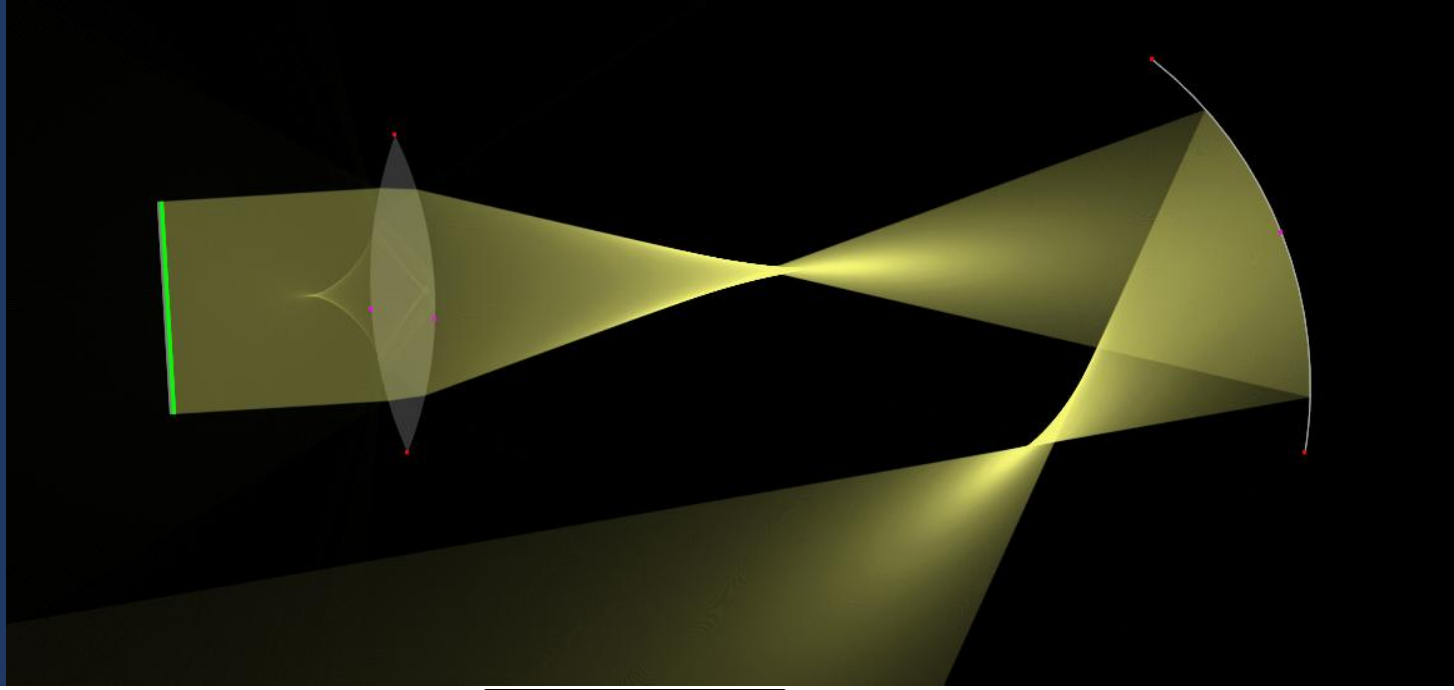
RAY OPTICS AND OPTICAL INSTRUMENTS



CHAPTER – 9

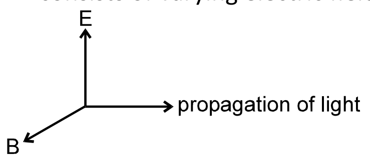
RAY OPTICS AND OPTICAL INSTRUMENTS

Blue lakes, ochre deserts, green forest, and multicolored rainbows can be enjoyed by anyone who has eyes with which to see them. But by studying the branch of physics called optics, which deals with the behavior of light and other electromagnetic waves, we can reach a deeper appreciation of the visible world. A knowledge of the properties of light allows us to understand the blue color of the sky and the design of optical devices such as telescopes, microscopes, cameras, eyeglasses, and the human eye. The same basic principles of optics also lie at the heart of modern developments such as the laser, optical fibers, holograms, optical computers, and new techniques in medical imaging.

Properties Of Light

(i) Speed of light in vacuum, denoted by c, is equal to 3×10^8 m/s approximately.

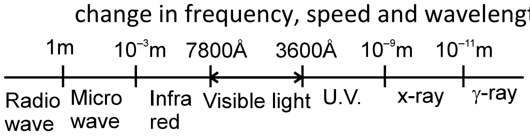
(ii) Light is electromagnetic wave (proposed by Maxwell). It consists of varying electric field and magnetic field.



(iii) Light carries energy and momentum.

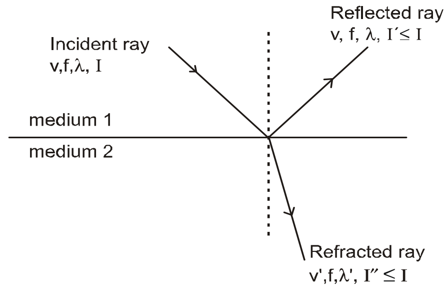
(iv) The formula $v = f\lambda$ is applicable to light.

(v) When light gets reflected in same medium, it suffers no change in frequency, speed and wavelength.

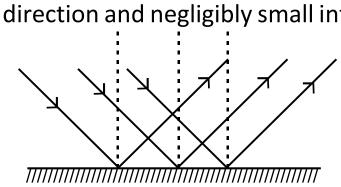


Electromagnetic spectrum

(vi) Frequency of light remains unchanged when it gets reflected or refracted.



(a) **Regular Reflection:** When the reflection takes place from a perfect plane surface it is called **Regular reflection**. In this case the reflected light has large intensity in one direction and negligibly small intensity in other directions.

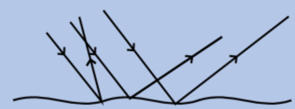


Regular Reflection

(b) **Diffused Reflection:** When the surface is rough, we do not get a regular behavior of light. Although at each point light ray gets reflected irrespective of the overall nature of surface, difference is observed because even in a narrow beam of light there are many rays which are reflected from different points of surface and it is quite possible that these rays may move in different directions due to irregularity of the surface. This process enables us to see an object from any position.
Such a reflection is called as **diffused reflection**.

Example

Reflection from a wall, from a newspaper.
This is why you cannot see your face in newspaper and in the wall.



Diffused Reflection

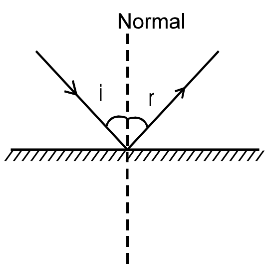
DO YOU KNOW?

In vacuum all the different colors of light travels with the same speed.

Laws Of Reflection

(a) The incident ray, the reflected ray and the normal at the point of incidence lie in the same plane. This plane is called the **plane of incidence (or plane of reflection)**. This condition can be expressed mathematically as $\vec{R}\cdot(\vec{I}\times\vec{N}) = \vec{N}\cdot(\vec{I}\times\vec{R}) = \vec{I}\cdot(\vec{N}\times\vec{R}) = 0$ where $\vec{I}$, $\vec{N}$ and $\vec{R}$ are vectors of any magnitude along incident ray, the normal and the reflected ray respectively.

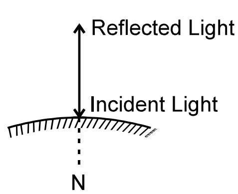
(a) The angle of incidence (the angle between normal and the incident ray) and the angle of reflection (the angle between the reflected ray and the normal) are equal, i.e.



