta_{air}}{\mu_\omega}$$

Important points :

1. In YDSE, the central fringe is bright, and all the bright fringes are of same intensity. Colour of bright fringes are of the colour of incident light.

2. If slits are of equal size, the intensity of all the dark firings are zero.

3. If slits are of unequal size, then the intensity of dark fringe is not zero.

4. All the fringes are of equal width.

5. If sources have random phase difference, then there will be no interference. The intensity at any point will be

$$I = a^2 + a^2 = 2a^2.$$

6. If white light is used in the experiment, then the central fringe will be white, and other fringes are overlapped colour fringes.

Condition of obserable interference

1. The sources must be coherent.

2. The separation between the slits should be small (order of mm), so that size of fringe is large enough to observe.

3. The amplitudes of interfering waves are equal or nearly equal, otherwise the intensities of bright and dark fringes are not differentiable.

Displacement of fringes

Suppose a transparent sheet of thickness t and refractive index μ is introduced infront of one of the slits of YDSE. The optical path of the light waves emerging from slit will increase by an amount (μ – l)t. In the arrangement shown the optical path of S_1P becomes $S_1P + (\mu - l)t$. Thus path difference between waves at P

$$\Delta x = S_2P - [S_1P + (\mu - l)t]$$
$$= (S_2P - S_1P) - (\mu - l)t$$

From the geometry of the figure

$$S_2P - S_1P = d\sin\theta$$

For small angle θ, $\sin\theta \simeq \tan\theta = \frac{y_n}{D}$

$$\therefore \quad \Delta x = \frac{dy_n}{D} - (\mu - l)t$$

For bright fringes the path difference λx = nλ. Thus

$$\frac{dy_n}{D} - (\mu - l)t = n\lambda \qquad n = 0, 1, 2.......$$

or

$$y_n = \frac{nD\lambda}{d} + \frac{D(\mu - 1)t}{d} \qquad ....(1)$$

In the absence of the sheet, the position of n^{th} bright, $y_n = n\frac{D\lambda}{d}$. Thus displacement of fringes

$$\Delta = \frac{D(\mu - 1)t}{d} \qquad (2)$$

The position of $(n-1)^{th}$ order bright fringe

$$y_{n-1} = \frac{(n-1)D\lambda}{d} + \frac{D(\mu - 1)t}{d}$$

The fringe width

$$\beta = y_n - y_{n-1}$$

or

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

This shows that when a transparent sheet is introduced in the path of the slit, the entire fringe pattern will shift towards that side but fringe width remains same.

The number of fringe shifted

$$N = \frac{\Delta}{\beta} = \frac{D(\mu - 1)t/d}{\left(\frac{D\lambda}{d}\right)}$$

or

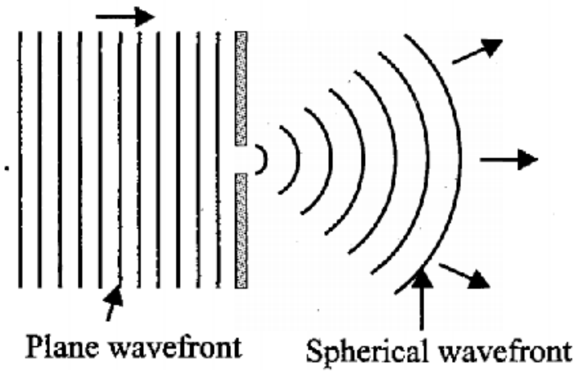
$$N = \frac{(\mu - 1)t}{\lambda}$$

11.5.3 Differaction of light

The phenomenon of bending o f light around the corners of an obstacle or aperture is called diffraction of light.

Due to bending of light around the comers of an obstacle or aperture, the light deviates from Its straight line path and enters into the geometrical shadow of the obstacle. The bending or diffraction of light becomes much more pronounced when the size of the obstacle or aperture is comparable to the wavelength of light ($\simeq 10^{-6}$ m). Thus the smaller the size of the obstacle or aperture, the greater is the bending of light around the corners of the obstacle or aperture and vice-versa.

Fig. shows the diffraction of light at a small aperture. A plane wavefront is advancing towards a small aperture. When the wavefront reaches the aperture, a major part of it is blocked and only a small portion of it passes through the



aperture. According to Huygens' principle, the aperture acts as a new source of secondary wavelets. Therefore, spherical wavefront emerges from the aperture and advances with the same speed as the speed of the plane wavefront approaching the aperture. Since wavefront is always pcipedicular to the direction of propagation of the wave, it is clear from Fig. that waves emerging from the aperture move not only straight but also bend. This is the diffraction of waves.

If a screen is placed behind the aperture, then we can obtain the intensity distribution of light emerging from the aperture on the screen. This is called diffraction pattern of the aperture.

Discussion. The following points are worth noting about diffraction of light :

(i) Diffraction of light is not easily noticed because the obstacles and apertures of the size of wavelength of light ($\simeq 10^{-6}$m) are hardly available.

(ii) In ray optics, we ignore diffraction and assume that light travels in straight lines. This assumption is reasonable because under ordinary conditions, diffraction (bending) of light is negligible.

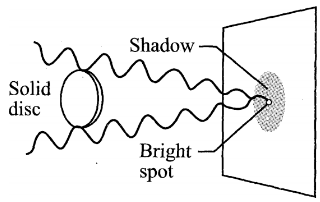
(iii) The smaller the size of the obstacle or aperture, the greater is the bending (or diffraction) of light around the corners of the obstacle or aperture and vice-versa.

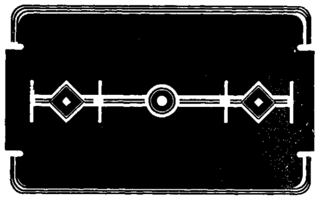
EXAMPLES OF DIFFRACTION OF LIGHT

We now give some common examples of diffraction of light.

(i) At the time of total solar eclipse, "shadow bands" are seen on the earth due to diffraction of sunlight.

(ii) Diffraction patterns are also observed surrounding the shadows of various opaque objects.For example, Fig. shows the shadow of diffraction pattern of a disc. The pattern shows a bright spot at the centre. There are also bright and dark circular fringes beyond the shadow . The bright spot at the centre of shadow is due to constmctive interference at this point.





(iii) Fig. shows the shadow produced when a razor blade is illuminated by a monochromatic point source. Some light is bent inside the geometrical shadow; the region that would be totally dark in the absence of any bending. Near the edges of the shadow, a diffraction pattern of alternate bright and dark bands appears.

(iv) It is due to the diffraction of light that the images of stars in a telescope do not appear as sharp points but appear as diffused spots.

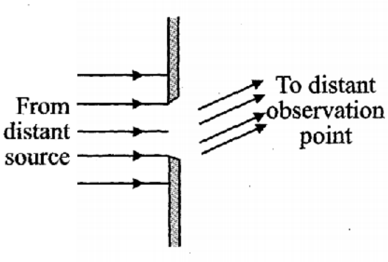
TYPES OF DIFFRACTION

The diffraction phenomenon is generally divided into the following two classes :

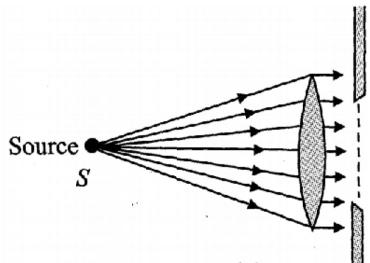
(i) Fraunhofer's diffraction (ii) Fresnel's diffraction.

These types are named after the scientists who first explained them.

(i) Fraunhofer's diffraction. This type of diffraction takes place at a narrow slit when parallel rays of light (i.e. plane wavefronts) are incident on it as shown in Fig. (i). Clearly, both the source and the screen should be at infinite distance from the narrow slit.

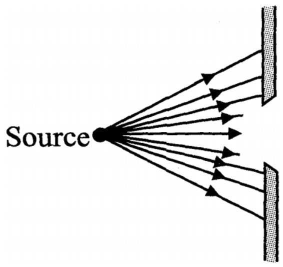


(i)



(ii)

To obtain Fraunhofer's diffraction in the laboratory, we use a converging lens (convex lens) as shown in Fig. (ii). The point source S is placed at the focus of the convex lens. After refraction through the lens, the parallel rays of light are incident on the slit.



(ii) Fresnel's diffraction. This type of diffraction takes place at a narrow slit when non–parallel rays of light are incident on it as shown in Fig. In this case, the source of light is close to the slit so that the wavefront is either spherical (in case of a point source) cylindrical (in case of a linear source). The screen is also at a finite distance from the slit. Fresnel's diffraction is rather complex to treat quantitatively. Therefore, we shall restrict our discussion to Fraunhofer's diffraction.

Diffraction of light at a single slit

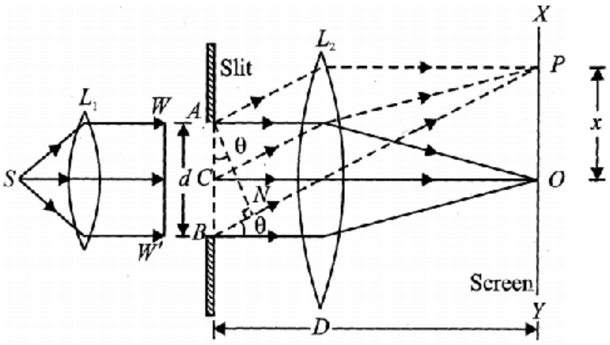
Fresnel gave the exact explanation for the phenomenon of diffraction of light. According to Fresnel, the diffraction occurs due to the interference of secondary wavelets from the portions of the wavefront not blocked by the obstacle or from the portions of the wavefront which are allowed to pass through the aperture.

Fig. shows the geometrical arrangement to study the diffraction of light at a single slit. A source S of monochromatic light of wavelength λ, is placed at the focus of a convex lens L_1. A parallel beam of light and hence a plane wavefront WW' emerging from the lens is incident on the slit AB of width d. The diffracted light is focussed by a convex lens L_2 on a screen XY placed at h distance D from the slit.

Each portion of the slit acts as a source of secondary wavelets. Therefore, light from one portion of the slit can interfere with light from another portion and the resultant intensity on the screen will depend upon whether interference is constructive or destructive. It is found that diffraction pattern on the screen consists of central bright band (called central maximum) having alternate dark and weak bright bands of decreasing intensity on both sides of central maximum as shown in Fig. The central bright band is considerably wider than the slit. Calculations show that most of the light incident on the slit is diffracted into the central maximum.

Theory. Each point on the plane wavefront AB (slit) acts as a coherent source. Therefore, the coherent sources on the wavefront AB send out secondary wavelets in all directions. The diffraction pattern on the screen is formed due to the superposition of these secondary wavelets.

Central maximum. Consider a point O on the screen which lies on the perpendicular bisector of the slit as shown in Fig. The wavelets which fall on the lens L_2 parallel to CO (i.e. 0 = 0°) meet at point O in phase..



It is because these waves are in phase with each other as they leave AB and their optical paths between the slit and point O are also equal. Thus all the waves arriving in phase at O give rise to central maximum i.e. central bright fringe is obtained at O.

Calculation of path difference. Suppose the secondary wavelets diffracted at an angle θ with CO are focussed at point P above O. These wavelets start from different parts of the slit AB in the same phase but they reach point P in different phases. Draw AN perpendicular from A on the ray from B. Then path difference between the secondary wavelets reaching P from A and B is BN i .e.,

Path difference = BN = AB sin θ = d sinθ

(∴ AB = d)

(i) Positions of secondary minima. If this path difference BN is λ (wavelength of light used), then point P will have minimum intensity i.e. P is a point of first secondary minima. This can be easily proved. The slit can be considered to be divided into two equal halves AC and CB.If the path difference between the secondary wavelets from A and B is λ, then path difference between secondary wavelets from A and C reaching P is λ/2 (i.e. a phase difference of 180^0) Similarly, the path difference between the wavelets from C and B reaching P is also λ/2. This is also true for any point in the upper half AC and the corresponding point in the lower half BC. Therefore, secondary waves from the upper half of the slit interfere destructively with secondly waves from the lower half of the slit. Hence P is a point of first secondary minimum.

Similarly, if the path difference BN = 2λ, the point P will be the position of second secondary minimum. Hence the various secondary minima are formed at positions given by ;

$$d \sin\theta_n = \pm n \lambda$$

Here n = 1, 2, 3 .. .an integer but not n = 0 where there is central maximum. The ± sign means that the secondary minima are formed on both sides of the central maximum.

(ii) Positions of secondary maxima. If the path difference BN = 3λ/2, then point P_1(say) will have maximum intensity i.e. P_1 is a point of first secondary maxima.

∴ BN = d sin θ' = 3λ/2 ...first secondary maxima

The reason is simple. We can divide the slit into three equal parts. The path difference between the corresponding points of the first two parts will be λ/2 (i.e. a phase difference of 180^0). Therefore, they will give rise to destructive interference. However, the wavelets from the third unused part will reinforce to produce weak first secondary maxima.

Similarly, the second secondary maxima is located on the screen when the path difference is 5λ/2

In general, the positions of the various secondary maxima are given by;

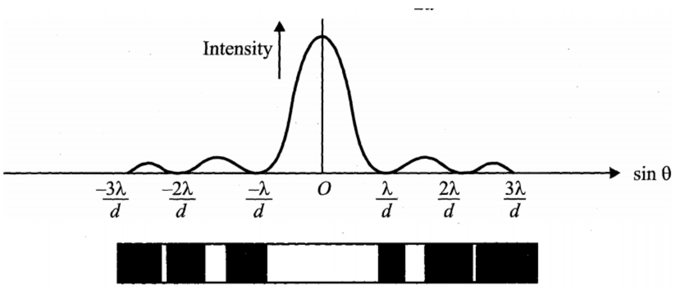
$d \sin \theta'_n = \pm (2n + 1) \lambda/2$...where n = 1, 2, 3.... an integer

The ± sign means that the secondary maxima are formed on both sides of the central maximum.

Intensity distribution curve. Fig. shows the intensity of diffraction pattern of a single slit function of sinθ. The diffraction pattern consists of central bright maximum along with secondary minima and maxima on either side of the central maximum.

Positions of secondary minima : $\sin\theta_n = \pm \frac{n\lambda}{d}$ where n = 1, 2, 3.....

Positions of secondary maxima : $\sin\theta' = \pm (2n+1)\frac{\lambda}{2d}$ where n = 1, 2, 3.....



The following points may be noted :

(a) The angular positions of the various secondary minima are :

$\sin\theta_n = \pm\frac{\lambda}{d}, \pm\frac{2\lambda}{d}, \pm\frac{3\lambda}{d}$.....

The angular positions of the various secondary maxima are :

$\sin\theta'_n = \pm\frac{3\lambda}{2d}, \pm\frac{5\lambda}{2d}$......

(b) The secondary maxima lie mid-way between the secondary minima.

(c) The intensity of secondary maxima decreases with distance from the centre O.

(d) The width of the central maximum is twice that of each secondary maximum.

(e) Calculations show that intensity at the first secondary maximum is less than 5% of the intensity at O, the middle of the central maximum. Thus, most of the light incident on the slit is diffracted into the central maximum.

White light diffraction pattern. We have seen above the diffraction pattern at single slit due to monochromatic light. However, when the slit is illuminated by white light, the diffraction pattern is coloured. The central maximum is white with few coloured bands on either side.

LINEAR WIDTH OF CENTRAL MAXIMUM

The linear width of the central maximum is the distance between the first secondary minimum on the two sides of the centre O of the central maximum.

In Fig., the distance between the first secondary minimum and centre 0 of the central maximum is x.

∴ Linear width of central maximum = 2x

Now the first secondary minimum occurs at

$\sin\theta = \lambda/d$ ...(i)

[∵ $d \sin\theta_n = n\lambda$, Here n = 1]

If f is the focal length of lens L_2 (Refer back to Fig.) which is held very close to the then f = D= distance of the slit from the screen.

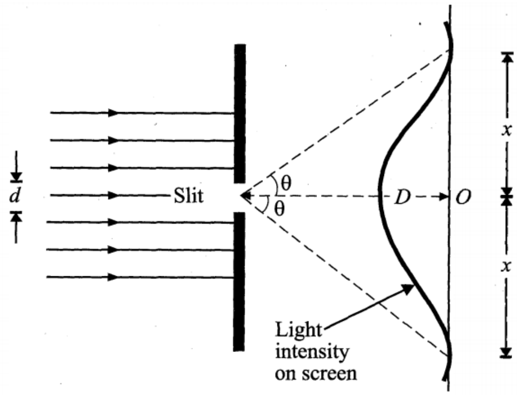
If θ is small, $\sin\theta \simeq \theta \simeq \tan\theta = \frac{x}{D} = \frac{x}{f}$ $(\because f = D)$

Eq. (i) becomes : $\frac{x}{D} = \frac{\lambda}{d}$

or $x = D\lambda/d$

∵ Linear width of central maximum

$= 2x = \frac{2D\lambda}{d} = \frac{2f\lambda}{d}$ $(\because f = D)$



Therefore, the linear width of the central maximum is

(i) directly proportional to the wavelength λ of light used. Therefore, the greater the waveength of the light used, the greater is the width of the central maximum and vice-versa.