$\angle i = \angle r$

Special Cases:

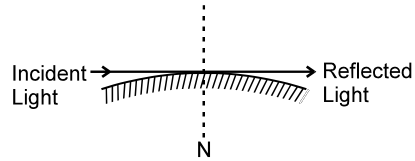
Normal Incidence: In case light is incident normally,
i = r = 0
δ = 180º



Note

We say that the ray has retraced its path

Grazing Incidence: In case light strikes the reflecting surface tangentially,
i = r = 90
δ = 0º or 360º

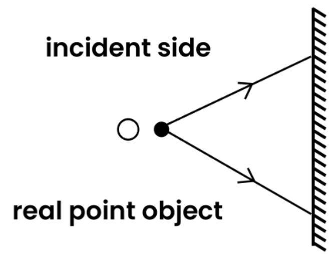


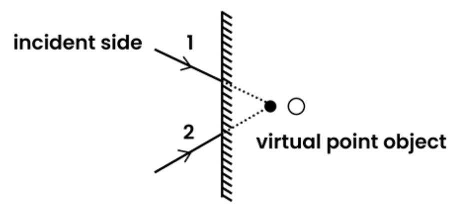
Note

In case of reflection speed (magnitude of velocity) of light remains unchanged but in Grazing incidence velocity remains unchanged

Object And Image

Object- Object is defined as point of intersection of **incident** rays.





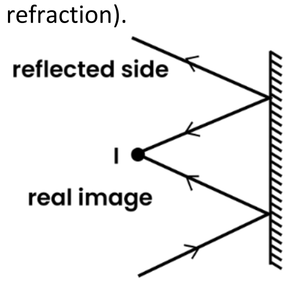
Rays 1 and 2 have originated from a point Source

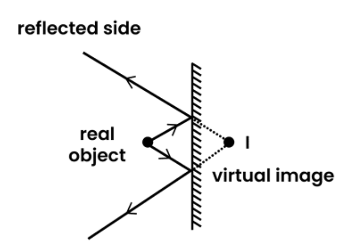
Let us call the side in which incident rays are present as incident side and the side in which reflected (refracted) rays are present, as reflected (refracted) side.

Note

An object is called **real** if it lies on incident side otherwise it is called **virtual**.

Image (I): Image is defined as point of intersection of **reflected** rays (in case of reflection) or **refracted** rays (in case of refraction).



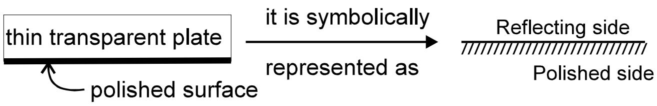


Note

An image is called **real** if it lies on reflected or refracted side otherwise it is called **virtual.**

Plane Mirror

Plane mirror is formed by polishing one surface of a plane thin glass plate. It is also said to be silvered on one side.



PLANE MIRROR

A beam of parallel rays of light, incident on a plane mirror will get reflected as a beam of parallel reflected rays.

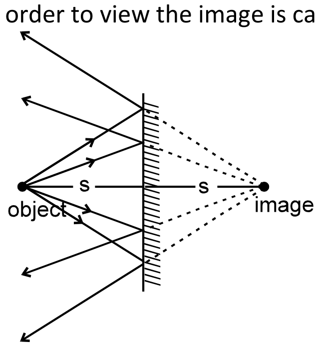
(i) Distance of object from mirror = Distance of image from the mirror.

(ii) All the incident rays from a point object will meet at a single point after reflection from a plane mirror which is called image.

(iii) The line joining a point object and its image is normal to the reflecting surface.

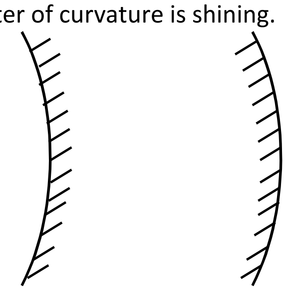
(iv) For a real object the image is virtual and for a virtual object the image is real

(v) The in region which observer's eye must be present in order to view the image is called **field of view**.



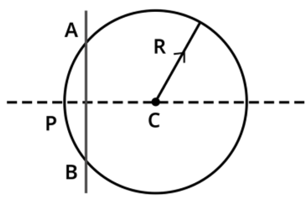
Spherical Mirror

Spherical Mirror Is formed by polishing one surface of a part of sphere. Depending upon which part is shining the spherical mirror is classified as (a) Concave mirror, if the side towards center of curvature is shining and (b) Convex mirror if the side away from the center of curvature is shining.



Concave mirror Convex mirror

Important terms related with spherical mirrors :



A spherical shell with the center of curvature, pole aperture and radius of curvature identified

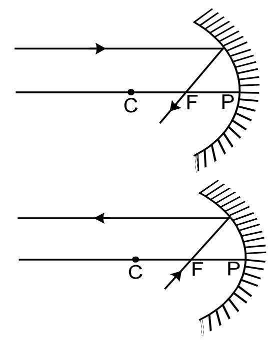
(a) **Center of Curvature (c) :** The center of the sphere from which the spherical mirror is formed is called the Center of curvature of the mirror. It is represented by C and is indicated in figure.

(b) **Pole (P) :** The center of the mirror is called as the Pole. It is represented by the point P on the mirror APB in figure.

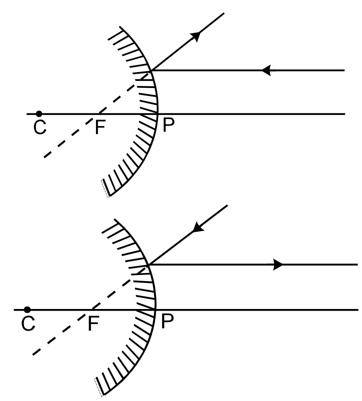
(c) **Principle Axis :** The PRINCIPLE Axis is a line which is perpendicular to the plane of the mirror and passes through the pole. The principle Axis can also be defined as the line which joins the Pole to the Center of Curvature of the mirror.

(d) **Aperture (a) :** he aperture is the segment or area of the mirror which is available for reflecting light. In figure. APB is the aperture of the mirror.

(e) **Principle focus (F) :** It is the point of intersection of all the reflected rays for which the incident rays strike the mirror (with small aperture) parallel to the PRINCIPLE axis. In concave mirror it is real and in the convex mirror it is virtual. The distance from pole to focus is called **focal length.**



Concave mirror



Convex mirror

Sign Convention

We are using co–ordinate sign convention.

(i) Take origin at pole (in case of mirror) or at optical center (in case of lens)

Take X axis along the Principal Axis, taking **positive direction along the incident light.**

u, v, R and **f** indicate the x coordinate of object, image, center of curvature and focus respectively.

(ii) y-co-ordinates are taken positive above Principle Axis and negative below Principle Axis'

h_1 and **h_2** denote the y coordinate of object and image respectively.

Note

λ This sign convention is used for reflection from mirror, refraction through flat or curved surfaces or lens.

Formulae For Reflection from Spherical Mirrors

(i) **Mirror formula:** $\frac{1}{v}+\frac{1}{u}=\frac{2}{R}=\frac{1}{f}$

X-coordinate of center of Curvature and focus of concave mirror are negative and those for convex mirror are positive. In case of mirrors since light rays reflect back in X-direction, therefore **-ve sign of v indicates real image and +ve sign of v indicates virtual image.**

(ii) **Lateral magnification** (or transverse magnification) denoted by m is defined as $m = \frac{h_2}{h_1}$ and is related as $m = -\frac{v}{u}$. From the definition of m positive sign of m indicates erect image and negative sign indicates inverted image.

(iii) In case of successive reflection from mirrors, the overall lateral magnification is given by $\mathbf{m_1 \times m_2 \times m_3}$ ......, where m_1, m_2 etc. are lateral magnifications produced by individual mirrors.

$\mathbf{h_1}$ and $\mathbf{h_2}$ denote the y coordinate of object and image respectively.

Q. 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

Sol. Magnification in the mirror, $m = -\frac{v}{u}$

$m = -2 \Rightarrow v = 2u$

As v and u have same signs so the mirror is concave and image formed is real.

$m = -\frac{1}{2} \Rightarrow v = \frac{u}{2} \Rightarrow$ Concave mirror and real image.

$m = +2 \Rightarrow v = -2u$

As v and u have different signs but magnification is 2 so the mirror is concave and image formed is virtual.

$m = +\frac{1}{2} \Rightarrow v = -\frac{u}{2}$

As v and u have different signs with magnification $\left(\frac{1}{2}\right)$ so the mirror is convex and image formed is virtual.

A → q and r; B→ q and r; C → q and s; D → p and s

Refraction Of Light

When the light changes its medium some changes occurs in its properties the phenomenon is known as refraction.

If the light is incident at an angle (0 < i < 90) then it deviates from its actual path. It is due to change in speed of light as light passes from one medium to another medium.

If the light is incident normally then it goes to the second medium without bending, but still it is called refraction.