(ii) inversely proportional to the width d of the slit. Therefore, if the width of the slit is small, the width of the central maximum is large and vice-versa.

(iii) is directly proportional to the distance D between the plane o f the slit and the screen. Therefore, width of central maximum increases with the increase in D and vice-versa

Angular width of central maximum. The angular width of central maximum is the angular separation between the first minima on the two sides of the central maximum. Thus referring to Fig.

Angular width of central maximum = 2θ

Now first secondary minimum occurs at $\sin\theta = \lambda/d$

If θ is small, sin θ ≃ θ so that:

$$\theta = \lambda/d$$

∴ Angular width of central maximum

$$= 2\theta = 2\lambda/d$$

Note that θ is called half angular width (θ=λ/d).

Note. We have seen that first secondary minimum occurs at

$$\sin\theta = \lambda/d$$

If the width of the slit (d) is large compared to the wavelength (λ) of light, then sinθ is very small and hence θ is very small. In this case, the first secondary minimum and central fringe are very close to each other. Practically, the whole of light is thus confined to a direction immediately in front of the incident direction i.e. no spreading occurs. This explains the rectilinear propagation of light. When the width of slit is very small say 2λ, then sin θ = λ/d = λ/2 λ = 1/2 or θ = 30°. Thus, light waves now spread through 30° on either side of the slit i.e. diffraction is quite pronounced.

VALIDITY OF RAY OPTICS

Ray optics or geometrical optics is based on the assumption that light travels in straight lines. However, the diffraction effects show that light does not travel in straight lines. Let us see under what situations the ray optics is valid.

From the theory of diffraction of light at a single slit, the linear width x of the central miximum from the centre O of the central maximum is

$$x = D\lambda/d$$

Here, λ = Wavelength of light used

d = Width of the slit

D = Distance of screen from the slit

If the diffraction spread x is small, then ray optics is valid.

Let us illustrate this point with an example. Suppose we have an aperture (i.e. hole or slit) of width d = 10 mm and wavelength of light used is $\lambda = 6 \times 10^{7}$ m. Then diffraction spread x at a distance D = 3m from the slit is

$$x = \frac{D\lambda}{d} = \frac{3\times 6\times 10^{7}}{10\times 10^{-3}}$$

$$= 18 \times 10^{-5}\ \text{m} = 0.18\ \text{mm}$$

This diffraction spread is quite small. Therefore, ray optics is valid in this situation

Fresnel distance. The diffraction spread x (=D λ/d) increases as D (= distance of screen from slit) increases. Fresnel distance is the distance D beyond which deviation of light becomes significant. It is defined as under :

The distance at which the diffraction spread (x) of a beam of light is equal to the size of the aperture (i.e. slit or hole) is called Fresnel distance. It is denoted by Z_F.

Diffraction spread, x = Dλ/d

When x = d, then $D = Z_F$.

∴ $d = Z_F\lambda/d$

Fresnel distance, $Z_F = d^2/\lambda$

If $D < Z_F$ then diffraction effects can be neglected and ray optics is valid. If $D >> Z_F$, the spreading due to diffraction is very pronounced and ray optics is not valid.

DIFFERENCE BETWEEN INTERFERENCE AND DIFFRACTION OF LIGHT

Interference	Diffraction
1. Interference is due to superposition of light waves coming from two coherent sources.	1. Diffraction is due to superposition of secondary wavelets coming from different points of the same wavefront.
2.In interference pattern, all bright fringes are of the same intensity.	2. In diffraction pattern, the intensity of successive bright fringes goes on decreasing.
3. The width of interference fringes may or may not be the same.	3. Diffraction fringes are never of the same width.
4. In interference pattern, the dark fringes are usually almost perfectly black.	4. In diffraction pattern, the dark fringes are not perfectly black.
5. In interference, bands are large in number.	5. In diffraction, bands are a few in number.

Example : 9

A slit 0.1mm wide is illuminated with a monochromatic light of wavelength 5000Å. How wide is the central maximum on a screen lm from the slit?

Solution.

Width of central maximum = $\frac{2D\lambda}{d}$

Here, D= 1 m ;λ = 5000Å = 5 x 10^{-7}m ;

d = 0.1 mm = 0.1 x 10^{-3}m

∴ Width of central maximum

$$= \frac{2 \times 1 \times (5 \times 10^{-7})}{0.1 \times 10^{-3}} = 10^{-2} \text{ m} = 1 \text{ cm}$$

Thus the central bright band from the narrow slit is 100 times as wide as the slit itself.

Example :10

Light of wavelength 6300 Å passes through a single slit. The angular deflection to the tenth dark band on the side of the central maximum is 3.6°. Calculate the slit width.

Solution.

In single – slit diffraction pattern, for n^{th} dark band, we have,

$d \sin \theta_n = n\lambda$ where n = 1, 2, 3....

Here λ = 6300 Å = 6.3 x 10^{-7} m; θ_n = 3.6° ; n = 10

∴ d sin 3.6° = 10 x 6.3 x 10^{-7}

∴ Slit width, $d = \frac{10 \times 6.3 \times 10^{-7}}{\sin 3.6°}$

= 0.1 x 10^{-3} m = 0.1 mm.

Example : 11

Light of wavelength 5500 Å passes through a single slit of width 0.01m. Find the angular deflection to the first dark band of the diffraction pattern.

Solution.

The angular deflection to the first dark band of the diffraction pattern is

$$\sin \theta = \frac{\lambda}{d} = \frac{5500 \times 10^{-10}}{0.01} = 5.5 \text{ x } 10^{-5}$$

∴ θ = 0.0032°

The diffraction is so small that it will hardly be noticed. The light will appear to form a sharp image of the opening with no observable diffraction. This is not surprising because the wavelength of light (5500 Å) is much less than the width of the slit (0.01m).

Example:12

For what distance is ray optics a good approximation when the aperture is 3 mm wide and wavelength is 500 nm?

Solution.

Here, d = 3mm = 3 x 10^{-3} m; λ = 500 nm = 500 x 10^{-9} m

Fresnel distance, $Z_F = \frac{d^2}{\lambda} = \frac{(3 \times 10^{-3})^2}{500 \times 10^{-9}} = 18$ m

Thus ray optics is valed upto a distance of 18m from the aperture.

Example : 13

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 size of the aperture.

Solution.

Here, d = 2mm = 2 x 10^3m; λ = 600 nm = 600x 10^{-9} m. The distance up to which light can travel such that its spread is less than the size of aperture is Fresnel distance.

Fresnel distance, $Z_F = \frac{d^2}{\lambda} = \frac{(2 \times 10^{-3})^2}{600 \times 10^{-9}} = 6.67$ m

Example : 14

Light of wavelength 5000 Å is diffracted by an aperture of width 2mm. For what distance travelled by the diffracted beam does the spreading due to diffraction become greater than the width of the aperture?

Solution.

Here, d = 2 mm = 2 x 10^{-3} m; λ = 5000 Å = 5000 x 10^{-10}m

Fresnel distance, $Z_F = \frac{d^2}{\lambda} = \frac{(2 \times 10^{-3})^2}{5000 \times 10^{-10}} = 8$ m

Therefore, at a distance greater than 8m, the spreading due to diffraction becomes greater than the width of the aperture.

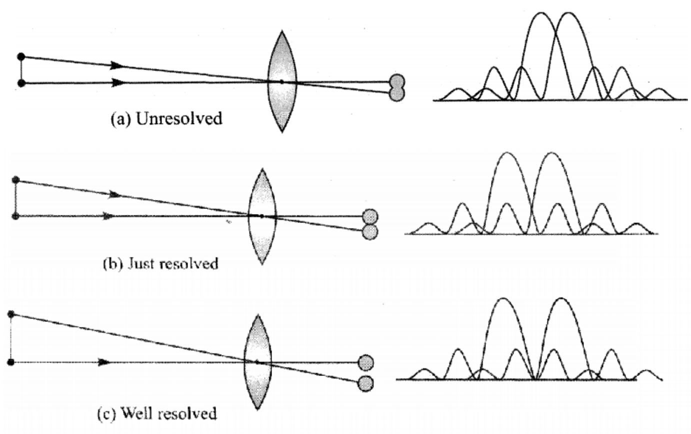
Resolution limit and resolving power

When we decrease the separation between the two point objects, a limit is reached when our eyes can not differentiate them separately, even they are not in contact. The minimum separation between two closely placed objects, the eyes can distinguish them separately is known as resolution limit (RL). The reciprocal of resolution limit is known as resolving power (RP). Thus

$$RP = 1/RL$$

Rayleigh criteria

According to Rayligh, two images of two objects are said to be just resolved when central maxima of one diffraction pattern falls on first minima of other (see figure).



(i) The resolution limit of normal human eye is one minute (1').

(ii) The resolution limit of a telescope is given by angle θ, where

$$\theta = \left[\frac{1.22\,\lambda}{d}\right] \text{rad},$$

Here λ is the wavelength of light used and d is the diameter of objective lens of the telescope.

(iii) The resolution limit of a microscope is given by

$$x = \left[\frac{1.22\,\lambda}{2\mu \sin\theta}\right] \text{metre},$$

where μ is the refractive index of medium between objects and lens; θ is the angle subtended by the objects at objective lens of the microscope, μ sinθ is called numerical aperture of the lens.

11.5.4 Polarisation

The phenomena of reflection, refraction, interference, diffraction are common to both transverse waves and longitudinal waves. But the transverse nature of light waves is demonstrated only by the phenomenon of polarisation.

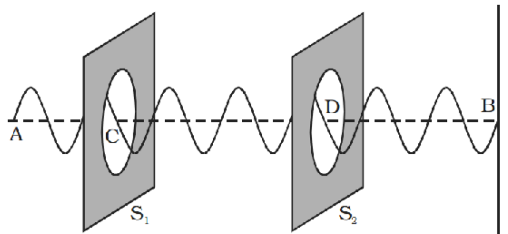
Polarisation of transverse waves.

Let a rope AB be passed through two parallel vertical slits S_1 and S_2 placed close to each other. The rope is fixed at the end B. If the free end A of the rope is moved up and down perpendicular to its length,transverse waves are generated with vibrations parallel to the slit. These waves pass through both S_1 and S_2 without any change in their amplitude. But if S_2 is made horizontal, the two slits are perpendicular to each other. Now, no vibrations will pass through S_2 and amplitude of vibrations will become zero. i.e the portion S_2B is without wave motion as shown in fig.

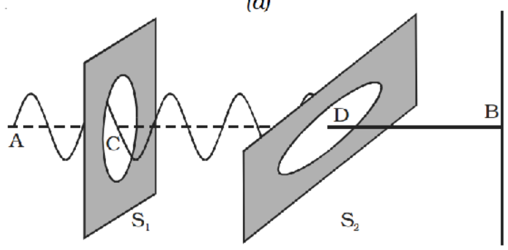
On the otherhand, if longitudinal waves are generated in the rope by moving the rope along forward and backward, the vibrations will pass through S_1 and S_2 irrespective of their positions.

This implies that the orientation of the slits has no effect on the propagation of the longitudinal waves, but the propagation of the transverse waves, is affected if the slits are not parallel to each other.

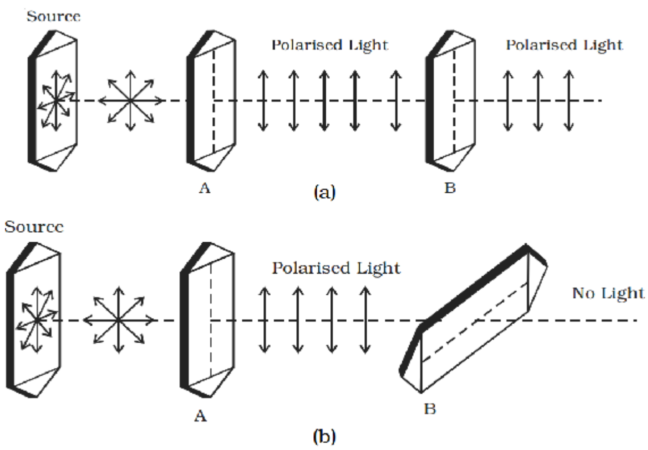
A similar phenomenon has been observed in light, when light passes through a tourmaline crystal.



(a)



(b)



Light from the source is allowed to fall on a tourmaline crystal which is cut parallel to its optic axis (Fig.a).

The emergent light will be slightly coloured due to natural colour of the crystal. When the crystal A is rotated, there is no change in the intensity of the emergent light. Place another crystal B parallel to A in the path of the light. When both the crystals are rotated together, so that their axes are parallel, the intensity of light coming out of B does not change. When the crystal B alone is rotated, the intensity of the emergent light from B gradually decreases. When the axis of B is at right angles to the axis of A, no light emerges from B (Fig.b).

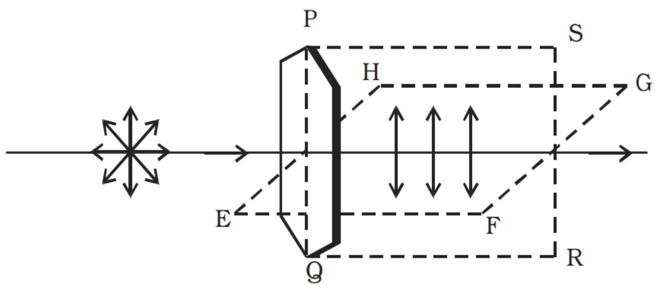
If the crystal B is further rotated, the intensity of the light coming out of B gradually increases and is maximum again when their axis are parallel.

Comparing these observations with the mechanical analogue discussed earlier, it is concluded that the light waves are transverse in nature.

Light waves coming out of tourmaline crystal A have their vibrations in only one direction, perpendicular to the direction of propagation. These waves are said to be polarised. Since the vibrations are restricted to only one plane parallel to the axis of the crystal, the light is said to be plane polarised. The phenomenon of restricting the vibrations into a particular plane is known as polarisation.

Plane of vibration and plane of polarisation

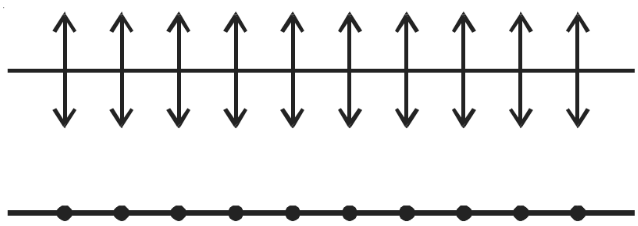
The plane containing the optic axis in which the vibrations occur is known as plane of vibration. The plane which is at right angles to the plane of vibration and which contains the direction of propagation of the polarised light is known as the plane of polarisation. Plane of polarisation does not contain vibrations in it. In the Fig PQRS represents the plane of vibration and EFGH represents the plane of polarisation.



Representation of light vibrations

In an unpolarised light, the vibrations in all directions may be supposed to be made up of two mutually perpendicular vibrations. These are represented by double arrows and dots (Fig).

The vibrations in the plane of the paper are represented by double arrows, while the vibrations perpendicular to the plane of the paper are represented by dots.

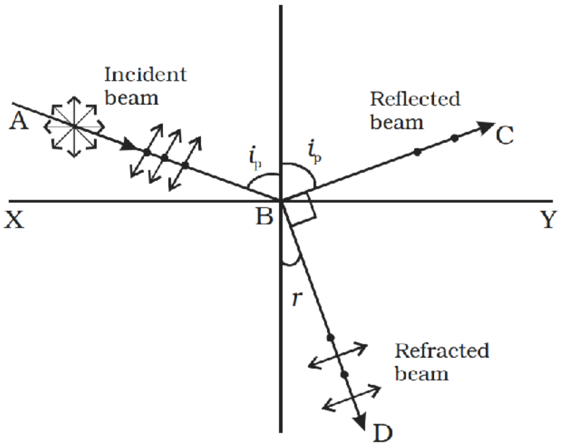


Polariser and Analyser

A device which produces plane polarised light is called a polariser. A device which is used to examine, whether light is plane polarised or not is an analyser. A polariser can serve as an analyser and vice versa.

A ray of light is allowed to pass through an analyser. If the intensity of the emergent light does not vary, when the analyser is rotated, then the incident light is unpolarised; If the intensity of light varies between maximum and zero, when the analyser is rotated through 90°, then the incident light is plane polarised; If the intensity of light varies between maximum and minimum (not zero), when the analyser is rotated through 90°, then the incident light is partially plane polarised.