Refractive index of a medium is defined as the factor by which speed of light reduces as compared to the speed of light in vacuum.

$$\mu = \frac{c}{v} = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}.$$

More (less) refractive index implies less (more) speed of light in that medium, which therefore is called denser (rarer) medium.

Laws Of Refraction

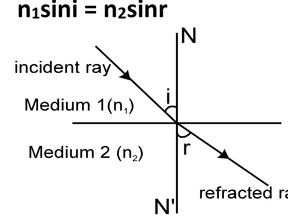
(a) The incident ray, the normal to any refracting surface at the point of incidence and the refracted ray all lie in the same plane called the plane of incidence or plane of refraction.

(b) $\frac{\text{Sin } i}{\text{Sin } r}$ = Constant for any pair of media and for light of a given wave length. This is known as *Snell's* Law.

Also, $\frac{\text{Sin}i}{\text{Sin}r} = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$

For applying in problems remember

$n_1 \sin i = n_2 \sin r$

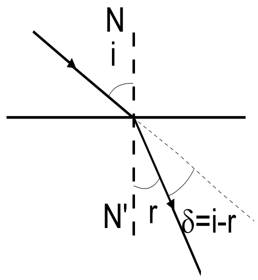


$\frac{n_2}{n_1} = {}_1n_2$ = Refractive Index of the second medium with respect to the first medium.

C = speed of light in air (or vacuum) = 3×10^8 m/s.

Deviation Of a Ray Due to Refraction

Deviation (δ) of ray incident at $\angle$ i and refracted at $\angle$ r is given by **$\delta = |i - r|$.**



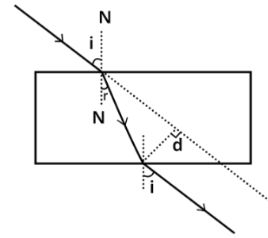
Refraction Through A Parallel Slab

When light passes through a parallel slab, having same medium on both sides, then

(a) Emergent ray is parallel to the incident ray.

> **Note**
>
> Emergent ray will not be parallel to the incident ray if the medium on both the sides of slab are different.

(b) Light is shifted laterally, given by (student should be able to derive it)



$$\mathbf{d} = \frac{t \sin(i - r)}{\cos r} \quad ; \quad t = \text{thickness of slab}$$

Q. A microscope is focused on a mark on a piece of paper and then a slab of glass of thickness 3 cm and refractive index 1.5 is placed over the mark. How should the microscope be moved to get the mark in focus again?

Sol. Apparent depth $= \frac{\text{real depth}}{\mu} = \frac{3}{1.5}$

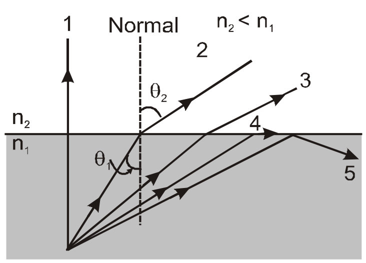
= 2 cm

As image appears to be raised by 1 cm, therefore, microscope must be moved upwards by 1 cm

Total Internal Reflection

An interesting effect called total internal reflection can occur when light is directed from a medium having a given refractive index toward one having a lower refractive index.

The refracted rays are bent away from the normal because n_1 is greater than n_2. At some particular angle of incidence i_c, called the critical angle, the refracted light ray moves parallel to the boundary so that angle of emergence θ_2 is 90° (as shown by ray 4).



For angles of incidence greater than i_c, the beam is entirely reflected at the boundary, as shown by ray 5 in above figure. This ray is reflected at the boundary as it strikes the surface. This ray and all those like it obey the law of reflection; that is, for these rays, the angle of incidence equals the angle of reflection. We can use Snell's law of refraction to find the critical angle.

$$n_1 \sin i_c = n_2 \sin 90^o$$

$$\sin i_c = \frac{n_2}{n_1}$$

This equation can be used only when n_1 is greater than n_2. That is, total internal reflection occurs only when light is directed from a medium of a given index of refraction toward a medium of lower index of refraction.

Applications Of Total Internal Refraction

Glittering Diamonds: The critical angle for total internal reflection is small when n_1 is considerably greater than n_2. For example, the critical angle for a diamond in air is 24°. Any ray inside the diamond that approaches the surface at an angle greater than this is completely reflected back into the crystal. This property, combined with proper faceting, causes diamonds to sparkle. The angles of the facets are cut so that light is "caught" inside the crystal through multiple internal reflections. These multiple reflections give the light a long path through the medium, and substantial dispersion of colors occurs. By the time the light exits through the top surface of the crystal, the rays associated with different colors have been fairly widely separated from one another.

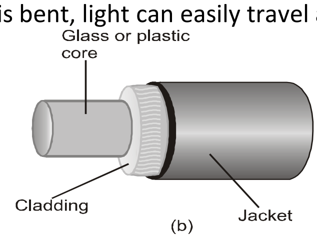
Optical Fibers

Another interesting application of total internal reflection is the use of glass or transparent plastic rods to "pipe" light from one place to another. As indicated in the figure (a), light is confined to traveling within a rod, even around curves, as the result of successive total internal reflections.

Optical fibers are fabricated with high quality composite glass/quartz fibers.

A practical optical fiber consists of a transparent **core** surrounded by a **cladding**, a material that has a lower refractive index than the core. The combination may be surrounded by a plastic jacket to prevent mechanical damage. Figure (b) shows a cutaway view of this construction.

Because the index of refraction of the cladding is less than that of the core, light traveling in the core experiences total internal reflection if it arrives at the interface between the core and the cladding at an angle of incidence that exceeds the critical angle. In this case, light "bounces" along the core of the optical fiber, losing very little of its intensity as it travels (This has been achieved by purification and special preparation of materials such as quartz. In silica glass fibers, it is possible to transmit more than 95% of the light over a fiber length of 1 km). Optical fibers are fabricated such that light reflected at one side of inner surface strikes the other at an angle larger than the critical angle. Even if the fiber is bent, light can easily travel along its length.



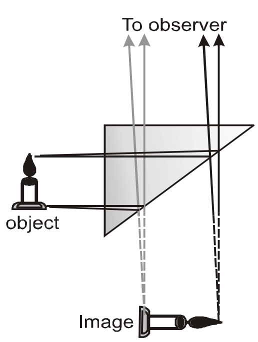
(b)

Any loss in intensity in an optical fiber is due essentially to reflections from the two ends and absorption by the fiber material. Optical fiber devices are particularly useful for viewing an object at an inaccessible location. For example, physicians often use such devices to examine internal organs of the body or to perform surgery without making large incisions. Optical fiber cables are replacing copper wiring and coaxial cables for telecommunications because the fibers can carry a much greater volume of telephone calls or other forms of communication than electrical wires can.

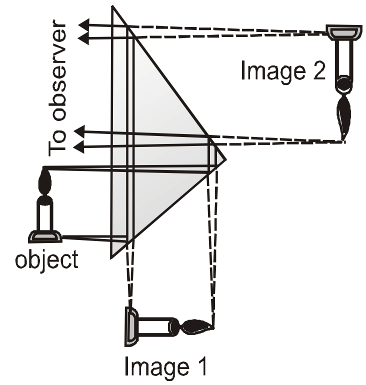
Prism

Prisms are transparent objects with triangular cross-sections that refract light at each surface. In typical prisms, the refractive index of the material filling the volume of the prism is substantially greater than that of air, and the ray bends toward the base of the triangle. However, if the inside and outside media are reversed, the ray may be bent away from the base.

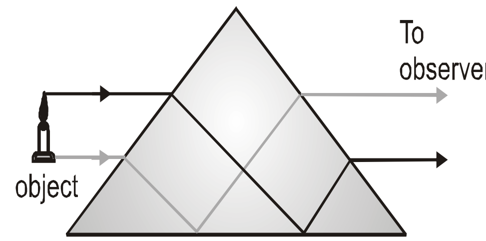
45° -45°-90° triangular glass prisms are often used in optical instruments. Because the critical angle of glass is less that 45°, light striking the surface from within is totally reflected. These prisms can therefore be used for the range of purposes shown in figure (a to c) with virtually no loss of light. Although mirrors could be used for some of these purpose as well, they do not reflect as great a percent of the light, and their reflecting coatings deteriorate with age. Binoculars often use prisms to redirect rays and turn inverted images upright as shown in figure (d).