Polarisation by reflection



The simplest method of producing plane polarised light is by reflection. Malus, discovered that when a beam of ordinary light is reflected from the surface of transparent medium like glass or water, it gets polarised. The degree of polarisation varies with angle of incidence.

Consider a beam of unpolarised light AB, incident at any angle on the reflecting glass surface XY.

Vibrations in AB which are parallel to the plane of the diagram are shown by arrows. The vibrations which are perpendicular to the plane of the diagram and parallel to the reflecting surface, shown by dots (Fig.).

A part of the light is reflected along BC, and the rest is refracted along BD. On examining the reflected beam with an analyser, it is found that the ray is partially plane polarised.

When the light is allowed to be incident at a particular angle,(for glass it is 57.5°) the reflected beam is completely plane polarised. The angle of incidence at which the reflected beam is completely plane polarised is called the polarising angle (i_p).

Brewster's law

Sir David Brewster conducted a series of experiments with different reflectors and found a simple relation between the angle of polarisation and the refractive index of the medium. It has been observed experimentally that the reflected and refracted rays are at right angles to each other, when the light is incident at polarising angle.

From Fig, $i_p + 90^0 + r = 180^0$

$$r = 90^0 - i_p$$

From Snell's law,

$$\frac{\sin i_p}{\sin r} = \mu$$

where μ is the refractive index of the medium (glass)

Substituting for r, we get

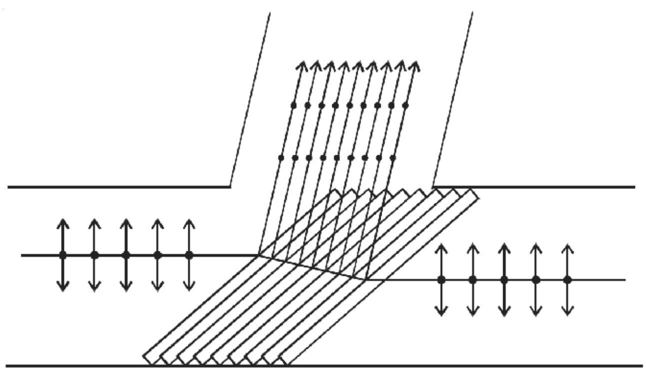
$$\frac{\sin i_p}{\sin (90^0 - i_p)} = \mu; \quad \frac{\sin i_p}{\cos i_p} = \mu$$

$\therefore \quad \tan i_p = \mu$

The tangent of the polarising angle is numerically equal to the refractive index of the medium.

Pile of plates

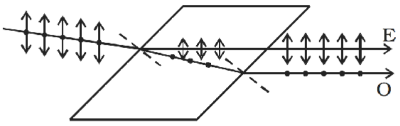
The phenomenon of polarisation by reflection is used in the construction of pile of plates. It consists of a number of glass plates placed one over the other as shown in Fig in a tube of suitable size. The plates are inclined at an angle of 32.5° to the axis of the tube. A beam of monochromatic light is allowed to fall on the pile of plates along the axis of the tube. So, the angle of incidence will be 57.5° which is the polarising angle for glass.



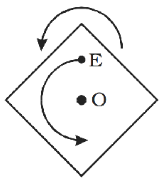
The vibrations perpendicular to the plane of incidence are reflected at each surface and those parallel to it are transmitted. The larger the number of surfaces, the greater is the intensity of the reflected plane polarised light. The pile of plates is used as a polariser and an analyser.

Double refraction

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



(a)



(b)

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

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

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

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

Types of crystals

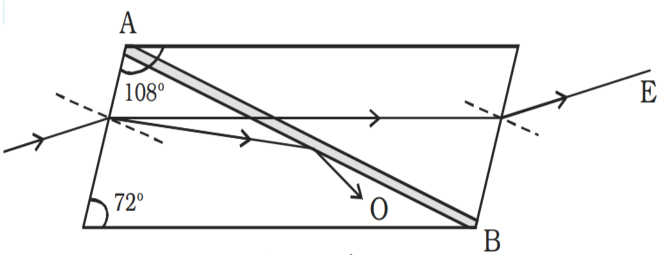
Crystals like calcite, quartz, ice and tourmaline having only one optic axis are called uniaxial crystals.

Crystals like mica, topaz, selenite and aragonite having two optic axes are called biaxial crystals.

Nicol prism

Nicol prism was designed by William Nicol. One of the most common forms of the Nicol prism is made by taking a calcite crystal whose length is three times its breadth. It is cut into two halves along the diagonal so that their face angles are 72^0 and 108^0. And the two halves are joined together by a layer of Canada balsam, a transparent cement as shown in Fig. For sodium light, the refractive index for ordinary light is 1.658 and for extra−ordinary light is 1.486. The refractive index for Canada balsam is 1.550 for both rays, hence Canada balsam does not polarise light.

A monochromatic beam of unpolarised light is incident on the face of the nicol prism. It splits up into two rays as ordinary ray (O) and extraordinary ray (E) inside the nicol prism (i.e) double refraction takes place. The ordinary ray is totally internally reflected at the layer of Canada balsam and is prevented from emerging from the other face. The extraordinary ray alone is transmitted through the crystal which is plane polarised. The nicol prism serves as a polariser and also an analyser.



Polaroids

A Polaroid is a material which polarises light. The phenomenon of selective absorption is made use of in the construction of polariods.

There are different types of polaroids. A Polaroid consists of micro crystals of herapathite (an iodosulphate of quinine). Each crystal is a doubly refracting medium, which absorbs the ordinary ray and transmits only the extra ordinary ray. The modern polaroid consists of a large number of ultra microscopic crystals of herapathite embedded with their optic axes, parallel, in a matrix of nitro –cellulose.

Recently, new types of polariod are prepared in which thin film of polyvinyl alcohol is used. These are colourless crystals which transmit more light, and give better polarisation.

Uses of Polaroid

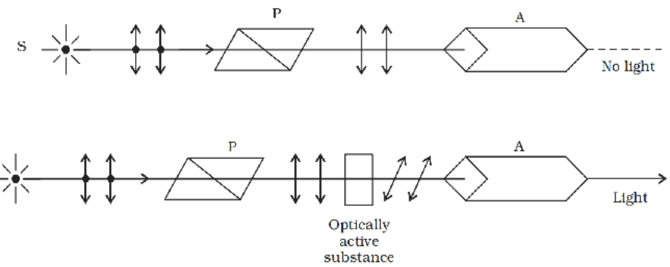
1. Polaroids are used in the laboratory to produce and analyse plane polarised light.
2. Polaroids are widely used as polarising sun glasses.
3. They are used to eliminate the head light glare in motor cars.
4. They are used to improve colour contrasts in old oil paintings.
5. Polaroid films are used to produce three – dimensional moving pictures.
6. They are used as glass windows in trains and aeroplanes to control the intensity of light. In aeroplane one polaroid is fixed outside the window while the other is fitted inside which can be rotated. The intensity of light can be adjusted by rotating the inner polaroid.
7. Aerial pictures may be taken from slightly different angles and when viewed through polaroids give a better perception of depth.
8. In calculators and watches, letters and numbers are formed by liquid crystal display (LCD) through polarisation of light.
9. Polarisation is also used to study size and shape of molecules.

Optical activity

When a plane polarised light is made to pass through certain substances, the plane of polarisation of the emergent light is not the same as that of incident light, but it has been rotated through some angle. This phenomenon is known as optical activity. The substances which rotate the plane of polarisation are said to be optically active. Examples : quartz, sugar crystals, turpentine oil, sodium chloride etc.

Optically active substances are of two types, (i) Dextro−rotatory (right handed) which rotate the plane of polarisation in the clock wise direction on looking towards the source. (ii) Laevo – rotatory (left handed) which rotate the plane of polarisation in the anti clockwise direction on looking towards the source.

Light from a monochromatic source S, is made to pass through a polariser P. The plane polarised light is then made to fall on an analyser A, which is in crossed position with P. No light comes out of A. When a quartz plate is inserted between the polariser and analyser some light emerges out of the analyzer A (Fig.). The emerging light is cut off again, when the analyzer is rotated through a certain angle.



This implies that light emerging from quartz is still plane polarised, but its plane of polarisation has been rotated through certain angle.

The amount of optical rotation depends on :

(i) thickness of crystal

(ii) density of the crystal or concentration in the case of solutions. , (iii) wavelength of light used

(iv) the temperature of the solutions.

Specific rotation

The term specific rotation is used to compare the rotational effect of all optically active substances.

Specific rotation for a given wavelength of light at a given temperature is defined as the rotation produced by one-decimeter length of the liquid column containing 1 gram of the active material in 1cc of the solution.

If θ is the angle of rotation produced by l decimeter length of a solution of concentration C in gram per cc, then the specific rotation S at a given wavelength λ for a given temperature t is given by

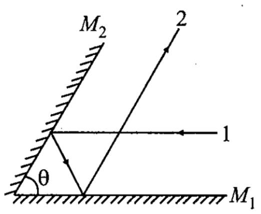
$$S = \frac{\theta}{l.c}$$

The instrument used to determine the optical rotation produced by a substance is called polarimeter.

Sugar is the most common optically active substance and this optical activity is used for the estimation of its strength in a solution by measuring the rotation of plane of polarisation

Exercises – I

1. Two plane mirrors M_1 and M_2 are inclined at angle θ as shown in the figure. A ray of light 1, which is parallel to M_1 strikes M_2 and after two reflections, the ray 2 becomes parallel to M_2. The angle θ is

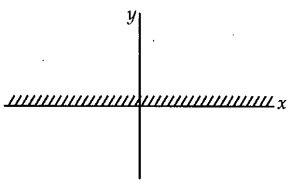


[1] 0°
[2] 30°
[3] 45°
[4] 60°

2. If a ray of light is incident on a plane mirror at an angle of incidence of 30°, then deviation produced by mirror is

[1] 30° [2] 60° [3] 90° [4] 120°

3. A plane mirror is placed along the x-axis facing negative y-axis. The mirror is fixed. A point object is moving with $(3\hat{i} + 4\hat{j})$ in front of the plane mirror. The relative velocity of image with respect to its object is



[1] $-8\,\hat{j}$
[2] $8\,\hat{j}$
[3] $3\,\hat{i} - 48\,\hat{j}$
[4] $-6\,\hat{i}$

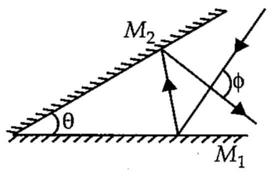
4. A boy is 1.8 m tall and can see his image in a plane mirror fixed on a wall. His eyes are 1.6 m from the floor level. The minimum length of the mirror is

[1] 0.1 m [2] 0.7 m
[3] 0.9 m [4] 0.5 m

5. A man runs towards a mirror at a speed of 15 ms^{-1}. The speed of the image relative to the man is

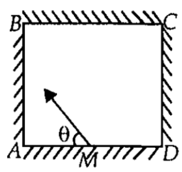
[1] 15 ms^{-1} [2] 30 ms^{-1}
[3] 35 ms^{-1} [4] 20 ms^{-1}

6. The reflecting surfaces of two mirrors M_1 and M_2 are at an angle θ (angle θ between 0° and 90°) as shown in the figure. A ray of light is incident on M_1. The emerging ray intersects the incident ray at an angle (ϕ). Then,



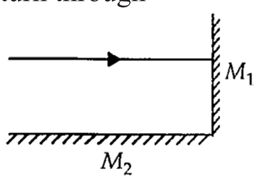
[1] ϕ = θ
[2] ϕ = 180° – θ
[3] ϕ = 90° – θ
[4] ϕ = 180° – 2θ

7. Four identical mirrors are made to stand vertically to form a square arrangement as shown in a top view. A ray starts from the midpoint M of mirror AD and after two reflections reaches comer D. Then, angle θ must be



[1] $\tan^{-1}(0.75)$
[2] $\cot^{-1}(0.75)$
[3] $\sin^{-1}(0.75)$
[4] $\cos^{-1}(0.75)$

8. A ray of light strikes a silvered surface inclined to another one at an angle of 90°. Then the reflected ray will turn through



[1] 0°
[2] 45°
[3] 90°
[4] 180°

Spherical mirrors

9. A concave mirror gives an image three times as large as the object placed at a distance of 20 cm from it. For the image to be real, the focal length should be

[1] 10 cm [2] 15 cm
[3] 20 cm [4] 30 cm

10. The speed at which the image of the luminous point object is moving, if the luminous point object is moving at speed v_0 towards a spherical mirror, along its axis, is (Given : R = radius of curvature , u = object distance)

[1] $v_i = -v_0$ [2] $v_i = -v_0\left(\frac{R}{2u-R}\right)$
[3] $v_i = -v_0\left(\frac{2u-R}{R}\right)$ [4] $v_i = -v_0\left(\frac{R}{2u-R}\right)^2$

11. An object is placed in front of a convex mirror of radius of curvature 20 cm. Its image is formed 8 cm behind the mirror. The object distance is

[1] 20 cm [2] 40 cm
[3] 60 cm [4] 80 cm

12. Two objects A and B when placed in turns in front of a concave mirror, give images of equal size. The focal length of the concave mirror is 7.5 cm and size of object A is three times the size of object B..The distance of B from the mirror, if A is placed 30 cm from the mirror, is

[1] 18 cm [2] 15 cm
[3] 20 cm [4] 25 cm

13. An object is placed in front of a spherical mirror of focal length f. If x and x' respectively represent the distance of the object and the image from the focus, then

[1] f = x + x' [2] f^2 = xx'
[3] f = |x - x'|
[4] f = x ± x depending upon whether image is real or virtual

14. When an object is kept at a distance of 30 cm from a concave mirror, the image is formed at a distance of 10 cm.If the object is moved with a speed of 9 m s^{-1}, the speed with which image moves is

[1] 10 m s^{-1} [2] 1 m s^{-1}
[3] 9 m s^{-1} [4] 0.9 m s^{-1}

15. If the reflected image formed is magnified and virtual, then the mirror system is

[1] Concave only [2] Convex only
[3] Plane [4] Concave or convex

16. If the lower half of a concave mirror's reflecting surface is made opaque, which of the following statements describe the image of an object placed in front of the mirror?

S1 : Intensity of the image will increase.
S2 : The image will show only half of the object.
S3 : No change in the image.
S4 : Intensity of the image will be reduced to half.