(a)



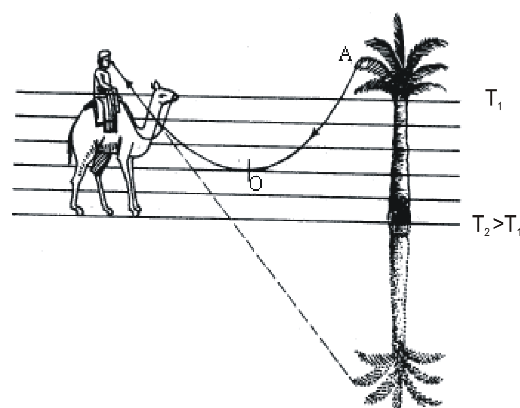
(b)



(c)

Mirage

The mirage is caused by the total internal reflection of light at layers of air of different densities. In a desert, the sand is very hot during day time and a result the layer of air in contact with it gets heated up and becomes lighter. The lighter air rises up and the denser air from above comes down.

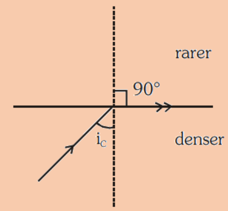


Mirage in a Desert

As a result, the successive upper layers are denser than those below them. A ray of light coming from a distant object, like the top a tree, gets refracted from a denser to a rarer medium. Consequently, the refracted ray bends away from the normal until at a particular layer, the light is incident at an angle greater than the critical angle. At this stage the incident ray suffers total internal reflection and is reflected upwards. When this reflected beam of light enters the eyes of the observer, it appears as if an inverted image of the tree is seen and the sand looks like a pool of water.

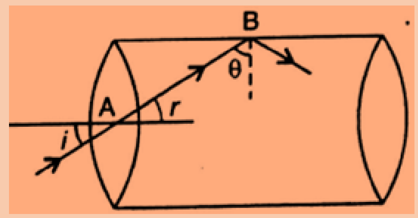
Q. In total internal reflection when the angle of incidence is equal to the critical angle for the pair of media in contact, what will be angle of refraction?

Sol. When the angle of refraction is equal to 90°, the angle of incidence is called the critical angle.



Q. 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?

Sol. The first idea is that for no refraction at its lateral face, angle of incidence should be greater than critical angle.



Let a light ray enters at A and refracted beam is AB.

At the lateral face, the angle of incidence is θ. For no refraction at this face, θ>C.

i.e., sinθ > sinC

but θ+r=90 ∘

⇒θ=90 ∘ −r

The second idea is that in the substitution for $\cos r$ can be found from Snell's law.

Now, from Snell's law, $n=\frac{\sin i}{\sin r}$ $\Rightarrow \sin r=\frac{\sin i}{n}$

$\therefore \cos r=\sqrt{1-\sin^2 r}=\sqrt{\left(1-\frac{\sin^2 i}{n^2}\right)}$ ∴ Eq. (i) gives,

$\sqrt{1-\frac{\sin^2 i}{n^2}}>\sin C$ Also $\sin C=\frac{1}{n}$

$\therefore 1-\frac{\sin^2 i}{n^2}>\frac{1}{n^2}$ or $n^2>\sin^2 i+1$

The maximum value of $\sin i$ is 1 . So, $n^2>2$

or $n>\sqrt{2}$

Refraction At Spherical Surfaces

For paraxial rays incident on a spherical surface separating two media:

$$\frac{n_2}{v}-\frac{n_1}{u}=\frac{n_2-n_1}{R} \quad \text{.....................} \text{ (a)}$$

where light moves from the medium of refractive index n_1 to the medium of refractive index n_2.

Transverse magnification (m) (of dimension perpendicular to Principle axis) due to refraction at spherical surface is given by

$$\mathbf{m}=\frac{v-R}{u-R}=\left(\frac{v/n_2}{u/n_1}\right)$$

Lens

A thin lens is called convex if it is thicker at the middle and it is called concave if it is thicker at the ends.

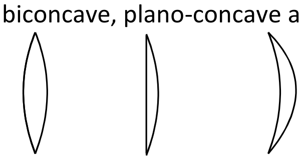
One surface of a convex lens is always convex . Depending on the other surface a convex lens is categorized as

(a) biconvex or convexo convex , if the other surface is also convex,

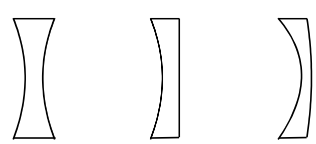
(b) Plano convex if the other surface is plane and

(c) Concavo convex if the other surface is concave.

Similarly concave lens is categorized as concavo-concave or biconcave, plano-concave and convexo-concave.



Bi convex Plano convex Concavo convex



Bi concave Plano concave Convexo concave

For a spherical, thin lens *having the same medium on both sides*:

$\frac{1}{v}-\frac{1}{u}=(n_{rel}-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$ ....(a),

where $n_{rel}=\frac{n_{lens}}{n_{medium}}$ and R_1 and R_2 are x coordinates of the centre of curvature of the 1st surface and 2nd surface respectively.

$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ → Lens Maker's Formula...............(b)

Lens has two Focii:

If $u = \infty$, then $\frac{1}{v} - \frac{1}{\infty} = \frac{1}{f}$ ⇒ $v = f$

⇒ If incident rays are parallel to PRINCIPLE axis then its refracted ray will cut the PRINCIPLE axis at 'f'. It is called 2nd focus.

In case of converging lens it is positive and in case of diverging lens it is negative.

COMBINATION OF LENSES

The equivalent focal length of thin lenses in contact is given by $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} \ldots$ where f_1, f_2, f_3 are focal lengths of individual lenses. If two converging lenses are separated by a distance d and the incident light rays are parallel to the common PRINCIPLE axis, then the combination behaves like a single lens of focal length given by the relation $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{1}{f_1 f_2}$ and the position of equivalent lens is $\frac{-dF}{f_1}$ with respect to 2nd lens

Q. 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. Then find the focal length of the lens.

Sol. Here, $v = +15$ cm, $u = +(15 - 5) = +10$ cm

According to lens formula

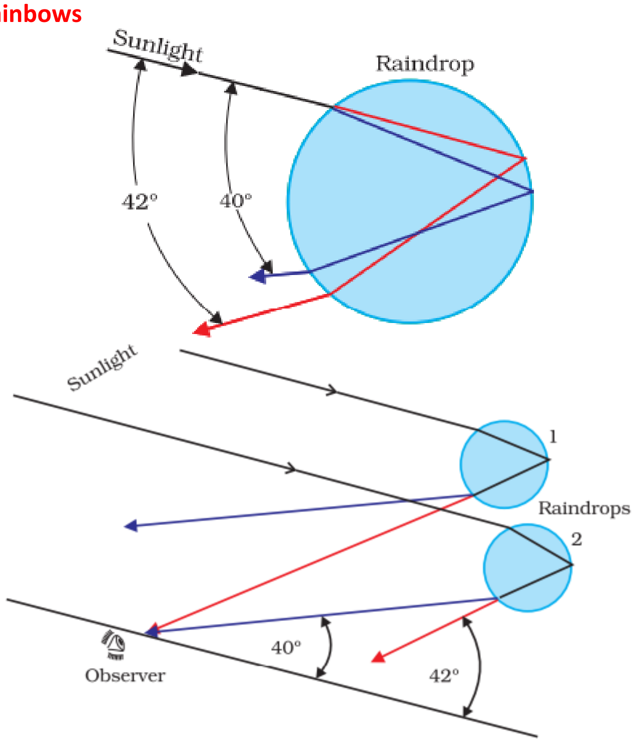
$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{15} - \frac{1}{10} = \frac{1}{f} \Rightarrow f = -30$ cm

Q. 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 1.39×10^9 m and its mean distance from the earth is 1.5×10^{11} m. What is the diameter of the sun's image on the paper?

Sol. $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}; \therefore$ Power $P = \frac{f_1 + f_2}{f_1 f_2}$

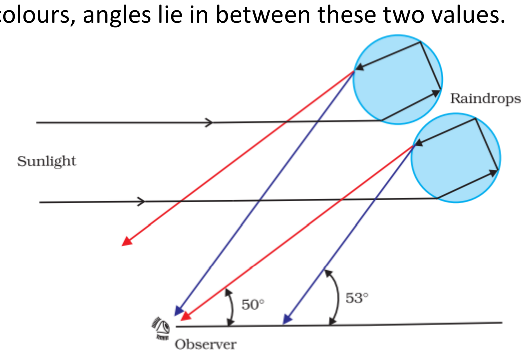
Some Important Natural Phenomena

Rainbows



The rainbow is an example of the dispersion of sunlight by the water drops in the atmosphere. This is a phenomenon due to combined effect of dispersion, refraction and reflection of sunlight by spherical water droplets of rain. The conditions for observing a rainbow are that the sun should be shining in one part of the sky (say near western horizon) while it is raining in the opposite part of the sky (say eastern horizon). An observer can therefore see a rainbow only when his back is towards the sun.

In order to understand the formation of rainbows, consider figure (a). Sunlight is first refracted as it enters a raindrop, which causes the different wavelengths (colours) of white light to separate. Longer wavelength of light (red) are bent the least while the shorter wavelength (violet) are bent the most. Next, these component rays strike the inner surface of the water drop and get internally reflected if the angle between the refracted ray and normal to the drop surface is greater then the critical angle (48º, in this case). The reflected light is refracted again as it comes out of the drop as shown in the figure. It is found that the violet light emerges at an angle of 40º related to the incoming sunlight and red light emerges at an angle of 42º. For other colours, angles lie in between these two values.



Primary rainbow

Figure (b) explains the formation of primary rainbow. We see that red light from drop 1 and violet light from drop 2 reach the observers eye. The violet from drop 1 and red light from drop 2 are directed at level above or below the observer. Thus the observer sees a rainbow with red colour on the top and violet on the bottom. Thus, the primary rainbow is a result of three-step process, that is, refraction, reflection and refraction.

Secondary rainbow

When light rays undergoes two internal reflections inside a raindrop, instead of one as in the primary rainbow, a secondary rainbow is formed as shown in figure (c). 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. Further, the order of the colours is reversed in it as is clear from figure (c).

Why Is The Sky Blue?

Our sky is blue because of the scattering of sunlight by the molecules of air of the atmosphere. How can we understand this phenomenon? After all, the diameter of air molecules is on the order of a few Angstroms, while the wavelength of light is much greater λ~ 5000 Å. That amounts to a ratio of about 1,000 to 1. As a result, diffraction effects are very strong so that *o*ne would expect that very little scattering of light by a single molecule would take place. The sky is bright on account of the sum of scattering by a vast number of molecules.

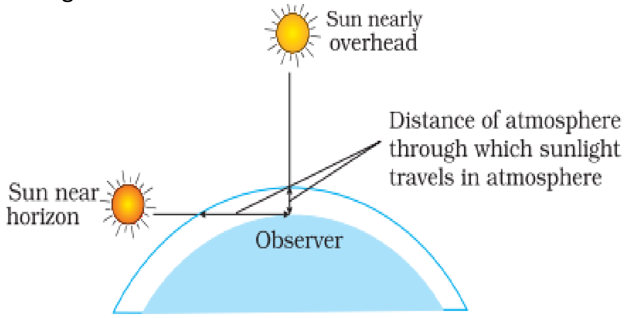
We can now understand why the sky is blue. A detailed analysis was provided about 100 years ago, when **Lord Rayleigh** showed that the intensity of scattered light behaves like:

$$I_{\text{scattered}} \propto \frac{1}{\lambda^4}$$

which gives the relationship between the intensity of scattered light and the wavelength of the light. We should expect the degree of scattering to increase with decreasing wavelength since there will be decreasing diffraction. As a consequence, the violet end of the visible spectrum, which has the shortest wavelength, is scattered most.

Now sunlight is whitish, consisting of a mixture of wavelengths which extends from the infrared to the ultraviolet. Since the violet end of the visible spectrum is scattered most, scattered sunlight looks bluish. On the other hand, when we look directly at the sun through the atmosphere or observe the horizon in the west at sunset, we are seeing light which has started out white (from the sun) and has had the violet end of the spectrum removed most by scattering. Such light looks reddish.

Interestingly if the density of air molecules was to be perfectly uniform, this sum would result in no net scattering; the sky would be perfectly transparent! It is the modest degree of non-uniformity of the density that is responsible for the scattering.

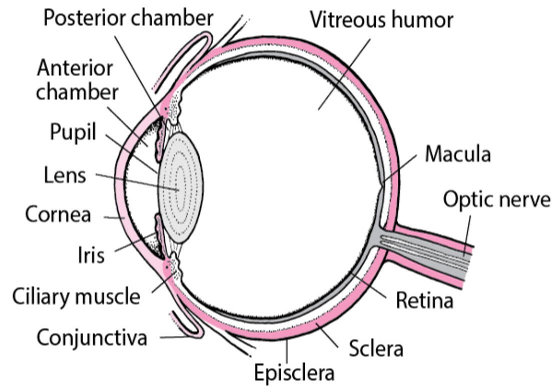


Optical Instruments

Human Eye

Structure of Eye

Light enters the eye through a curved front surface, the cornea. It passes through the pupil which is the central hole in the iris. The size of the pupil can change under control of muscles. The light is further focused by the eye-lens on the retina. The retina is a film of nerve fibres covering the curved back surface of the eye. The retina contains rods and cones which sense light intensity and colour, respectively, and transmit electrical signals via the optic nerve to the brain which finally processes this information. The shape (curvature) and therefore the focal length of the lens can be modified somewhat by the ciliary muscles. For example, when the muscle is relaxed, the focal length is about 2.5 cm and (for a normal eye) objects at infinity are in sharp focus on the retinas



When the object is brought closer to the eye, in order to maintain the same image-lens distance ($\cong$ 2.5 cm), the focal length of the eye-lens becomes shorter by the action of the ciliary muscles. This property of the eye in called **accommodation**.

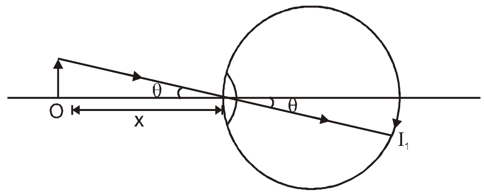
If the object is too close to the eye, the lens cannot curve enough to focus the image on to the retina, and the image is blurred.

The closest distance for which the lens can focus light on the retina is called the **least distance of distinct vision or the near point.** The standard value (for normal vision) taken here is 25 cm (the near point is given the symbol D.)

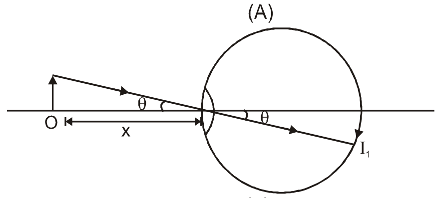
When the image is situated at infinity the ciliary muscles are least strained to focus the final image on the retina, this situation is known as **normal adjustment**.

Regarding Eye:

In eye convex eye-lens forms real inverted and diminished image at the retina by changing its convexity (the distance between eye lens and retina is fixed)
The human eye is most sensitive to yellow green light having wavelength 5550 Å and least to violet (4000Å) and red (7000 Å)
The size of an object as perceived by eye depends on its visual-angle when object is distant its visual angle θ and hence image I_1 at retina is small (it will appear small) and as it is brought near to the eye its visual angle θ_0 and hence size of image I_2 will increase.



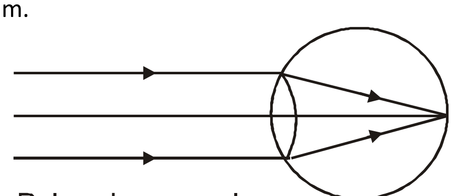
(A)



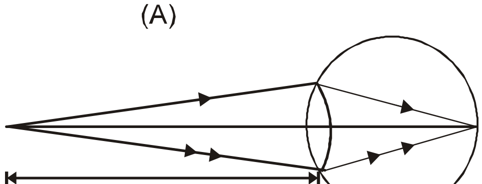
(A)

The far and near point for normal eye are usually taken to be infinity and 25 cm respectively i.e.., normal eye can see very distant object clearly but near objects only if they are at distance greater than 25 cm from the eye. The ability of eye to see objects from infinite distance to 25 cm from it is called **Power of accommodation.**

If object is at infinity i.e. parallel beam of light enters the eye is least strained and said to be relaxed or unstrained. However, if the object is at least distance of distinct vision (L.D.D.V) i.e., D (=25 cm) eye is under maximum strain and visual angle is maximum.