[1] S1 only [2] S2 only
[3] S2 and S3 [4] S4 only

17. An object is placed at 15 cm in front of a concave mirror whose focal length is 10 cm. The image formed will be

[1] Magnified and inverted
[2] Magnified and erect
[3] Reduced in size and inverted
[4] Reduced in size and erect. '

18. An object placed in front of a concave mirror at a distance of x cm from the pole gives a 3 times magnified real image. If it is moved to a distance of (x + 5) cm, the magnification of the image becomes 2. The focal length of the mirror is

[1] 15 cm [2] 20 cm
[3] 25 cm [4] 30 cm

Refraction of light

19. A vessel of depth (2d) is half filled with a liquid of refractive index μ_1 The remaining upper half is filled with another immiscible liquid of refractive index μ_1. The apparent depth of the vessel, when viewed normally, is

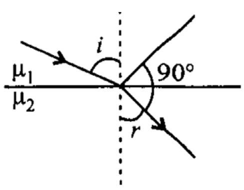
20. The refractive index of water with respect to air is 4/3 and the refractive index of glass with respect to air is 3/2. Then the refractive index of water with respect to glass is
[1] 9/8 [2] 8/9
[3] 1/2 [4] 2

21. A plane glass slab is kept over various coloured letters, the letter which appears least raised is
[1] Blue [2] Violet
[3] Green [4] Red

22. A ray of light strikes a transparent surface from air at an angle θ. If the angle between the reflected and refracted ray is a right angle, the refractive index of the other medium is given by
[1] $\mu = 1/\tan\theta$ [2] $\mu = \tan^2\theta$
[3] $\mu = \sin\theta$ [4] $\mu = \tan\theta$

23. A ray incident at a point at an angle of incidence of 60° enters a glass sphere of refractive index $\sqrt{3}$ and is reflected and refracted at the farther surface of the sphere. The angle between the reflected and refracted rays at this surface is
[1] 50° [2] 60° [3] 90° [4] 40°

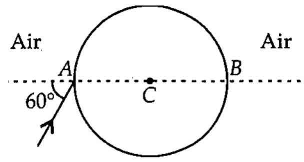
24. If light is incident on a surface separating two media is partly reflected and partly refracted as shown in figure, then



[1] $\sin i = \frac{\mu_2}{(\mu_1^2 \mu_2^2)^{1/2}}$
[2] $\tan i = \frac{\mu_1}{\mu_2}$
[3] $\sin i = \tan r$
[4] $\sin i = \sec r$

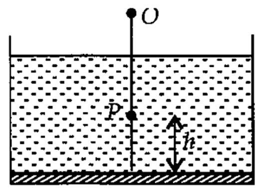
25. A ray of light strikes a glass plate at an angle of 60°. If the reflected and refracted rays are perpendicular to each other, the index of refraction of glass is
[1] 1/2 [2] $\sqrt{3/2}$
[3] 3/2 [4] $\sqrt{3}$

26. A ray of light falls on a transparent sphere with centre C as shown in the figure. The ray emerges from sphere parallel to line AB. The refractive index of sphere is
[1] $\mu = \sqrt{2}$
[2] $\mu = \sqrt{3/2}$
[3] $\mu = \sqrt{3}$
[4] $\mu = \sqrt{5/2}$



27. Refractive indices of water and glass are 4/3 and 3/2 respectively. A ray of light travelling in water is incident on the water glass interface at 30°. The angle of refraction is
[1] $\sin^{-1}(8/18)$ [2] $\sin^{-1}(4/3)$
[3] $\sin^{-1}(3/2)$ [4] $\sin^{-1}(18/8)$

28. A plane mirror is placed at the bottom of a tank containing a liquid of refractive index μ. P is a small object at a height h above the mirror. An observer O vertically above P, outside the liquid sees P and its image in the mirror. The apparent distance between these two will be
[1] 2 μh
[2] 2h/μ
[3] 2h/μ – 1
[4] $h\left(1 + \frac{1}{\mu}\right)$



29. 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 cc per minute is (μ_1 = refractive index of air,μ_2= refractive index of water)
[1] $\frac{x\pi R^2 \mu_1}{\mu_2}$ [2] $\frac{x\pi R^2 \mu_1}{\mu_2}$
[3] $\frac{x\pi R^2 \mu_1}{\mu_2}$ [4] $\pi R^2 x$

30. A ray of light is incident on a glass slab of thickness t, at an angle i, r is the angle of refraction in the glass slab.Distance travelled in the glass slab is
[1] t cos r [2] t tan r
[3] t/cos r [4] t/sin r

31. A ray of light is incident on a thick slab of glass of thickness t as shown in figure. The emergent

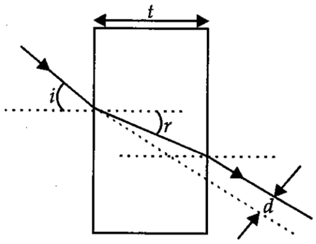
ray is parallel to the incident ray but displaced sideways by a distance d. If the angles are small then d is,

[1] $t\left(1-\frac{i}{r}\right)$

[2] $rt\left(1-\frac{i}{r}\right)$

[3] $it\left(1-\frac{r}{i}\right)$

[4] $t\left(1-\frac{r}{i}\right)$



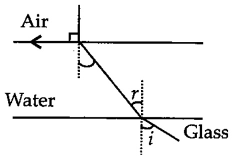
32 A ray of light is incident at the glass-water interface at an angle i as shown in the figure. Air It finally emerges parallel to Water water-air interface. The value of μ_g would be
(Refractive index of water, $\mu_w = 4/3$)

[1] 4/3 sin i

[2] 1/sin i

[3] 4/3

[4] None of these



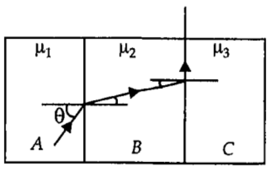
33. A, B and C are the parallel sided transparent media of refractive index μ_1, μ_2 and μ_3 respectively. They are arranged as shown in the figure. A ray is incident at an angle θ on the surface of separation of A and B which is as shown in the figure. After the refraction into the medium B, the ray grazes the surface of separation of the media B and C. Then, sin θ =

[1] μ_3 / μ_1

[2] μ_1 / μ_3

[3] μ_2 / μ_3

[4] μ_1 / μ_2



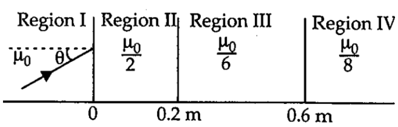
34. A light beam is travelling from region I to region IV (Refer figure). The refractive indices in regions I, II, III and IV are μ_0 ,$\mu_0/6$, $\mu_0/8$, and respectively. The angle of incidence θ for which the beam just misses entering region IV is

[1] $\sin^{-1}(3/4)$

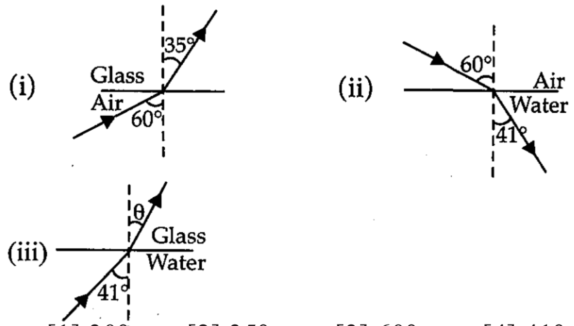
[1] $\sin^{-1}(1/8)$

[1] $\sin^{-1}(1/4)$

[1] $\sin^{-1}(1/3)$



35. Refraction of light from air to glass and from air to water are shown in figure (i) and (ii) below. The value of the angle θ in the case of refraction as shown in figure (iii) will be



[1] 30° [2] 35° [3] 60° [4] 41°

36. The refractive indices of water, glass and diamond are 1.33, 1.50, 2.40 respectively. The refractive index of diamond relative to water and of glass relative to diamond, respectively are nearly

[1] 1.80, 0.625 [2] 0.554, 0.625

[3] 1.80, 1.6 [4] 0.554, 1.6

37. A vessel of depth x is half filled with oil of refractive index μ_1, and the other half is filled with water of refractive index μ_2.The apparent depth of the vessel when viewed from above is

[1] $\frac{x(\mu_1+\mu_2)}{2\mu_1\mu_2}$ [2] $\frac{x\mu_1\mu_2}{2(\mu_1+\mu_2)}$

[3] $\frac{x\mu_1\mu_2}{(\mu_1+\mu_2)}$ [4] $\frac{2x(\mu_1+\mu_2)}{\mu_1\mu_2}$

38. Sun is visible a little before the actual sunrise and until a little after the actual sunset. This is due to

[1] Total internal reflection [2] Reflection

[3] Refraction [4] Polarization

39. When a light ray enters a refracting medium, it is found that the magnitude of the angle of refraction is equal to half the angle of reflection. If μ is the refractive index of the medium, then the angle of incidence is

[1] $2\sin^{-1}(\mu/2)$ [2] $2\cos^{-1}(\mu/2)$

[3] $\cos^{-1}(\mu/2)$ [4] $\sin^{-1}(\mu/2)$

40. A metal coin is at the bottom of a breaker filled to a height of 6 cm. The refractive index of the liquid is (4/3). To an observer looking above the surface of the liquid, the coin will appear raised up by will appear raised up by

[1] 4.5 cm [2] 6.75 cm

[3] 1.5 cm [4] 7.5 cm

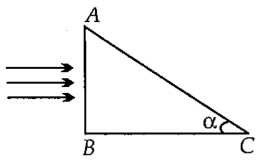
TOTAL INTERNAL REFLECTION AND ITS APPLICATIONS

41. Which of the following is used in optical fibres?
[1] Total internal reflection
[2] Scattering
[3] Diffraction [4] Refraction

42. If the critical angle for total internal reflection from a medium to vacuum is 30°, the velocity of light in the medium is
[1] 3×10^8 m/s [2] 1.5×10^8 m/s
[3] 6×10^8 m/s [4] $\sqrt{3} \times 10^8$ m/s

43. Critical angle of glass is θ_1 and that of water is θ_2. The critical angle for water and glass surface would be ($\mu_g = 3/2$, $\mu_w = 4/3$)
[1] Between θ_1 and θ_2 [2] Greater than θ_2
[3] Less than θ_1 [4] Less than θ_2

44. A ray of light is incident normally on the prism ($\mu = 3/2$) immersed in a liquid as shown in the figure. The largest value for the angle α so that ray is totally reflected at the face AC is 30°. The refractive index of the given liquid is
[1] $\sqrt{3}/2$
[2] 3/4
[3] 4/3
[4] $3\sqrt{3}/4$



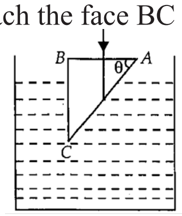
45. A fish looking from within water sees the outside world through a circular horizon. If the fish is $\sqrt{7}$ m below the surface of water, what will be the radius of the circular horizon ?
[1] 3 m [2] $3/\sqrt{7}$ m
[3] $\sqrt{7}$ m [4] $3\sqrt{7}$ m

46. A ray of light is incident at an angle a on the boundary separating two transparent media. It is transmitted. If the angle of incidence is increased very slightly, the ray gets reflected in the same medium. The difference between angles of deviation in the two cases will be close to
[1] α [2] 90° – α
[3] 180° – α [4] 180° – 2α

47. Critical angle for light going from medium (i) to (ii) is θ. The speed of light in medium (i) is v, then the speed of light in medium (ii) is
[1] v(1 – cosθ) [2] v/sin θ
[3] v/ cos θ [4] v/(1 – sin θ)

48. 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
[1] Only a reflected ray and no refracted ray
[2] Only a refracted ray and no reflected ray
[3] A reflected ray and a refracted ray and the angle between them would be less than 180°– 2θ
[4] A reflected ray and a refracted ray and the angle between them would be greater than 180°– 2θ.

49. A glass prism of refractive index 1.5 is immersed in water ($\mu = 4/3$) Refer figure. A light beam incident normally on the face AB is totally reflected to reach the face BC if
[1] $\sin\theta \le 2/3$
[2] $\cos\theta \ge 8/9$
[3] $\sin\theta \le 8/9$
[4] $\cos\theta \le 8/9$



50. Light travels in two medial A and B with speeds 1.8×10^8 ms^{-1}and 2.4×10^8 ms^{-1} respectively. Then the critical angle between them is
[1] $\sin^{-1}(2/3)$ [2] $\tan^{-1}(3/4)$
[3] $\sin^{-1}(2/3)$ [4] $\sin^{-1}(3/4)$

51. A bulb is placed at a depth of $2\sqrt{7}$ m in water ($\mu_w = 4/3$) and a floating oaque disc is placed over the bulb so that the bulb is not visible from the surface. What is the minimum diameter of the disc?
[1] 8 m [2] 12 m [3] 15 m [4] 20 m

REFRACTIONS AT SPHERICAL SURFACES

52. 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 sphere is
[1] 2 cm [2] 4 cm [3] 6 cm [4] 12 cm

53. A transparent sphere of radius R and refractive index μ is kept in air. At what distance from the surface of the sphere should a point object be placed so as to form a real image at the same distance from the sphere?
[1] μR `
[2] R/μ – 1
[3] R/μ + 1
[4] R/μ

Lens and lens maker's formula

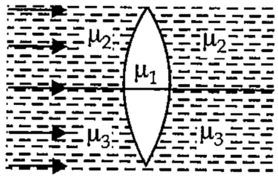
54. A double convex thin lens made out of glass (refractive index, μ = 1.5) has both radii of curvature of magnitude 20 cm. Incident light rays parallel to the axis of the lens will converge at a distance d cm such that
[1] d = 10
[2] d = 20/3
[3] d = 40
[4] d = 20

55. A substance is behaving as convex lens in air and concave in water, then its refractive index is
[1] Greater than air but less than water
[2] Greater than both air and water
[3] Smaller than air
[4] Almost equal to water

56. A convex lens of focal length 20 cm made of glass of refractive index 1.5 is immersed in water having refractive index 1.33. The change in the focal length of lens is
[1] 62.2 cm
[2] 5.82 cm
[3] 58.2 cm
[4] 6.22cm

57. The focal length of a biconvex lens of refractive index 1.5 is 0.06 m. Radii of curvature are in the ratio 1:2. Then radii of curvature of two lens surfaces are
[1] 0.045 m, 0.09 m
[2] 0.09 m, 0.18 m
[3] 0.04 m, 0.08 m
[4] 0.06 m, 0.12 m

58. A double convex lens, made of a material of refractive index μ_1, is placed inside two liquids of refractive indices μ_2 and μ_3, as shown in the figure. $\mu_1 > \mu_2 > \mu_3$. A wide, parallel beam of light is incident on the lens from the left. The lens will give rise to

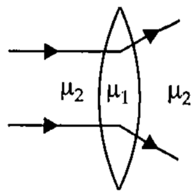


[1] A single convergent beam
[2] Two different convergent beams
[3] Two different divergent beams
[4] A convergent and divergent beam

59. What is the radius of curvature of a double convex lens made of glass of refractive index 1.55 if its focal length is 20 cm?
[1] 22 cm
[2] 25 cm
[3] 30 cm
[4] 32 cm

60. A convex lens of focal length 0.15 m is made of a material of refractive index 3/2. When it is placed in a liquid, its focal length is increased by 0.225 m. The refractive index of the liquid is
[1] 7/4
[2] 5/4
[3] 9/4
[4] 3/2.

61. A convex lens made up of material of refractive index μ_1, is immersed in a medium of refractive index μ_2 as shown in the figure. The relation between μ_1 and μ_2 is



[1] $\mu_1 < \mu_2$
[2] $\mu_1 > \mu_2$
[3] $\mu_2 = \mu_2$
[4] $\mu_2 = \sqrt{\mu_2}$

62. An equiconvex crown glass lens has a focal length 20 cm for violet rays. Its focal length for red rays is ($\mu_v = 1.5$ and $\mu_r = 1.47$)
[1] 20.82 cm
[2] 21.28 cm
[3] 22.85 cm
[4] 24.85 cm

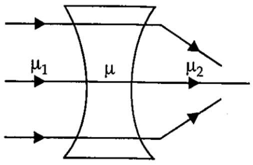
63. The focal length of the lens of refractive index (μ= 1.5) in air is 10 cm. If air is replaced by water of μ = 4/3, its focal length is
[1] 20 cm
[2] 30 cm
[3] 40 cm
[4] 25 cm

64. What is the refractive index of material of a plano-convex lens, if the radius of curvature of

the convex surface is 10 cm and focal length of the lens is 30 cm?

[1] 6/5 [2] 7/4
[3] 2/3 [4] 4/3

65. If the behaviour of light rays is as shown in the figure. The relation between refractive indices μ, μ_1 and μ_2 is



[1] $\mu > \mu_1 > \mu_2$
[2] $\mu < \mu_1 < \mu_2$
[3] $\mu < \mu_2$, $\mu = \mu_1$
[4] $\mu_2 < \mu_1$, $\mu = \mu_2$

66. An equiconvex lens of glass of focal length 0.1 m is cut along a plane perpendicular to principal axis into two equal parts. The ratio of focal length of new lenses formed is

[1] 1 : 1 [2] 1 : 2
[3] 2 : 1 [4] 2 : 1/2

Thin lens formula and magnification

67. A concave lens forms the image of an object such that the distance between the object and image is 10 cm and the magnification produced is 1/4. The focal length of the lens will be

[1] – 6.2 cm [2] – 4.4 cm
[3] – 8.6 cm [4] – 10cm

68. 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. The focal length of the lens is

[1] 770/36 cm [2] 77/36 cm
[3] 36/770 cm [4] 360/77 cm.

69. The distance between an object and a divergent lens is m times the focal length of the lens. The linear magnification produced by the lens will be equal to

[1] m [2] 1/m [3] m + 1 [4] 1/m+1

70. The image of an electric bulb fixed in a wall is to be obtained on the wall opposite to it at a distance of 3 m. The maximum possible focal length of the convex lens is

[1] 3.25 m [2] 1.55 m
[3] 0.75 m [4] 0.28 m

Power of a lens

71. A thin glass (refractive index 1.5) lens has optical power of –8 D in air. Its optical power in a liquid medium with refractive index 1.6 will be

[1] 1D [2] –1D [3] 25 D [4] –25 D

72. The power of a biconvex lens is 10 dioptre and the radius of curvature of each surface is 10 cm. Then the refractive index of the material of the lens is

[1]3/2 [2] 4/3
[3] 9/8 [4] 5/3.

Combination of thin lenses in contact

73. Two identical glass (μ_g = 3/2) equiconvex lenses of focal length f are kept in contact. The space between the two lenses is filled with water (μ_w = 4/3). The focal length of the combination is

[1] f [2] f/2
[3] 4/3 f [4] 3/4 f.