Relaxed or normal eye
(A)



Maximum strained eye
(B)

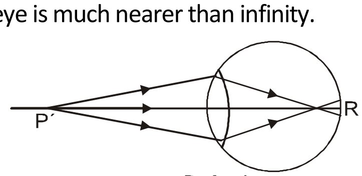
The limit of resolution of eye is one minute i.e. two object will not be visible distinctly to the eye if the angle subtended by them on the eye is lesser than one minute.

The persistence of vision is (1/10) sec i.e., If time interval between two consecutive light pulses is lesser than 0.1 sec eye cannot distinguish them separately. This fact is taken into account in motion pictures.

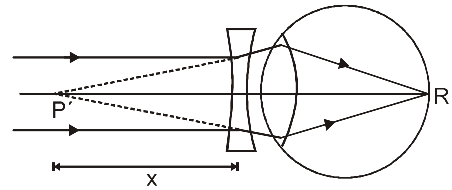
Defects of vision

1. Myopia [or short-sightedness or near - sightedness]

In it distant objects are not clearly visible. The far point for a myopic eye is much nearer than infinity.



Defective eye
(A)



Corrected eye
(B)

If P´ is far point for a myopic eye, then the image of an object placed at the point P´ will be formed on the retina as shown in the figure (a).

The myopic eye will get cured against this defect, if it is able to see the objects at infinity clearly. In order to correct the eye for this defect, a concave lens of suitable focal length is placed close to the eye, so that the parallel ray of light from point P´ of the myopic eye as shown in figure (b). If x is the distance of the far point from the eye, then for the concave lens placed before the eye :

$u = \infty$ and $v = -x$

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

solving, $f = -x$

Thus, myopic eye is cured against the defect by using a concave lens of focal length equal to the distance of its far point from the eye.

2. Hypermetropia [Or Long-sightedness or far-sightedness].

In it near object are not clearly visible i.e., Near Point is at a distance greater than 25 cm and hence image of near object is formed behind the retina.

In case of a hypermetropic eye, when the object lies at the point N (at the near point for a normal eye), its image is formed behind the retina as shown in figure (a).

The near point N´ for hypermetropic eye is farther than N, the near point for a normal eye.

Such defect will get cured, if the eye can see an object clearly, when place at the near point N for the normal eye. To correct this defect, a convex lens of suitable focal length is placed close to the eye so that the rays of light form an object placed at the point N after refraction through the lens appear to come from the near point N´ of the hypermetropic eye as shown in figure (b).

Let x be the distance of the near point N´ from the eye and D, the least distance of distinct vision i.e. the distance of near point N for the normal eye. Then, for the convex lens placed before the eye,

$u = -D$ and $v = -x$

If f is the focal length of the required convex lens, then from the lens formula, we have

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \quad \Rightarrow \quad \frac{1}{-x} - \frac{1}{-D} = \frac{1}{f} \quad \Rightarrow$$

$$f = \frac{xD}{x-D} \quad \text{...(a)}$$

Thus, an eye suffering from hypermetropia can be cured against the defect by using a convex lens of focal length given by equation (a).

3. Presbyopia

In this both near and far objects are not clearly visible i.e., far point is lesser than infinity and near point greater than 25 cm. It is an old age disease as at old age ciliary muscles lose their elasticity and so cannot of eye-lens effectively and hence eye loses its power of accommodation.

Compound Microscope

When we need greater magnification than what we can get with a simple magnifier, the instrument that we usually use is a compound microscope.

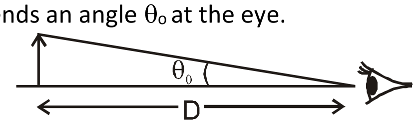
The essential parts of a compound microscope are two convex lenses of different focal length placed coaxially. These lenses are referred to as:

(a) Objective lens or objective: It is a lens of small aperture and small focal length placed facing the object.

(b) Eye piece: It is a lens of large aperture and small focal length placed facing the object.

The object O to be viewed is placed just beyond the first focal point of the **objective** lens that forms a real and enlarged image I´ as shown in figure. In a properly designed instrument this image lies just inside the first focal point of the **eyepiece**. The eyepiece acts as a simple magnifier, and forms a final virtual image of I. The position of may be anywhere between the near and far points of the eye.

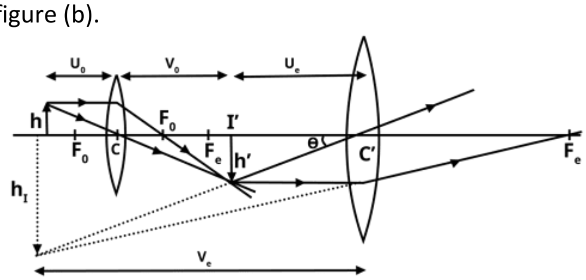
In figure (a) the object is at the near point, where it subtends an angle θ_o at the eye.



unaided eye
(a)

$$\theta_0 \approx \tan\theta_0 \approx \frac{h}{D}$$
...(a)

(i) When image is formed at near point, D: Let θ_i be the angle subtended by the final image at the eye as shown in figure (b).



Angular magnification or magnifying power (M) is defined as the ratio of the angle subtended by the final image at the eye to the angle subtended by the object seen directly at the eye when both lie at near point D.

The angular magnification produced is,

$$M = \frac{\theta_i}{\theta_0} \approx \frac{\tan\theta_i}{\tan\theta_0} \qquad ...(b)$$

$\theta_i \approx \tan\theta_i = \frac{h_i}{v_e} = \frac{h_i}{D}$ (Θ v_e = D in magnitude)

$\theta_o \approx tan\,\theta_o = \frac{h}{D} \Rightarrow$ M = $\frac{h_i}{h}$ ...(c)

Linear magnification, m = $\frac{h_i}{h}$ = $m_o \times m_e$ ...(d)

M = $m_o m_e$ (from eq. (c) and eq. (d))

where m_o = linear magnification produced by objective lens = $\frac{V_0}{U_0}$ ...(5)

m_e = linear magnification produced by eye piece = $\frac{V_e}{U_e}$

using lens formula for eye piece, $\frac{1}{v_e} - \frac{1}{u_e} = \frac{1}{f_e}$

$m_e = \frac{v_e}{u_e} = 1 - \frac{v_e}{f_e} = 1 + \frac{D}{f_e}$ ...(6)

($\because v_e = -D$)

$\frac{v_o}{u_o}\left(1 + \frac{D}{f_e}\right)$

From equations (c), (d) and (6) we have

$M = \frac{v_o}{u_o}\left(1 + \frac{D}{f_e}\right)$, ...(7)

In practice, the focal length of objective lens is very small and the object is just placed outside the focus of the objective lens,

$u_o = -f_o$

Since the focal length of the eye lens is also small, the distance of image I′ from objective lens is nearly equal to the length of the microscope tube, L

$v_o = L$

substituting in equation (7),

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

This equation shows that a compound microscope will have high magnifying power, if the objective lens and the eye piece both have small focal length. The negative sign shows that final image will be inverted w.r.t. object.

(ii) When image is formed at infinity: The magnifying power of compound microscope is given by

M = $m_o m_e$

Magnification produced by objective lens, $m_o = \frac{V_0}{U_0}$

The eye lens produces the final image at infinity. Then,

$m_e = \frac{D}{f_e}$ (as discussed in case of simple microscope)

Therefore, $M = \frac{v_o}{u_o}\frac{D}{f_e}$, $M = -\frac{L}{f_o}\frac{D}{f_e}$

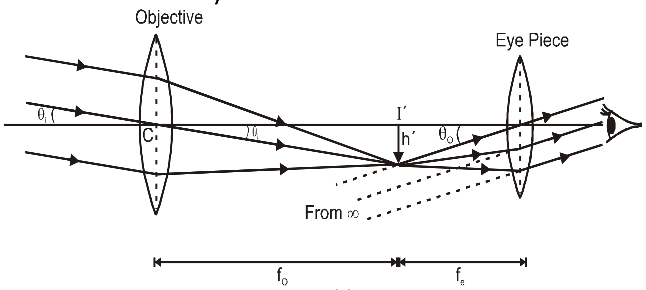
Telescope

It is an optical instrument used to increase the visual angle of distant large objects such as a star a planet or a cliff etc. Astronomical telescope consists of two converging lenses. The one facing the object is called objective and has large focal length and aperture. Other lens is called eye piece. It has small aperture and is of small focal length. The distance between the two lenses is adjustable.

The objective forms a real and inverted image at its focal plane of the distant object. The distance of the eye piece is adjusted, till the final image is formed at the near point, D. In case, the position of the eye piece is so adjusted that final image is formed at infinity, the telescope is said to be in normal adjustment.

(i) When the image is formed at infinity (Normal adjustment)

When a parallel beam of light rays from a distant object falls on objective, its real and inverted image I′ is formed on the other side of the objective and at a distance f_o. If the position of the eye piece is adjusted, so that the image lies at its focus, then the final highly magnified image will be formed at infinity.



(a)

Angular magnification or magnifying power (M) here is defined as the ratio of the angle subtended by the final image at the eye as seen through the telescope to the angle subtended by the object, seen directly at the eye when both the object and the image lie at infinity.

$$M = \frac{\theta_i}{\theta_o} = \frac{\tan\theta_i}{\tan\theta_o} \qquad \text{(for small angle } \tan\theta \approx \theta)$$

From figure (a), $\tan\theta_i = \frac{h'}{CI'}$, $\tan\theta_o = \frac{h'}{C'I'}$

$$M = \frac{CI'}{C'I'} = -\frac{f_o}{f_e} \qquad (CI' = f_o,\ C'I' = -f_e)$$

If f_o is large and f_e is small, the magnification will be high.

In normal adjustment the length of tube

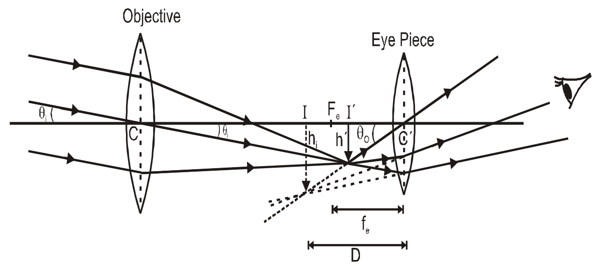
$L = (f_o + u_e)$

(ii) If the final image is formed at D (near point)

When a parallel beam of light rays from a distant object falls on objective, its real and inverted image I× is formed on the other side of the objective and at a distance f_o. If the position of the eye piece is adjusted, so that the final image I is formed at near point D.

Angular magnification or magnifying power(M) here is defined as the ratio of the angle subtended by the final image formed at near point at the eye to the angle subtended by the object lying at infinity seen directly at the eye.

$$M = \frac{\theta_i}{\theta_o} = \frac{\tan\theta_i}{\tan\theta_o} \qquad \text{(for small angle } \tan\theta \approx \theta)$$



(b)

From figure (b), $\tan\theta_o = \frac{h'}{CI'}$, $\tan\theta_i = \frac{h'}{C'I'}$

$$\Rightarrow \qquad M = \frac{CI'}{C'I'} = -\frac{f_o}{u_e}$$

For eye lens, $\frac{1}{v_e} - \frac{1}{u_e} = \frac{1}{f_e}$,

$$\Rightarrow \frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{D} \qquad (\Theta\ \ u_e = -u_e,\ v_e = -D)$$

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

If f_o is large and f_e is small, the magnification will be high.

Q. 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, then find the distance between the retina and the cornea-eye lens.

Sol. Converging power of cornea,

$P_c = +40$ D

Least converging power of eye lens, $P_e = +20$ D

Power of the eye-lens, $P = P_c + P_e$

$= 40\text{ D} + 20\text{ D} = 60\text{ D}$

Power of the eye lens

$$P = \frac{1}{\text{Focal length of the eye lens } (f)}$$

$$f = \frac{1}{P} = \frac{1}{60\text{ D}} = \frac{1}{60}\text{m} = \frac{100}{60}\text{cm} = \frac{5}{3}\text{cm}$$

Distance between the retina and cornea-eye lens = Focal length of the eye lens

$= \frac{5}{3}\text{ cm} = 1.67\text{ cm}$

SUMMARY

- **Laws of Reflection:**
  The reflection at a plane surface always takes place in accordance with the following two laws:
  (i) The incident ray, the reflected ray and normal to surface at the point of incidence all lie in the same plane.
  (ii) The angle of incidence, i is equal to the angle of reflection
  r, i. e.,
  $\angle i = \angle r$
- **Formation of Image by the Plane Mirror:**
  The formation of image of apoint object O by a plane mirror is represented in figure. The image formed *I* has the following characteristics:
  (i) The size of image is equal to the size of object.
  (ii) The object distance = Image distance i.e., OM = MI.
  (iii) The image is virtual and erect.
  (iv) When a mirror is rotated through a certain angle, the reflected ray is rotated through twice this angle.
- **Reflection of Light from Spherical Mirror:**
  a) A spherical mirror is a part cut from a hollow sphere.
  b) They are generally constructed from glass.
  c) The reflection at spherical mirror also takes place in accordance with the laws of
  reflection.
- **Sign Convention:**
  Following sign conventions are the new cartesian sign convention:
  (i) All distances are measured from the pole of the mirror & direction of the incident light is taken as positive. In other words, the distances measured toward the right of the origin are positive.
  (ii) The distance measured against the direction of the incident light are taken as negative. In other words, the distances measured towards the left of origin are taken as negative.
  (iv) The distance measured in the upward direction, perpendicular to the principal axis of the mirror, are taken as positive & the distances measured in the downward direction are taken as negative.
- **Focal Length of a Spherical Mirror:**
  a) The distance between the focus and the pole of the mirror is called focal length of the mirror and is represented by *f*.
  b) The focal length of a concave mirror is positive and that of a convex mirror is positive and that of a convex mirror is negative.
  (c) The focal length of a mirror (concave or convex) is equal to half of the radius of
  curvature of the mirror, i.e., $f = \frac{R}{2}$.
- **Principal Axis of the Mirror:**
  The straight line joining the pole and the centre of curvature of spherical mirror extended on both sides is called principal axis of the mirror.
- **Mirror Formula:**
  $$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$
  Where u= distance of the object from the pole of mirror
  v = distance of the image from the pole of mirror
  f = focal length of the mirror
  $$f = \frac{r}{2}$$
  Where *r* is the radius of curvature of the mirror.
- **Magnification:**
  It is defined as the ratio of the size of the image to that of the object.
  Linear magnification,
  $$m = \frac{I}{O} = -\frac{v}{u} = \frac{f-v}{f} = \frac{f}{f-u}$$
  Where *I* size of image and *O* = size of object.
- Magnification, m is positive, implies that the image is real and inverted.
- Magnification, m is negative, implies that the image is virtual and erect.
- **Refraction:**
  When a ray of light falls on the boundary separating the two media, there is a change in direction of ray. This phenomenon is called refraction.
- **Laws of Refraction.**
  (i) The incident ray normal at the point of incidence and refracted ray all lie in one plane.
  (ii) For the same pair of media and the same color of light, the ratio of the sine of the angle
  of incidence to the sine of the angle of refraction is constant i.e.,
  $$\frac{\sin i}{\sin r} = {}_a\mu_b$$
  Where ${}_a\mu_b$ is a constant known as Refractive Index of the medium b with respect to the medium a, i is the angle incidence in medium a and r is the angle of refraction in medium b.
- **Principle of Reversibility of Light:**
  As light follows a reversible path,
  $$\frac{\sin i}{\sin r} = {}_a\mu_b$$

Multiplying we get,

$$_a\mu_b X _b\mu_a = \frac{\sin i}{\sin r} x \frac{\sin r}{\sin i} = 1$$

$$_a\mu_b = \frac{1}{_a\mu_b}$$

- **Methods to Determine Refractive Index of a Medium:**
  Refractive index of a medium can also be determined from the following:

  (i) $\mu = \frac{\text{Velocity of light in air}}{\text{Velocity of light in the medium}}$