74. Two thin equiconvex lenses each of focal length 0.2 m are placed coaxially with their optic centres 0.5 m apart. Then the focal length of the combination is

[1] – 0.4 m [2] 0.4 m
[3] – 0.1 m [4] 0.1 m

75. The size of the image of an object, which is at infinity, as formed by a convex lens of focal length 30 cm is 2cm. 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, the new size of the image is

[1] 1.25 cm [2] 2.5 cm
[3] 1.05 cm [4] 2 cm

76. The power of a convex lens is 2 dioptres. Its power is to be reduced to 1.5 dioptres, by putting

another lens in combination with it. Which of the following lenses will serve the purpose?
[1] A concave lens of focal length 2 m.
[2] A concave lens of focal length 4 m.
[3] A convex lens of focal length 2 m.
[4] A concave lens of focal length 1 m.

77. A lens of power 6 D is put in contact with a lens of power -4 D. The combination will behave like a
[1] Divergent lens of focal length 25 cm
[2] Convergent lens of focal length 50 cm
[3] Divergent lens of focal length 20 cm
[4] Convergent lens of focal length 100 cm

78. A convex lens A of focal length 20 cm and a concave lens B 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 a parallel beam, then the distance d in cm will be
[1] 25 [2] 15 [3] 30 [4] 50

79. Two thin lenses have a combined power of +9 D. When they are separated by a distance of 20 cm, their equivalent power becomes + 27/5 D. Their individual powers (in dioptres) are
[1] 1, 8 [2] 2, 7
[3] 3, 6 [4] 4, 5

Combination of a lens and a mirror

80. The plane face of a plano-convex 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 focal length
[1] μR (b) R/2(μ – 1)
[3] R^2/μ [4] [(μ + 1)/(μ – 1)]R.

81. A point object is placed at a distance of 12 cm on the axis of a convex lens of focal length 10 cm.
On the other side of the lens, a convex mirror is placed at a distance of 10 cm from the lens such that the image formed by the combination coincides with the object itself. What is the focal length of convex mirror?
[1] 25 cm [2] 50 cm
[3] 10 cm [4] 20 cm

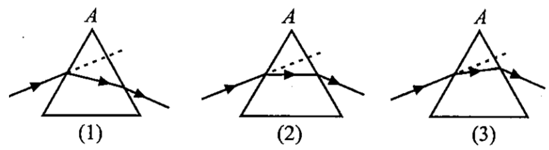
Refraction and dispersion of light through a prism

82. If one face of a prism of prism angle 30° and $\mu = \sqrt{2}$ is silvered, the incident ray retraces its initial path. The angle of incidence is
[1] 60° [2] 30°
[3] 45° [4] 90°

83. A thin prism P_1 with angle 4° 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. What is the angle of the prism P_2 ?
[1] 3° [2] 6° [3] 9° [4] 12°

84. When white light moves through vacuum
[1] All colours have same speed
[2] Different colours have different speeds
[3] Violet has more speed than red
[4] Red has more speed than violet.

85. The given figure shows three cases of a ray passing through a prism of refracting edge A. The case corresponding to minimum deviation is



[1] 1 [2] 2 [3] 3 [4] None

86. A ray of light passes through an equilateral prism such that the angle of incidence is equal to the angle of emergence and the latter is equal to 3/4th of the angle of prism. The angle of deviation is
[1] 45° [2] 39°
[3] 20° [4] 30°.

87. A ray of light passes through an equilateral prism (μ = 1.5). The angle of minimum deviation

is (Given sin 48°36' = 0.75)
[1] 45° [2] 37°12' [3] 20° [4] 30°

88. Which colour shows maximum deviation when passed through a prism?
[1] Yellow [2] Red
[3] Violet [4] Green

89. A ray of light is incident normally on one of the faces of a prism of apex angle 30° and refractive index $\sqrt{2}$. The angle of deviation of the ray is
[1] 0° [2] 12.5°
[3] 15° [4] 22.5°

90. A prism of refractive index 1.5 is placed in water of refractive index 1.33. The refracting angle of a prism is 60°. What is the angle of minimum deviation in water? (Given sin 34° = 0.56)
[1] 4° [2] 8° [3] 12° [4] 16°

91. A prism of certain angle deviates the red and blue rays by 8° and 12° respectively. Another prism of the same angle deviates the red and blue rays by 10° and 14° respectively. The prisms are small angled and made of different materials. The dispersive powers of the materials of the prisms are in the ratio
[1] 5 : 6 [2] 9 : 11
[3] 6 : 5 [4] 11 : 9

92. Dispersive power depends on the
[1] Material of the prism
[2] Shape of the prism
[3] Size of the prism
[4] Size, shape and material of the prism.

93. A ray is incident at an angle of incidence i on one surface of a prism of small angle A and emerges normally from opposite surface. If the refractive index of the material of prism is μ, the angle of incidence i is nearly equal to
[1] – A/μ [2] A/2μ
[3] μA [4] μA/2.

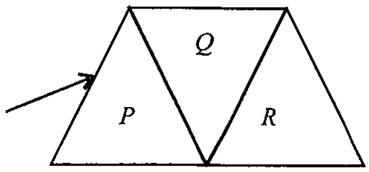
94. A prism of refractive index μ and angle A is placed in the minimum deviation position. If the angle of minimum deviation is A, then the value of A in terms of p is
[1] $\sin^{-1}(\mu/2)$ [2] $\sin^{-1}\left(\sqrt{\frac{\mu-1}{2}}\right)$
[3] $2\cos^{-1}(\mu/2)$ [4] $\cos^{-1}(\mu/2)$

95. A ray of light is incident at 60 (d °)on one face of a prism of angle 30° and the emergent ray makes 30° with the incident ray. The refractive index of the prism is
[1] 1.732 [2] 1.414
[3] 1.5 [4] 1.33

96. For an angle of incidence θ on an equilateral prism of refractive index $\sqrt{3}$, the ray refracted is parallel to the base inside the prism. The value of θ is
[1] 30° [2] 45°
[3] 60° [4] 75°

97. The angle of minimum deviation in an equilateral prism of refractive index 1.414 is
[1] 60° [2] 30° [3] 90° [4] 45°

98. A ray of light suffers minimum deviation in equilateral prism P. Additional prisms Q and R of identical shape and of same material as that of P are now combined as shown in figure. The ray will now suffer

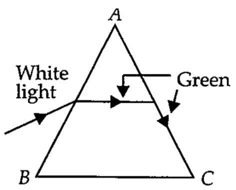


[1] Greater deviation [2] No deviation
[3] Same deviation as before
[4] Total internal reflection.

99. Two beams of red and violet colours are made to pass separately through a prism of A = 60°. In the minimum deviation position, the angle of refraction inside the prism will be
[1] Greater for red colour
[2] Equal but not 30° for both the colours
[3] Greater for violet colour
[4] 30° for both the colours.

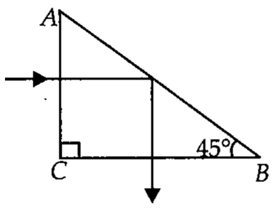
100. A ray of light passes through an equilateral prism such that the angle of incidence is equal to emergence and later is equal to (3/4)th the angle of prism. The angle of deviation is
[1] 45° [2] 20°
[3] 39° [4] 30°

101. White light is incident on face AB of a glass prism. The path of the green component is shown in the figure. If the green light is just totally internally reflected at face AC as shown, the light emerging from face AC will contain



[1] Yellow, orange and red colours
[2] Violet, indigo and blue colours
[3] All colours
[4] All colours except green.

102. A ray of light incident normally on one of the faces of a right angle prism is found to be totally reflected as shown in figure. What is the minimum value of the refractive index of the material of the prism?
[1] $\sqrt{2}$
[2] $\sqrt{3/2}$
[3] 4/3
[4] 3/4



Scattering of Light

103. Check the correct statements on scattering of light.
S1 : Rayleigh scattering is responsible for the bluish appearance of sky.
S2 : Rayleigh scattering is proportional to $1/\lambda^4$ when the size of the scatterer is much less than λ.
S3 : Clouds having droplets of water (large scattering objects) scatter all wavelengths are almost equal and so are generally white.
S4 : The sun looks reddish at sunset and sunrise due to Rayleigh scattering.
[1] S1 only [2] S1 and S2
[3] S2 and S3 [4] S1, S2 and S3

104. When sunlight is scattered by atmospheric atoms and molecules, the amount of scattering of light of wavelength 440 nm is A. The amount of scattering for the light of wavelength 660 nm is approximately
[1] 4/9 A [2] 2.25 A
[3] A/5 [4] 0.66 A.

105. When sunlight is scattered by minute particles of atmosphere, the intensity of light scattered away is directly proportional to
[1] $(\text{wavelength of light})^4$
[2] $(\text{frequency of light})^4$
[3] $(\text{wavelength of light})^2$
[4] $(\text{frequency of light})^2$

Human Eye

106. An under-water swimmer cannot see very clearly even in absolutely clear water because of
[1] Absorption of light in water
[2] Scattering of light in water
[3] Reduction of speed of light in water
[4] Change in the focal length of eye lens.

107. The power and type of lens by which a person can see clearly the distant objects, if the person cannot see objects beyond 40 cm, are
[1] – 2.5 D and concave lens
[2] – 2.5 D and convex lens
[3] – 3.5 D and concave lens
[4] – 3.5 D and convex lens

108. Different objects at different distances arc seen by the eye. The parameter that remains constant is
[1] The focal length of the eye lens
[2] The object distance from the eye lens
[3] The radii of curvature of the eye lens
[4] The image distance from the eye lens.

109. A man's near point is 0.5 m and far point is 3 m. Power of spectacle lenses required for (i) reading purposes, (ii) seeing distant objects, respectively, are

[1] –2 D and +3 D [2] + 2 D and –3 D
[3] +2 D and – 0.33 D [4] – 2 D and +0.33 D

110. The least distance of distinct vision of a person is 75 cm. The focal length of the reading spectacles for such a person should be
[1] 37.5 cm [2] 40 cm
[3] 25 cm [4] 50 cm

Microscope and astronomical telescopes (refracting and reflecting)

111. The image formed by an objective of a compound microscope is
[1] Virtual and diminished
[2] Real and diminished
[3] Real and enlarged
[4] Virtual and enlarged

112. Magnifying power of telescope can be increased by
[1] Increasing the length of telescope
[2] Increasing focal length of objective
[3] Increasing the diameter of objective
[4] Increasing the focal length of eye piece.

113. If the ratio of magnifications produced by a simple microscope in near point adjustment and far point adjustment is 6/5, then the focal length of the lens is (Take D = 25 cm)
[1] 5 cm [2] 10 cm
[3] 55 cm [4] 0.2 cm

114. The objective of a compound microscope is essentially
[1] A concave lens of small focal length and small aperture
[2] Convex lens of small focal length and large aperture
[3] Convex lens of large focal length and large aperture
[4] Convex lens of small focal length and small aperture.

115. The length of a telescope is 36 cm. The focal lengths of its lenses can be
[1] 30 cm, 6 cm [2] – 30 cm, – 6 cm
[3] 30 cm, – 6 cm [4] – 30 cm, 6 cm

116. The magnifying power of an astronomical telescope is 8 and the distance between the two lenses is 54 cm. The focal lengths of eye lens and objective lens will be respectively
[1] 6 cm and 48 cm [2] 48 cm and 6 cm
[3] 8 cm and 64 cm [4] 64 cm and 8 cm

117. In a laboratory, four convex lenses L_1 L_2, L_3 and L_4 of focal lengths 2, 4, 6, and 8 cm respectively are available. Two of these lenses form a telescope of length 10 cm and magnifying power 4. The objective and eye lenses mare respectively.
[1] L_2, L_3 [2] L_1, L_4
[3] L_1, L_2 [4] L_4, L_1

118. A telescope has an objective lens of focal length 200 cm and an eye piece 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?
[1] 5 cm [2] 10 cm
[3] 1 cm [4] 2 cm.

119. Magnification at least distance of distinct vision of a simple microscope having its focal length 5 cm is
[1] 2 [2] 4 [3] 5 [4] 6

120. Focal length of objective and eye piece of telescope are 200 cm and 4 cm respectively. What is the length of telescope for normal adjustment?
[1] 196 cm [2] 204 cm
[3] 250 cm [4] 225 The focal

121. lengths of the objective and of the eye-piece of a compound microscope are/, and fe respectively. If L is the tube length and D, the least distance of distinct vision, then its angular magnification, when the image is formed at infinity, is

122. The focal lengths of the objective and of the eye-piece of a compound microscope are f_0 and f_e respectively. If L is the tube length and D, the least distance of distinct vision, then its angular magnification, when the image is formed at infinity, is

[1] $\left(1-\frac{L}{f_0}\right)\left(\frac{D}{f_e}\right)$ [2] $\left(1-\frac{L}{f_0}\right)\left(\frac{D}{f_e}\right)$

[3] $\left(1-\frac{L}{f_0}\right)\left(\frac{D}{f_e}\right)$ [4] $\left(1-\frac{L}{f_0}\right)\left(\frac{D}{f_e}\right)$

123. A square card of side length 1 mm is being seen through a magnifying lens of focal length 10 cm. The card is placed at a distance of 9 cm from the lens. The apparent area of the card through the lens is

[1] 1 cm^2 [2] 0.81 cm^2

[3] 0.27 cm^2 [4] 0.60 cm^2

124. When a telescope is in normal adjustment, the distance of the objective from the eyepiece is found to be 100 cm. If the magnifying power of the telescope, at normal adjustment, is 24, the focal lengths of the lenses are

[1] 96 cm, 4 cm [2] 48 cm, 2 cm

[3] 50 cm, 50 cm [4] 80 cm, 20 cm

Wave front and Huygens principle

125. Spherical wave fronts, emanating from a point source, strike a plane reflecting surface. What will happen to these wave fronts, immediately after reflection?

[1] They will remain spherical with the same curvature, both in magnitude and sign.

[2] They will become plane wave fronts.

[3] They will remain spherical, with the same curvature, but sign of curvature reversed.

[4] They will remain spherical, but with different curvature, both in magnitude and sign.

126. A point source that emits waves uniformly in all directions, produces wavefronts that are

[1] Spherical [2] Elliptical

[3] Cylindrical [4] Planar

Reflection and refraction of plane wave at a plane surface

127. The refractive index of glass is 1.9. If light travels through a glass slab of thickness d in time t and takes the same time to travel through a transparent beaker filled with water upto a level of 1.5 d, then the refractive index of water is

[1] 1.27 [2] 1.33

[3] 1.20 [4] 1.50

128. Light propagates 2 cm distance in glass of refractive index 1.5 in time t_0. In the same time t_0, light propagates a distance of 2.25 cm in a medium. The refractive index of the medium is

[1] 4/3 [2] 3/2

[3] 8/3 [4] 1/2

129. Light of wavelength 5000 Å falls on a plane reflecting surface. For what angle of incidence is the reflected ray normal to the incident ray?

[1] 0° [2] 30°

[3] 90° [4] 45°

130. The time required for the light to pass through a glass slab (refractive index = 1.5) of thickness 4 mm is ($c = 3 \times 10^8$ m s^{-1}, speed of light in free space)

[1] 10^{-11} s [2] 2×10^{-11} s

[3] 2×10^{-11} s [4] 2×10^{-5} s

131. Light of certain colour has 2000 waves to the milli metre in air. What will be the wavelength of this light in a medium of refractive index 1.25?

[1] 1000 Å [2] 2000 Å

[3] 3000 Å [4] 4000 Å.

Interference

132. In Young's double slit experiment, the wavelength of light was changed from 7000 Å to 3500 Å . While doubling the separation between the slits, which of the following is not true for this experiment?

[1] The width of fringes changes.
[2] The colour of bright fringes changes.
[3] The separation between successive bright fringes changes.
[4] The separation between successive dark fringes remains unchanged.

133. In the Young's double slit experiment, a mica slab of thickness t and refractive index μ is introduced in the ray from first source S_1. By how much distance, fringes pattern will be displaced?

[1] $\frac{d}{D}(\mu-1)t$ [2] $\frac{D}{d}(\mu-1)t$

[2] $\frac{d}{(\mu-1)D}$ [4] $\frac{D}{d}(\mu-1)$

134. The two coherent sources with intensity ratio β produce interference. The fringe visibility will be

[1] $\frac{2\sqrt{\beta}}{1+\beta}$ [2] 2β

[3] $\frac{2}{(1+\beta)}$ [4] $\frac{\sqrt{\beta}}{1+\beta}$

135. Two slits,4 mm apart, are illuminated by light of wavelength 6000 Å. What will be the fringe width on a screen placed 2 m far from the slits?
[1] 0.12 mm   [2] 0.3 mm
[3] 3.0 mm   [4] 4.0 mm

136. Soap bubble looks coloured due to
[1] Dispersion   [2] Reflection
[3] Interference   [4] None of these

137. In Young's double slit experiment, the two slits are 0.2 mm apart. The interference fringes for light of wavelength 6000 Å are found on the screen 80 cm away. The distance of fifth dark fringe, from the central fringe, will be
[1] 6.8 mm   [2] 7.8 mm
[3] 9.8 mm   [4] 10.8 mm

138. If an interference pattern has maximum and minimum intensity in the ratio of 36 : 1, then what will be the ratio of amplitudes ?
[1] 5 : 7   [2] 7 : 4
[3] 4 : 7   [4] 7 : 5

139. In Young's double slit experiment, the wave – length of red light is 7.8 x 10^{-5} cm and that of blue light 5.2 x 10^{-5} cm. The value of n for which $(n + 1)^{th}$ blue bright band coincides with n^{th} red band is
[1] 4   [2] 3   [3] 2   [4] 1

140. In Young's double slit experiment, 62 fringes are visible in the field of view with sodium light (λ= 5893 Å). If green light (λ = 5461 v) is used, then the number of visible fringes will be
[1] 62   [2] 67   [3] 85   [4] 55

141. In a Young's double slit experiment, the intensity at a point where the path difference is λ/6 (λ being the wavelength of light used) is I. If I_0 denotes the maximum intensity, I/I_0 is equal to
[1] 3/4   [2] $1/\sqrt{2}$ [3] $\sqrt{3}/2$ [4] 1/2.

142. Which of the following is false for interference of light?
[1] Coherence of the sources is an essential condition for interference.
[2] The minima of the interference pattern need not be of zero intensity.
[3] Interference simply redistributes light energy, without destroying any of it.
[4] The minima of the interference pattern must always be of zero intensity.

143. Two sources of light of wavelength 2500Å and 3500 Å are used in Young's double slit experiment simultaneously. Which orders of fringes of two wavelength patterns coincide ?
[1] 3^{rd} order of 1^{st} source and 5^{th} of the 2nd
[2] 7^{th} order of 1^{st} and 5^{th} order of 2nd
[3] 5^{th} order of 1^{st} and 3^{rd} order of 2nd
[4] 5^{th} order of 1^{st} and 7^{th} order of 2nd

144. The two slits are 1 mm apart from each other and illuminated with a light of wavelength 5 x 10^{-7} m. If the distance of the screen is 1 m from the slits, then the distance between third dark fringe and fifth bright fringe is
[1] 1.5 mm   [2] 0.75 mm
[3] 1.25 mm   [4] 0.625 mm

145. In Young's double slit experiment, the distance between the two slits is 0.1 mm and wavelength of light used is 4×10^{-7} m. If the width of fringe on screen is 4 mm, the distance between screen and slits is
[1] 0.1 mm [2] 1 cm
[3] 0.1 cm [4] 1 m

146. In Young's double slit experiment, fringes are obtained using light of wavelength 4800 Å. One slit is covered with a thin glass film of refractive index 1.4 and another slit is covered by a film of same thickness but refractive index 1.7. By doing so, the central fringe is shifted to fifth bright fringe in the original pattern. The thickness of glass film is
[1] 2×10^{-3} mm [2] 4×10^{-3} mm
[3] 6×10^{-3} mm [4] 8×10^{-3} mm

147. In a Young's double slit experiment, d = 0.5 mm and D = 100 cm. It is found that 9^{th} bright fringe is at a distance of 7.5 mm from the second dark fringe of fringe pattern. The wavelength of light used is (in Å)
[1] 2500/7 [2] 2500
[3] 5000 [4] 5000/7.

148. In certain Young' double slit experiment the slit separation is 0.05 cm. The slit to screen distance is 100 cm. When blue light is used, the distance from central fringe to the fourth order bright fringe is 0.36 cm. What is the wavelength of blue light ?
[1] 4000 Å [2] 4300 Å
[3] 4400 Å [4] 4500 Å

149. The intensity ratio of the maxima and minima in an interference pattern produced by two coherent sources of light is 9 : 1. The intensities of the used light sources are in ratio
[1] 3 : 1 [2] 4 : 1
[3] 9 : 1 [4] 10 : 1

150. In Young's double slit experiment, first slit has width four times the width of the second slit. The ratio of the maximum intensity to the minimum intensity in the interference fringe system is
[1] 2 : 1 [2] 4: 1
[3] 9 : 1 [4] 8 : 1

151. Young's double slit experiment is performed in a liquid. The 10^{th} bright fringe in liquid lies where 6^{th} dark fringe lies in air. The refractive index of the liquid is approximately
[1] 1.2 [2] 1.6
[3] 1.5 [4] 1.8

152. In Young's double slit experiment, the slits are horizontal. The intensity at a point P as shown in figure is 3/4 I_0 , where I_0 is the maximum intensity. Then the value of θ is, (Given the distance between the two slits S_1 and S_2 is 2λ)
[1] $\cos^{-1}(1/12)$ [2] $\sin^{-1}(1/12)$
[2] $\tan^{-1}(1/12)$ [4] $\sin^{-1}(3/5)$

153. The slits in Young's double slit experiment are illuminated by light of wavelength 6000 Å. If the path difference at the central bright fringe is zero, what is the path difference for light from the slits at the fourth bright fringe?
[1] $2.4. \times 10^{-6}$ m [2] 1.2×10^{-6} m
[3] 10^{-6} m [4] 0.5×10^{-6} m

154. In a Young's double slit experiment, the angular width of a fringe formed on a distant screen is 1°. The slit separation is 0.01 mm. The wavelength of the light is
[1] 0.174 nm [2] 0.174 Å
[3] 0.174 μm [4] 0.174×10^{-4} m

155. Light from two coherent sources of the same amplitude A and wavelength λ illuminates the screen. The intensity of the central maximum is I_0. If the sources were incoherent, the intensity at the same point will be
[1] $4I_0$ [2] $2 I_0$ [3] I_0 [4] $I_0/2$

156. In a Young's double slit experiment, let S_1 and S_2 be the two slits, and C be the centre of the screen. If $\angle S_1 C S_2 = \theta$ and λ is the wavelength, the fringe width will be

[1] λ/θ [2] $\lambda\theta$
[3] $2\lambda/\theta$ [4] $\lambda/2\theta$

157. When interference of light takes place
[1] Energy is created in the region of maximum intensity
[2] Energy is destroyed in the region of maximum intensity
[3] Conservation of energy holds good and energy is redistributed
[4] Conservation of energy does not hold good.

158. In an interference experiment using waves of same amplitude, path difference between the waves at a point on the screen is $\lambda/4$. The ratio of intensity at this point with that at the central bright fringe is
[1] 1 [2] 0.5 [3] 1.5 [4] 2.0

159. The ratio of maximum and minimum intensities in the interference pattern of two sources is 4 : 1. The ratio of their amplitudes is
[1] 1 : 3 [2] 3 : 1
[3] 1 : 9 [4] 1 : 16

160. In Young's double slit experiment, one of the slits is wider than the other, so that the amplitude of the light from one slit is double that from the other slit. If I_m be the maximum intensity, the resultant intensity when they interfere at phase difference ϕ is given by
[1] $\frac{I_m}{3}\left(1+2\cos^2\frac{\phi}{2}\right)$ [2] $\frac{I_m}{5}\left(1+4\cos^2\frac{\phi}{2}\right)$
[3] $\frac{I_m}{9}\left(1+8\cos^2\frac{\phi}{2}\right)$ [4] $\frac{I_m}{9}\left(8+\cos^2\frac{\phi}{2}\right)$

161. Interference fringes were produced in Young's double slit experiment using light of wavelength 5000 Å. When a film of material 2.5 x 10^{-3} cm thick was placed over one of the slits, the fringe pattern shifted by a distance equal to 20 fringe widths. The refractive index of the material of the film is
[1] 1.25 [2] 1.33
[3] 1.4 [4] 1.5

162. Two monochromatic light waves of amplitudes A and 2A interfering at a point have a phase difference of 60°. The intensity at that point will be proportional to
[1] $3A^2$ [2] $5A^2$
[3] $7A^2$ [4] $9A^2$

163. In a double slit experiment, the coherent sources are spaced 2d apart and the screen is placed at a distance D from the slit. If n^{th} bright fringe is formed on the screen exactly opposite to a slit, the value of n must be
[1] $d^2/2\lambda D$ [2] $2d^2/\lambda D$
[3] $d^2/\lambda D$ [4] $d^2/4\lambda D$.

164. In an interference experiment, two parallel vertical slits S_1 and S_2 are used. A thin glass plate is introduced in the path of light from S_1. Then
[1] Fringe pattern remains unaltered
[2] Fringe pattern as a whole is laterally shifted towards S_1
[3] Fringe pattern as a whole is laterally shifted towards S_2
[4] Fringe width decreases.

165. In Young's double slit experiment, if d, D and λ represent the distance between the slits, the distance of the screen from the slits and wavelength of light used respectively, then the band width is inversely proportional to
[1] λ [2] d [3] D [4] λ^2

166. Young's experiment is performed with light of wavelength 6000 Å wherein 16 fringes occupy a certain region on the screen. If 24 fringes occupy the same region with another light, of wavelength λ , then λ is
[1] 6000 Å [2] 4500 Å
[3] 5000 Å [4] 4000 Å.

167. In a two slit experiment with monochromatic light, fringes are obtained on a screen placed at some distance from the plane of slits. If the screen is moved by 5 x 10^{-2} m . towards the slits, the change in fringe width is 3 x 10^{-5}m.

If the distance between slits is 10-3 m, the wavelength oflight will be

[1] 3000 □ [2] 4000 □
[3] 6000 □ [4] 7000 □

168. In a Young's double slit experiment (slit distance d) monochromatic light of wavelength λ is used and the fringe pattern observed at a distance L from the slits. The angular position of the bright fringes are

[1] $\sin^{-1}(N\lambda/d)$ [2] $\sin^{-1}\left(\frac{\left(N+\frac{1}{2}\right)\lambda}{d}\right)$
[3] $\sin^{-1}(N\lambda/d)$ [4] $\sin^{-1}\left(\frac{\left(N+\frac{1}{2}\right)\lambda}{L}\right)$

169. In Young's double slit experiment, the distance between the centres of adjacent fringes is 0.10 mm. If the distance of the screen from the slits is doubled, the distance between the slits is halved and the wavelength of light is changed from 6.4 x 10^{-7} m to 4.0 x 10^{-7} m, then the new distance between the fringes will be

[1] 0.10 mm [2] 0.15 mm
[3] 0.20 mm [4] 0.25 mm

170. What is the minimum thickness of a thin film required for constructive interference in the reflected light from it? Given, the refractive index of the film = 1.5, wavelength of the light incident on the film = 600 nm.

[1] 100 nm [2] 300 nm
[3] 50 nm [4] 200 nm

171. In a double-slit experiment, the two slits are separated by one millimetre and the screen is placed one metre away. The fringe separation for blue green light of wavelength 500 nm is

[1] 10 mm [2] 0.5 mm
[3] 20 mm [4] 15 mm

172. In the case of light waves from two coherent sources S_1 and S_2, there will be constructive interference at an arbitrary point P, if the path difference $S_1P - S_2P$ is

[1] $\left(n+\frac{1}{2}\right)\lambda$ [2] nλ
[3] $\left(n-\frac{1}{2}\right)\lambda$ [4] λ/2.

173. Two beams of light having intensities I and 4I interfere to produce a fringe pattern on a screen. The phase difference between the beams is π/2 at point A and π at point B. Then the difference between the resultant intensities at A and B is

[1] 2I [2] 4I [3] 5I [4] 7I

174. In Young's double slit experimental setup, if the wavelength alone is doubled, the band width P becomes

[1] β/2 [2] 2β
[3] 4β [4] β

Diffraction

175. 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

[1] 1.2 cm [2] 1.2 mm
[3] 2.4 cm [4] 2.4 mm

176. A single slit of width a 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 illuminated by yellow light of wavelength 600 nm , the width of the diffraction pattern is

[1] Zero and the pattern vanishes.
[2] y/3 [2] 3y [4] none of these

177. For what distance is ray optics a good approximation when the aperture is 4 mm wide and the wavelength is 400 nm ?

[1] 20 m [2] 40 m
[3] 30 m [4] 50 m

178. Light of wavelength λ is incident on a slit of width d. The resulting diffraction pattern is observed on a screen at a distance D. The linear width of the principal maximum is equal to the width of the slit, if D equals

[1] $d^2/2\lambda$ [2] d/λ
[3] $2\lambda^2/d$ [4] 2λ/d.

179. 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?
[1] $3I_0$ [2] I_0 [3] $4I_0$ [4] $2I_0$

180. A narrow slit of width 2 mm is illuminated by monochromatic light of wavelength 500 nm. The distance between the first minima on either side on a screen at a distance of 1 m is
[1] 5 mm [2] 0.5 mm
[3] 1 mm [4] 10 mm

181. A diffraction pattern is obtained using a beam of red light. What happens if the red light is replaced by blue light?
[1] No change.
[2] Diffraction bands become narrower and crowded together.
[3] Band become broader and farther apart.
[4] Bands disappear altogether.

182. A parallel beam of light of wavelength 6000 Å gets diffracted by a single slit of width 0.3 mm. The angular position of the first minima of diffracted light is
[1] 2×10^{-3} rad [2] 3×10^{-3} rad
[3] 1.8×10^{-3} rad [4] 6×10^{-3} rad

183. A parallel beam of monochromatic 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
[1] Zero [2] $\pi/2$
[3] π [4] 2π.

Resolving power of optical instruments

184. A telescope, whose objective lens has an aperture of 1 mm for the wavelength of light 500 Å, then limiting resolving power of the telescope is
[1] 2.1×10^{-5} rad [2] 4.1×10^{-5} rad
[3] 5.1×10^{-5} rad [4] 6.1×10^{-5} rad

185. The head lights of a jeep are 1.2 m apart. If the pupil of the eye of an observer has a diameter of 2 mm and light of wavelength 5896 Å is used, what should be the maximum distance of the jeep from the observer if the two head lights are just separated?
[1] 33.4 km [2] 33.4 m
[3] 3.34 km [4] 3.34 m

186. Two point white dots are 1 mm 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]
[1] 6 m [2] 3 m
[3] 5 m [4] 1 m

187. The resolving power of a microscope is
[1] Inversely proportional to numerical aperture
[2] Directly proportional to wavelength
[3] Directly proportional to numerical aperture
[4] Independent of numerical aperture.

Polarisation

188. The angle of incidence at which reflected light is totally polarized for reflection from air to glass (refractive index μ), is
[1] $\sin^{-1}(\mu)$ [2] $\sin^{-1}(1/\mu)$
[3] $\tan^{-1}(1/\mu)$ [4] $\tan^{-1}(\mu)$

189. A ray of light is incident on the surface of glass plate of refractive index 1.55 at the polarising angle. The angle of refraction is
[1] 75°11' [2] 32°50'
[3] 147°11' [4] 0°

190. The critical angle of a certain medium is $\sin^{-1}$ (3/5). The polarizing angle of the medium is
[1] $\sin^{-1}$ (4/5) [2] $\tan^{-1}$ (5/3)
[3] $\tan^{-1}$(3/4) [4] $\tan^{-1}$ (4/3)

191. When light is incident at polarizing angle, which one is completely polarized?
[1] Reflected light
[2] Refracted light
[3] (1) and (2) both
[4] Neither (1) nor (2)

192. When the angle of incidence is 60° on the surface of a glass slab, it is found that the reflected ray is completely polarized. The velocity of light in glass is
[1] $\sqrt{2}$ x 10^8 ms^{-1}
[2] $\sqrt{3}$ x 10^8 ms^{-1}
[3] 2 x 10^8 ms^{-1}
[4] 3 x 10^8 ms^{-1}

193. If the polarizing angle of a piece of glass for green light is 54.74°, then the angle of minimum deviation for an equilateral prism made of same glass is(Given : tan 54.74° = 1.414)
[1] 45° [2] 54.74°
[3] 60° [4] 30°

194. Angle between the plane of vibration and plane of polarization is
[1] 30° [2] 90°
[3] 60° [4] 70°

195. An unpolarized light beam is incident on a surface at an angle of incidence equal to Brewster's angle. Then,
[1] The reflected and the refracted beams are both partially polarized,
[2] The reflected beam is partially polarized and the refracted beam is completely polarized and are at right angles to each other.
[3] The reflected beam is completely polarized and the refracted beam is partially polarized and are at right angles to each other.
[4] Both the reflected and the refracted beams are completely polarized and are at right angles to each other.

196. Two linear polarizers are crossed at an angle of 60°. The fraction of intensity of light transmitted by the pair is
[1] 1/4 [2] 1/8
[3] 3/8 [4] 1/2.

197. A beam of natural light falls on a system of 5 polaroids, which are arranged in succession such that the pass axis of each polaroid is turned through 60° with respect to the preceding one. The fraction of the incident light intensity that passes through the system is
[1] 1/64 [2] 1/32
[3] 1/256 [4] 1/512.

198. A transparent thin plate of a polaroid is placed on another similar plate such that the angle between their axes is 30°. The intensities of the emergent and the unpolarized incident light will be in the ratio of
[1] 1 : 4 [2] 1 : 3
[3] 3 : 4 [4] 3 : 8

199. Light is incident on a glass surface at polarizing angle of 57.5°. Then the angle between the incident ray and the refracted ray is
[1] 57.5° [2] 115°
[3] 205° [4] 145°

200. The velocity of light in air is 3 x 10^8 m s^{-1} and that in water is 2.2 x 10^8 m s^{-1}. The polarising angle of incidence is
[1] 45° [2] 50°
[3] 53.74° [4] 63°

PREVIOUS YEAR

1. The ratio of resolving powers of an optical microscope for two wavelength λ_1 = 4000 Å and λ_2 = 6000 Å is
[1] 9 : 4 [2] 3 : 2
[3] 16 : 81 [4] 8 : 27

2. Young's double slit experiment is first performed in air and then in a medium other than air. It is found that 8^{th} bright fringe in the medium lies where 5^{th} dark fringe lies in

air. The refractive index of the medium is nearly

[1] 1.59 [2] 1.69
[3] 1.78 [4] 1.25

3. A beam of light from a source L is incident normally on a plane mirror fixed at a certain distance x from the source. The beam is reflected back as a spot on a scale placed just above the source L. When the mirror is rotated through a small angle θ, the spot of the light is found to move through a distance y on the scale. The angle θ is given by

[1] $\frac{y}{x}$ [2] $\frac{x}{2y}$
[3] $\frac{x}{y}$ [4] $\frac{y}{2x}$

4. A thin prism having refracting angle 10° is made of glass of refractive index 1.42. This prism is combined with another thin prism of glass of refractive index 1.7. This combination produces dispersion without deviation. The refracting angle of second prism should be

[1] 6° [2] 8°
[3] 10° [4] 4°

5. Two polaroids P1 and P2 are placed with their axis perpendicular to each other. Un polarised light I0 is incident on P1. A third polaroid P3 is kept in between P1 and P2 such that its axis makes an angle 45° with that of P1. The intensity of transmitted light through P2 is

[1] $\frac{I_0}{4}$ [2] $\frac{I_0}{8}$
[3] $\frac{I_0}{16}$ [4] $\frac{I_0}{2}$

6. Two identical glass (μg = 3/2) equiconvex lenses of focal length f each are kept in contact. The space between the two lenses is filled with water (μw = 4/3). The focal length of the combination is

[1] $f/3$ [2] f
[3] $4f/3$ [4] $3f/4$

7. An air bubble in a glass slab with refractive index 1.5 (near normal incidence) is 5 cm deep when viewed from one surface and 3 cm deep when viewed from the opposite face. The thickness (in cm) of the slab is

[1] 8 [3] 10
[3] 12 [4] 16

8. The interference pattern is obtained with two coherent light sources of intensity ratio n. In the interference pattern, the ratio

$\frac{I_{max} - I_{min}}{I_{max} + I_{min}}$ will be

[1] $\frac{\sqrt{n}}{n+1}$ [2] $\frac{2\sqrt{n}}{n+1}$
[3] $\frac{\sqrt{n}}{(n+1)^2}$ [4] $\frac{2\sqrt{n}}{(n+1)^2}$

9. A person can see clearly objects only when they lie between 50 cm and 400 cm from his eyes. In order to increase the maximum distance of distinct vision to infinity, the type and power of the correcting lens, the person has to use, will be

[1] Convex, +2.25 diopter
[2] Concave, -0.25 diopter
[3] Concave, -0.2 diopter
[4] Convex, +0.15 diopter

10. A linear aperture whose width is 0.02 cm is placed immediately in front of a lens of focal length 60 cm. The aperture is illuminated normally by a parallel beam of wavelength 5 x 10-5 cm. The distance of the first dark band of the diffraction pattern from the centre of the screen is

[1] 0.10 cm [2] 0.25 cm
[3] 0.20 cm [4] 0.15 cm

11. Match the corresponding entries of column 1 with column 2. [Where m is the magnification produced by the mirror]

Column 1	Column 2
(A) $m = -2$	(p) Convex mirror
(B) $m = -\frac{1}{2}$	(q) Concave mirror
(C) $m = +2$	(r) Real image
(D) $m = +\frac{1}{2}$	(s) Virtual image

[1] A → p and s; B → q and r; C → q and s; D → q and r
[2] A → r and s; B → q and s; C → q and r; D → p and s
[3] A → q and r; B → q and r; C → q and s; D → p and s
[4] A → p and r; B → p and s; C → p and q; D → r and s

12. In a diffraction pattern due to a single slit of width a, the first minimum is observed at an angle 30° when light of wavelength 5000 Å is incident on the slit. The first secondary maximum is observed at an angle of

[1] $\sin^{-1}\left(\frac{1}{2}\right)$ [2] $\sin^{-1}\left(\frac{3}{4}\right)$
[3] $\sin^{-1}\left(\frac{1}{4}\right)$ [4] $\sin^{-1}\left(\frac{1}{3}\right)$

13. The intensity at the maximum in a Young's double slit experiment is I0. Distance between two slits is $d = 5\lambda$, where λ is the wavelength of light used in the experiment. What will be the intensity in front of one of the slits on the screen placed at a distance $D = 10d$?

[1] $\frac{3}{4}I_0$ [2] $\frac{I_0}{2}$
[3] I_0 [4] $\frac{I_0}{4}$

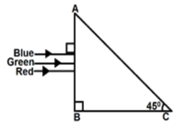
14. A astronomical telescope has objective and eyepiece of focal lengths 40 cm and 4 cm respectively. To view an object 200 cm away from the objective, the lenses must be separated by a distance

[1] 50.0 cm [2] 54.0 cm
[3] 37.3 cm [4] 46.0 cm

15. The angle of incidence for a ray of light at a refracting surface of a prism is 45°. The angle of prism is 60°. If the ray suffers minimum deviation through the prism, the angle of minimum deviation and refractive index of the material of the prism respectively, are

[1] 45°; $\sqrt{2}$ [2] 30°; $\frac{1}{\sqrt{2}}$
[3] 45°; $\frac{1}{\sqrt{2}}$ [4] 30°; $\sqrt{2}$

16. 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
[1] Not separate the three colours at all
[2] Separate the red colour part from the green and blue colours
[3] Separate the blue colour part from the red and green colours
[4] Separate all the three colours from one another

17. At the first minimum adjacent to the central maximum of a single-slit diffraction pattern, the phase difference between the Huygen's wavelet from the edge of the slit and the wavelet from the midpoint of the slit is

[1] π radian [2] $\frac{\pi}{8}$ radian
[3] $\frac{\pi}{4}$ radian [4] $\frac{\pi}{2}$ radian

18. In an astronomical telescope in normal adjustment a straight black line of length L is drawn on inside part of objective lens. The eye-piece forms a real image of this line. The length of this image is I. The magnification of the telescope is

[1] $\frac{L+I}{L-I}$ [2] $\frac{L}{I}$
[3] $\frac{L}{I}+1$ [4] $\frac{L}{I}-1$

19. Two slits in Young's experiment have widths in the ratio 1 : 25. The ratio of intensity at the maxima and minima in the interference pattern, $\frac{I_{max}}{I_{min}}$ is,

[1] $\frac{49}{121}$ [2] $\frac{4}{9}$

[3] $\frac{9}{4}$ [4] $\frac{121}{49}$

20. For a parallel beam of monochromatic light of wavelength 'λ', diffraction is produced by a single slit whose width 'a' is of the order of the wavelength of the light. If 'D' is the distance of the screen from the slit, the width of the central maxima will be

[1] $\frac{Da}{\lambda}$ [2] $\frac{2Da}{\lambda}$

[3] $\frac{2D\lambda}{a}$ [4] $\frac{D\lambda}{a}$

21. Two identical thin plano-convex glass lenses (refractive index 1.5) each having radius of curvature of 20 cm are placed with their convex surfaces in contact at the centre. The intervening space is filled with oil of refractive index 1.7. The focal length of the combination is

[1] -50 cm [2] 50 cm

[3] -20 cm [4] -25 cm

22. The refracting angle of a prism is cot (A/2). The angle of minimum deviation is

[1] 90° -A [2] 180° + 2A

[3] 180° - 3A [4] 180° 2A

23. In a double slit experiment, the two slits are 1 mm apart and the screen is placed 1 m away. A monochromatic light of wavelength 500 nm is used. What will be the width of each slit for obtaining ten maxima of single slit pattern?

[1] 0.5 mm [2] 0.02 mm

[3] 0.2 mm [4] 0.1 mm

24. A beam of light of λ = 600 mm from a distant source falls on a single slit 1 mm wide and the resulting diffraction pattern is observed on a screen 2 m away. The distance between first dark fringes on either side of the central bright fringe is

[1] 1.2 cm [2] 1.2 mm

[3] 2.4 cm [4] 2.4 mm

25. In the Young's double slit experiment, the intensity of light at a point on the screen where the path difference λ is K, (λ being the wavelength of light used). The intensity at a point where the path difference is λ/4 will be

[1] K [2] K/4

[3] K/2 [4] zero

26. If the focal length of objective lens is increased then magnifying power of

[1] Microscope will increase but that of telescope decrease.

[2] Microscope and telescope both will increase

[3]Microscope and telescope both will decrease

[4] Microscope will decrease but that of telescope will increase.

27. The angle of a prism is A. One of its refracting surfaces is silvered. Light rays falling at an angle of incidence 2A on the first surface returns back through the same path after suffering reflection at the silvered surface. The refractive index μ, of the prism is

[1] 2sinA [2] 2cosA

[3] $\frac{1}{2}$ coaA [4] tanA

28. A plano convex lens fits exactly into a plano concave lens. Their plane surfaces are parallel to each other. If lenses are made of different materials of refractive indices μ1 and μ2 and R is the radius of curvature of the curved surface of the lenses, then the focal length of the combination is

[1] $\frac{R}{(\mu_1 - \mu_2)}$ [2] $\frac{2R}{(\mu_2 - \mu_1)}$

[3] $\frac{R}{2(\mu_1 + \mu_2)}$ [4] $\frac{R}{2(\mu_1 - \mu_2)}$

29. In Young's double slit experiment, the slits are 2 mm apart and are illuminted by photons of two wavelengths λ_1 = 12000 Å and λ_2 = 10000 Å. At what minimum distance from the common central bright fringe on the screen 2 m

from the slit will a bright fringe from one interference pattern coincide with a bright fringe from the other?

[1] 4 mm [2] 3 m
[3] 8 mm [4] 6 mm

30. For a normal eye, the cornea of eye provides a converging power of 40 D and the least converging power of the eye lens behind the cornea is 20 D. Using this information, the distance between the retina and the cornea-eye lens can be estimated to be

[1] 1.67 cm [2] 1.5 cm
[3] 5 cm [4] 2.5 cm

31. A parallel beam of fast moving electrons is incident normally on a narrow slit. A fluorescent screen is placed at a large distance from the slit. If the speed of the electrons is increased, which of the following statements is correct?

[1] The angular width of the central maximum will decrease
[2] The angular width of the central maximum will be unaffected
[3] Diffraction pattern is not observed on the screen in the case of electrons
[4] The angular width of the central maximum of the diffraction pattern will increase

32. In Young's double slit experiment the distance between the slits and the screen is doubled. The separation between the slits is reduced to half. As a result the fringe width

[1] Is halved
[2] Becomes four times
[3] Remains unchanged
[4] Is doubled

33. A parallel beam of light of wavelength λ is incident normally on a screen placed perpendicular to the direction of the incident beam. At the second minimum of the direction of the incident beam. At the second minimum of the diffraction pattern, the phase difference between the rays coming from the two edges of slit is

[1] 2π [2] 3π
[3] 4π [4] $\pi\lambda$

34. The reddish appearance of the sun at sunrise and sunset is due to

[1] The scattering of light
[2] The polarization of light
[3] The colour of the sun
[4] The colour of the sky

35. Two plane mirrors are inclined at 70°. A ray incident on one mirror at angle, θ after reflection falls on second mirror and is reflected from there parallel to first mirror. The value of θ is

[1] 45° [2] 30° [3] 55° [4] 50°

36. When a biconvex lens of glass having refractive index 1.47 is dipped in a liquid, it acts as a plane sheet of glass. This implies that the liquid must have refractive index

[1] Equal to that of glass
[2] Less than one
[3] Greater than that of glass
[4] Less than that of glass

37. A ray of light is incident at an angle of incidence i, on one face of a prism of angle A (assumed to be small) and emerges normally from the opposite face. If the refractive index of the prism is μ, the angle of incidence i, is nearly equal to

[1] 4μ [2] $\frac{\mu A}{2}$
[3] $\frac{A}{\mu}$ [4] $\frac{A}{2\mu}$

38. A concave mirror of focal length f1 is placed at a distance of d from a convex lens of focal length f2. A beam of light coming from infinity and falling on this convex lens – concave mirror combination returns to infinity. The distance d must equal

[1] f_1+f_2 [2] $-f_1+f_2$
[3] $2f_1+f_2$ [4] $-2f_1+f_2$

39. The magnifying power of a telescope is 9. When it is adjusted for parallel rays the distance between the objective and eyepiece is 20 cm. The focal length of lenses are
[1] 10 cm, 10 cm
[2] 15 cm, 5 cm
[3] 18 cm, 2 cm
[4] 11 cm, 9 cm

40. For the angle of minimum deviation of a prism to be equal to its refracting angle, the prism must be made of a material whose refractive index
[1] lies between $\sqrt{2}$ and 1
[2] lies between 2 and $\sqrt{2}$
[3] is less than 1
[4] is greater than 2

41. A rod of length 10 cm lies along the principal axis of a concave mirror of local length 10 cm in such a way that its end closer to the pole is 20 cm away from the mirror. The length of the image is
[1] 10 cm [2] 15 cm
[3] 2.5 cm [4] 5 cm

42. Which of the following is not due to total internal reflection?
[1] Working of optical fibre
[2] Difference between apparent and real depth of a pond
[3] Mirage on hot summer days
[4] Brilliance of diamond

43. A biconvex lens has a radius of curvature of magnitude 20 cm. Which one of the following options describe best the image formed of an object of height 2 cm placed 30 cm from the lens?
[1] Virtual, upright, height = 1 cm
[2] Virtual, upright, height = 0.5 cm
[3] Real, inverted, height = 4 cm
[4] Real, inverted, height = 1 cm

44. A thin prism of angle 15° made of glass of refractive index μ1 = 1.5 is combined with another prism of glass of refractive index μ2 = 1.75. The combination of the prisms produces dispersion without deviation. The angle of the second prism should be
[1] 5° [2] 7°
[3] 10° [4] 12°

45. A converging beam of rays is incident on a diverging lens. Having passed through the lens the rays intersect at a point 15 cm from the lens on the opposite side. If the lens is removed the point where the rays meet will move 5 cm closer to the lens. The focal length of the lens is
[1] 5 cm [2] -10 cm
[3] 20 cm [4] -30 cm

46. A ray of light travelling in a transparent medium of refractive index μ, falls on a surface separating the medium from air at an angle of incidence of 45°. For which of the following value of μ the ray can undergo total internal reflection?
[1] μ = 1.33 [2] μ = 1.40
[3] μ = 1.50 [4] μ = 1.25

47. A lens having focal length f and aperture of diameter d forms an image of intensity I. Aperture of diameter $\frac{d}{2}$ in central region of lens is covered by a black paper. Focal length of lens and intensity of image now will be respectively
[1] f and $\frac{I}{4}$ [2] $\frac{3f}{4}$ and $\frac{I}{2}$
[3] f and $\frac{3I}{4}$ [4] $\frac{f}{2}$ and $\frac{I}{2}$

48. The speed of light in media M1 and M2 are 1.5 x 108 m/s and 2.0 x 108 m/s respectively. A ray of light enters from medium M1 to M2 at an incidence angle i. If the ray suffers total internal reflection, the value of i is
(a) Equal to $\sin^{-1}\left(\frac{2}{3}\right)$
(b) Equal to or less than $\sin^{-1}\left(\frac{3}{5}\right)$
(c) Equal to or greater than $\sin^{-1}\left(\frac{3}{4}\right)$
(d) Less than $\sin^{-1}\left(\frac{2}{3}\right)$

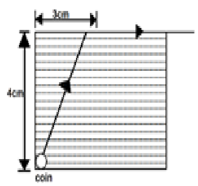
49. A ray of light is incident on a 60° prism at the minimum deviation position. The angle of refraction at the first face (i.e., incident face) of

the prism is
[1] zero [2] 30°
[2] 45° [4] 60°

50. Two thin lenses of focal lengths f_1 and f_2 are in contact and coaxial. The power of the combination is
[1] $\frac{f_1+f_2}{2}$ [2] $\frac{f_1+f_2}{f_1f_2}$
[3] $\sqrt{\frac{f_1}{f_2}}$ [4] $\sqrt{\frac{f_2}{f_1}}$

51. A boy is trying to start a fire by focusing sunlight on a piece of paper using an equiconvex lens of focal length 10 cm. The diameter of the sun is 1.39 x 109 m and its mean distance from the earth is 1.5 x 1011 m. What is the diameter of the sun's image on the paper?
[1] 6.5 x 10^{-5}m [2] 12.4 x 10^{-4}m
[3] 9.2 x 10^{-4}m [4] 6.5 x 10^{-4}m

52. 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?



[1] 2.4 x 10^8m/s [2] 3.0 x 10^8m/s
[3] 1.2 x 10^8m/s [4] 1.8 x 10^8m/s

53. The frequency of a light wave in a material is 2 x 1014 Hz and wavelength is 5000 Å. The refractive index of material will be
[1] 1.50 [2] 3.00
[3] 1.33 [4] 1.40

54. A microscope is focussed 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?
[1] 2 cm upward [2] 1 cm upward
[3] 4.5 cm downward [4] 1 cm downward

55. A convex lens and a concave lens, each having same focal length of 25 cm, are put in contact to from a combination of lenses. The power in diopters of the combination is
[1] zero [2] 25
[3] 50 [4] infinite

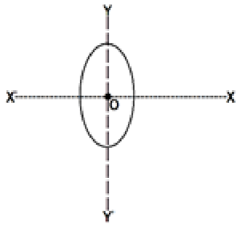
56. The angular resolution of a 10 cm diameter telescope at a wavelength of 5000 Å is of the order of
[1] 10^6 rad [2] 10^{-2} rad
[3] 10^{-4} rad [4] 10^{-6} rad

57. A telescope has an objective lens of 10 cm diameter and is situated at a distance of one kilometer 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
[1] 0.5 m [2] 5 m
[3] 5 mm [4] 5 cm

58. The refractive index of the material of a prism is √2 and its refracting angle is 30°. 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 reflection from the mirrored surface if its angle of incidence on the prism is
[1] 45° [2] 60° [3] 0 [4] 30°

59. 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
[1] Two points propagating in two different non parallel directions
[2] Two points propagating in two different parallel directions
[3] One point propagating in two different parallel directions
[4] One point propagating in the same directions

60. An equiconvex lens is cut into two halves along (i) XOX' and YOY' as shown in the figure. Let f,f',f'' be the focal lengths of the complete lens, of each half in case (i), and of each half in case (ii), respectively. Choose the correct statement from the following



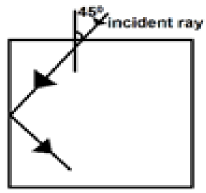
[1] $f' = f, f'' = 2f$ [2] $f' = 2f, f'' = f$
[3] $f' = f, f'' = f$ [4] $f' = 2f, f'' = 2f$

61. 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
[1] Become zero
[2] Become infinite
[3] Become small, but non-zero
[4] Remain unchanged

62. A bulb is located on a wall. Its image 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
[1] only $\frac{d}{4}$
[2] only $\frac{d}{2}$
[3] more than $\frac{d}{4}$ but less than $\frac{d}{2}$
[4] less than $\frac{d}{4}$

63. Diameter of human eye lens is 2 mm. What will be the minimum distance between two points to resolve them, which are situated at a distance of 50 meter from eye. The wavelength of light is 5000 Å
[1] 2.32 m   [2] 4.28 mm
[3] 1.25 cm   [4] 12.48 cm

64. 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



[1] $\frac{\sqrt{3}+1}{2}$
[2] $\frac{\sqrt{2}+1}{2}$
[3] $\sqrt{\frac{3}{2}}$
[4] $\sqrt{\frac{7}{6}}$

65. Optical fibre are based on
[1] Total internal reflection
[2] Less scattering
[3] Refraction
[4] Less absorption coefficient

66. A ray of light travelling in air have wavelength λ, frequency n, velocity v and intensity I. If this ray enters into water then these parameters are λ′, n′, v′ and I′ respectively. Which relation is correct from following?
[1] $\lambda = \lambda'$ [2] $n = n'$
[3] $v = v'$ [4] $I = I'$

67. A disc is placed on a surface of pond which has refracting 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,
[1] ∞   [2] 3 m
[3] 6 m   [4] 4 m

68. 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
[1] 3.75 cm   [2] 3 cm
[3] 10.5 cm   [4] 2.5 cm

69. A tall man of height 6 feet, want to see his full image. Then required minimum length of the mirror will be
[1] 12 feet   [2] 3 feet
[3] 6 feet   [4] any length

70. For a plano convex lens (μ = 1.5) has radius of curvature 10 cm. It is silvered on its plane surface. Find focal length after silvering

[1] 10 cm [2] 20 cm
[3] 15 cm [4] 25 cm

71. Rainbow is formed due to
[1] Scattering and refraction
[2] Internal reflection and dispersion
[3] Reflection only
[4] Diffraction and dispersion

72. A plano convex lens is made of refractive index 1.6. The radius of curvature of the curved surface is 60 cm. The focal length of the lens is
[1] 200 cm [2] 100 cm
[3] 50 cm [4] 400 cm

73. Colours appear on a thin soap film and on soap bubbles due to the phenomenon of
[1] Interference [2] Dispersion
[3] Refraction [4] diffraction

74. If the refractive index of a material of equilateral prism is $\sqrt{3}$, then angle of minimum deviation of the prism is
[1] 60° [2] 45° [3] 30° [4] 75°

75. 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?
[1] 50 cm [2] 30 cm
[3] 12 cm [4] 60 cm

76. 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?
[1] n = 1.1 [2] n = 1
[3] n > $\sqrt{2}$ [4] n = 1.3

77. An astronomical telescope of tenfold angular magnification has a length of 44 cm. The focal length of the objective is
[1] 44 cm [2] 440 cm
[3] 4 cm [4] 40 cm

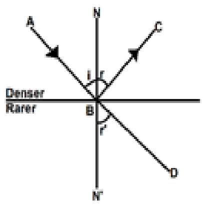
78. The focal length of converging lens is measured for violet, green and red colours. It is respectively f_v, f_g, f_r. We will get
[1] $f_v < f_r$ [2] $f_g > f_r$
[3] $f_v = f_g$ [4] $f_g < f_r$

79. 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
[1] n, 2λ and $\frac{v}{\mu}$ [2] $\frac{2n}{\mu}, \frac{\lambda}{\mu}$ and v
[3] $\frac{n}{\mu}, \frac{\lambda}{\mu}$ and $\frac{v}{\mu}$ [4] n, $\frac{\lambda}{\mu}$ and $\frac{v}{\mu}$

80. 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?
[1] + 7.5 D [2] – 0.75 D
[3] + 6.5 D [4] – 6.5 D

81. The refractive index of water is 1.33. What will be the speed of light in water?
[1] 4 x 10^8 m/s [2] 1.33 x 10^8 m/s
[3] 3 x 10^8 m/s [4] 2.25 x 10^8 m/s

82. A ray of light from a denser medium strikes a rare 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 r and r'. The critical angle would be



[1] $\sin^{-1}$ (tan r) [2] $\sin^{-1}$ (sin r)
[3] $\cos^{-1}$ (tan r) [4] $\tan^{-1}$ (sin r)

83. 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 focal lengths of a concave

lens for violet and red light respectively, then we must have

[1] $f_V > f_R$ and $F_v > F_R$
[2] $f_V < f_R$ and $F_v > F_R$
[3] $f_V > f_R$ and $F_v < F_R$
[4] $f_V < f_R$ and $F_v < F_R$

84. 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 light to travel this thickness of glass is

[1] $\frac{t}{\mu c}$ [2] $\frac{\mu t}{c}$
[3] tμc [4] $\frac{tc}{\mu}$

85. A lens is placed between a source of light and a wall. It forms images of area A_1, and A_2 on the wall, for its two different positions. The area of the source of light is

[1] $\frac{A_1 - A_2}{2}$ [2] $\frac{1}{A_1} + \frac{1}{A_2}$
[3] $\sqrt{A_1 A_2}$ [4] $\frac{A_1 + A_2}{2}$

86. Exposure time of camera lens at f/2.8 setting is 1/200 second. The correct time of exposure at f/5.6 is

[1] 0.20 second [2] 0.40 second
[3] 0.02 second [4] 0.04 second

87. 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?

[1] 13 cm [2] 14 cm
[3] 12.5 cm [4] 12 cm

88. Four lenses of focal length ±15 cm and ±150 cm are available for making a telescope. To produce the largest magnification, the focal length of the eyepiece should be

[1] + 15 cm [2] + 150 cm
[3] – 150 cm [4] -15 cm

89. The blue colour of the sky is due to the phenomenon of

[1] Scattering [2] Dispersion
[3] Reflection [4] Refraction

90. Ray optics is valid, when characteristic dimensions are

[1] Much smaller than the wavelength of light
[2] Of the same order as the wavelength of light
[3] Of the order of one millimeter
[4] Much larger than the wavelength of light

91. A small source of light is 4 m below the surface of water of refractive index 5/3. In order to cut off all the light, coming out of water surface, minimum diameter of the disc placed on the surface of water is

[1] 6 m [2] ∞
[3] 3 m [4] 4 m

92. A parallel beam of monochromatic light of wavelength 5000 Å is incident normally on a single narrow slit focussed by a convex lens on a single narrow slit of width 0.001 mm. The light is focussed by a convex lens on a screen placed in focal plane. The first minimum will be formed for the angle of diffraction equal to

[1] 0° [2] 15°
[3] 30° [4] 50°

93. Interference was observed in interference chamber where air was present, now the chamber is evacuated, and if the same light is used, a careful observer will see

[1] No interference
[2] Interference with brighter bands
[3] Interference with dark bands
[4] Interference with larger width

94. Time taken by sunlight to pass through a window of thickness 4 mm whose refractive index is $\frac{3}{2}$ is

[1] 2 x 10^{-4} s (b) 2 x 10^{8} s
[2] 2 x 10^{-11} s (d) 2 x 10^{11} s

95. There is a prism with refractive index equal to $\sqrt{2}$ and the refractive angle equal to 30°. One of the refractive surface of the prism is polished. A beam of monochromatic light will be retrace

its path if its angle of indence over the refracting surface of the prism is

[1] 0° [2] 30° [3] 45° [4] 60°

96. If yellow light emitted by sodium lamp in Young's double slit expt is replaced by monochromatic blue of light of the same intensity

[1] Fringe width will decrease
[2] Fringe width will increase
[3] Fringe width will remain unchanged
[4] Fringe will becomes less intense

97. In Young's double slit experiment carried out with light of wavelength (λ) = 5000 Å, the distance between the slits is 0.2 mm and the screen is at 200 cm from the slits. The central maximum is at x=0. The third maximum (taking the central maximum asa zeroth maximum) will be at x equal to

[1] 1.67 cm [2] 1.5 cm
[3] 0.5 cm [4] 5.0 cm

98. A beam of monochromatic light is refracted from vacuum into a medium of refractive index 1.5. The wavelength of refracted light will be

[1] Depend on intensity of refracted light
[2] Same
[3] Smaller
[4] Larger

99. Green light 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 (c = 3 x 108 ms^{-1})

[1] 3460 Å [2] 5460 Å
[3] 4861 Å [4] none of these

100. Ratio of intensities of two waves are given by 4 : 1. Then ratio of the amplitudes of the two waves is

[1] 2 : 1 [2] 1 : 2
[3] 4 : 1 [4] 1 : 4

101. In Young's experiment, two coherent sources are placed 0.90 mm apart and fringe are observed one metre away. If it produces second dark fringe at a distance of 1 mm from central fringe, the wavelength of monochromatic light is used would be

[1] 60 x 10^{-4} cm [2] 10 x 10^{-4} cm
[3] 10 x 10^{-5} cm [4] 6 x 10^{-5} cm

102. In Young's double slit experiment, the fringe width is found to be 0.4 mm. If the whole apparatus is immersed in water of refractive index $\frac{4}{3}$, without disturbing the geometrical arrangement, the new fringe width will be

[1] 0.30 mm [2] 0.40 mm
[3] 0.53 mm [4] 450 microns

103. The Young's double slit experiment is performed with blue and with green light of wavelengths 4360 Å and 5460 Å respectively. If x isthe distance of 4th maxima from the central one, then

[1] x(blue) = x(green)
[2] x(blue) > x(green)
[3] x(blue) < x(green)
[4] $\frac{x(blue)}{x(green)} = \frac{5460}{4360}$

104. Interference is possible in

[1] Light waves only
[2] Sound waves only
[3] Both light and sound waves
[4] Neither light nor sound waves

105. Which of the phenomenon is not common to sound and light waves ?

[1] Interference
[2] Diffraction
[3] Coherence
[4] Polarisation

106. Which one of the following phenomena is not explained by Huygen's construction of wave front?

[1] Refraction
[2] Reflection
[3] Diffraction
[4] Origin of spectra

107. 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

[1] 10 cm [2] 2.5 cm
[3] 5 cm [4] 7.5 cm

Answer Keys

Exercise – 1

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A	**4**	**4**	**1**	**3**	**2**	**4**	**2**	**4**	**2**	**4**	**2**	**2**	**2**	**2**	**1**
Q	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
A	**4**	**1**	**4**	**3**	**2**	**4**	**4**	**3**	**1**	**4**	**3**	**1**	**2**	**2**	**3**
Q	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
A	**3**	**2**	**1**	**2**	**2**	**1**	**1**	**3**	**2**	**3**	**1**	**2**	**2**	**4**	**1**
Q	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
A	**2**	**2**	**3**	**3**	**4**	**2**	**3**	**2**	**4**	**1**	**3**	**1**	**4**	**1**	**2**
Q	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
A	**1**	**2**	**3**	**4**	**3**	**1**	**2**	**1**	**4**	**3**	**1**	**1**	**4**	**1**	**2**
Q	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
A	**1**	**2**	**2**	**3**	**2**	**1**	**3**	**1**	**1**	**2**	**4**	**2**	**3**	**3**	**2**
Q	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
A	**3**	**1**	**3**	**3**	**1**	**3**	**2**	**3**	**4**	**4**	**1**	**1**	**4**	**3**	**2**
Q	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
A	**4**	**1**	**4**	**3**	**1**	**3**	**2**	**1**	**4**	**1**	**1**	**4**	**1**	**4**	**2**
Q	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135
A	**1**	**4**	**1**	**1**	**3**	**1**	**1**	**1**	**4**	**2**	**4**	**4**	**2**	**1**	**2**
Q	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150
A	**3**	**4**	**4**	**3**	**2**	**1**	**4**	**2**	**3**	**4**	**4**	**3**	**4**	**2**	**3**
Q	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165
A	**4**	**1**	**1**	**3**	**4**	**1**	**3**	**2**	**2**	**3**	**3**	**3**	**2**	**2**	**2**
Q	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180
A	**4**	**3**	**1**	**4**	**1**	**2**	**2**	**2**	**2**	**4**	**3**	**2**	**1**	**2**	**2**
Q	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195
A	**1**	**1**	**4**	**4**	**3**	**3**	**3**	**4**	**2**	**2**	**1**	**2**	**4**	**2**	**1**
Q	196	197	198	199	200										
A	**2**	**4**	**4**	**3**	**3**										

Previous Year

Q	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A	**2**	**3**	**4**	**1**	**2**	**4**	**3**	**2**	**2**	**4**	**3**	**2**	**2**	**2**	**4**
Q	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
A	**2**	**1**	**2**	**3**	**3**	**1**	**4**	**3**	**4**	**3**	**4**	**2**	**1**	**4**	**1**
Q	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
A	**1**	**2**	**3**	**1**	**4**	**1**	**1**	**3**	**3**	**2**	**4**	**2**	**3**	**3**	**4**
Q	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
A	**3**	**3**	**3**	**2**	**2**	**3**	**4**	**2**	**2**	**1**	**3**	**3**	**1**	**2**	**1**
Q	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
A	**2**	**2**	**3**	**3**	**1**	**2**	**2**	**3**	**2**	**1**	**2**	**2**	**1**	**1**	**1**
Q	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
A	**3**	**4**	**1**	**4**	**2**	**4**	**1**	**2**	**2**	**3**	**3**	**4**	**1**	**1**	**4**
Q	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
A	**1**	**3**	**4**	**3**	**3**	**1**	**2**	**3**	**1**	**1**	**4**	**1**	**3**	**3**	**4**
Q	106	107													
A	**4**	**3**													