  (ii) $\mu = \frac{1}{\text{sinc}}$

  Where *c* is the critical angle.
- **Critical Angle:**
  The Critical angle is the angle of incidence in a denser medium corresponding to which the refracted ray just grazes the surface of separation.
- **Apparent Depth of a Liquid:**
  If the object be placed at the bottom of a transparent medium, say water, and viewed from above, it will appear higher than it actually is.
  The refractive index μ in this case is:
  Refractive index of the medium, $\mu = \frac{\text{Real Depth}}{\text{Apparent Depth}}$
- **Refraction through a Single Surface:**
  If 1 2 μ_1, μ_2 are refractive indices of first and second media, R the radius of curvature of spherical surface, formula is

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

  where u and v are the distances of the object and the image from the centre of the refracting surface of radius of curvature R respectively.
- **Refraction through a Thin Lens**
  If R_1 and R_2 are radii of curvature of first and second refracting surfaces of a thin lens of focal length f, then lens-makers formula is

  $\frac{1}{f} = \left(\frac{\mu_2 - \mu_1}{\mu_1}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

  If the lens is surrounded by air, $\mu_1 = 1$ and $\mu_2 = \mu$, then

  $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$
- **Thin lens formula:**
  $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$
- **Magnification Produced by a Lens:**
  $m = \frac{I}{O} = \frac{v}{u}$
  Where I is size of image and O is size of object.
- **Power of a Lens:**
  The power of a lens P is its ability to deviate the ray towards axis.

  $P = \frac{1}{f\,(\text{inmetres})} Diopters$
  $= \frac{100}{f\,(incm)} Diopters$
- **Focal Length of Thin Lenses:**
  The focal length (f) of thin lenses of focal lengths f_1, f_2, f_3,………. placed in contact of each other is,
  $\frac{1}{-} = \frac{1}{f_1'} + \frac{1}{f_2'} + \frac{1}{f_3'} + \ldots .$
- **Refraction Through Prism:**
  When a ray of monochromatic light is refracted by a prism, the deviation δ produced by the prism is
  $\delta = i + e - A$
  Where i = angle of incidence
  e = angle of emergence
  A = angle of the prism
- **Angle of Deviation:**
  The angle of deviation δm is minimum, when ray passes symmetrically through the prism. The refractive index μ of the prism is
  $\mu = \frac{sin\left(\frac{A+\delta m}{2}\right)}{sin\frac{A}{2}}$
- **Dispersion:**
  The splitting of white light into constituent colours is called the dispersion. A prism causes deviation as well as dispersion.
- **Optical Instruments:**
  Optical instruments are the devices which help human eye in observing highly magnified images of tiny objects, for detailed examination and in observing very far objects whether terrestrial or astronomical.
- **Human Eye:**
  (a) It is the most familiar and complicated optical instrument provided by nature to living beings. In this device, light enters through a curved front surface, called cornea, passes through the pupil – central hole in the iris.
  (b) The light is focused by the eye lens on the retina.
  (c) The retina senses light intensity and colour and transmits the electrical signals via optical nerves to the brain.
  (d) Brain finally processes the information.
- **Microscope:**
  (a) A simple microscope is a short focal length convex lens.
  (b) The magnifying power of a simple microscope is
  $M = 1 + \frac{D}{f}$
  (c) The magnifying power, M of a compound microscope is
  $M = M_0 x M_e = \frac{v}{u}\left(1 + \frac{D}{f_e}\right)$
  Where, M_o and M_e denotes the linear magnifying of the objective and eye lens.
- **Telescope:**
  a) The magnifying power, M of refracting telescope is

$M = \frac{f_0}{f_e}$

$L = (f_0 - f_e)$

Where L is the length of the telescope.

b) For the final image is formed at the least distance of distant vision, the magnifying power is

$M = \frac{f_0}{f_e}(1 + \frac{F_e}{D}$

(c) The resolving power of a telescope

$$\theta = \frac{1.22\lambda}{d}$$

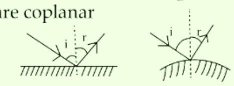
Where, λ = wavelength of light, θ = angle subtended by the point object at the objective and d = diameter of the objective of the telescope

MIND MAP

Ray Optics & Optical Instruments

Sign Conversion
- Pole is taken as origin
- Principle axis as the X-axis
- All distance measured from origin (or pole).
- All distance measured in the direction of incident ray is taken + ve.
- All distance measured in the direction opposite to the incident ray is taken - ve.

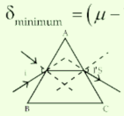
Reflection of Light
- $\angle i = \angle r$
- Incident ray reflected ray and normal to the reflecting surface are coplanar



Prism
Angle of deviation $\delta = i - i' - A$

$\delta_{minimum} = 2i - A\,[i = i'] \rightarrow$

$\delta_{minimum} = (\mu - 1)A$, if A is small



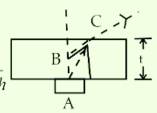
Scattering of Light
Light scattered i.e. redirected in different paths when interacts with particle matters e.g. sunset, sunrise, colours, blue colour of sky

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

Lateral Magnification $= \frac{h_2}{h_1} = -\frac{v}{u}$

Refraction of light
$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{\mu_2}{\mu_1}$$

$$\mu = \frac{\text{real depth}}{\text{apparent depth}}$$



$\Delta t = \left(1 - \frac{1}{\mu}\right)t$ = image shift

Total internal refection
When ray passes from optically denser to rarer medium. If incident angle (i) further increased than $(\theta)_C$ critical angle entire light is then reflected back to the denser medium again is called T.I.R. It is used in optical fibre.

Critical Angle
- Incident angle (θ_c) for which angle of refraction is 90°

i.e. $\sin\theta_c = 1/\mu$

$$\theta_c = \sin^{-1}\left(\frac{1}{\mu}\right)$$

When ray passes from optically denser to rarer medium.

Refraction on Spherical surface
$\mu_1 \; (\mu_2$

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

Lateral Magnification

$$m = \frac{h_2}{h_1} = \frac{\mu_1 v}{\mu_2 u}$$

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

Lens Maker's Formula
$$\frac{1}{v} - \frac{1}{u} = \frac{\mu_2 - \mu_1}{\mu_1}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{f} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad [\text{If } \mu_2 = \mu, \mu_1 = 1 \ (air)$$

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad \text{(lens formula)}$$

Lateral Magnification $= \frac{h_2}{h_1} = \frac{v}{u}$

Power of a lens
$$P = \frac{1}{f}$$

[For combination of lens]

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

Optical Instruments

Microscope
$M = 1 + \frac{D}{f}$ [image at near point]

$M = D/f$ [image at infinite]

Compound Microscope
$M = \frac{v}{u}\left[\frac{D}{f_e}\right]$ [normal adjustment]

$$M = \frac{v}{u}\left(1 + \frac{D}{f_e}\right) = -\frac{1}{f_o}\left(1 + \frac{D}{f_e}\right)$$

For final image at least distance

Telescope
$M = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$ [image at near point]

$M = -\frac{fo}{fe}$ [image at infinite]

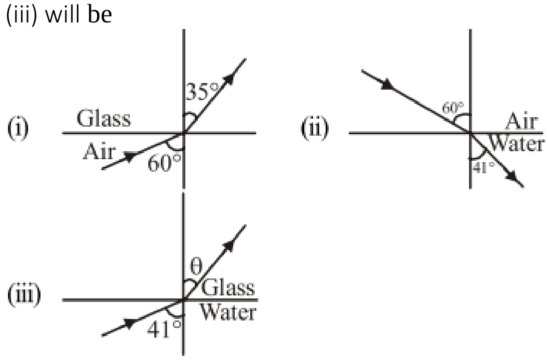
QUESTIONS FOR PRACTICE

MCQ

Q1. A double convex lens is made of glass which has its refractive index 1.45 for violet rays and 1.50 for red rays. If the focal length for violet ray is 20 cm, the focal length for red ray will be
(a) 9 cm (b) 18 cm
(c) 20 cm (d) 22 cm

Q2. If two + 5 diopter lenses are mounted at some distance apart, the equivalent power will always be negative if the distance is
(a) greater than 40 cm (b) equal to 40 cm
(c) equal to 10 cm (d) less than 10 cm

Q3. Refraction of light from air to glass and from air to water are shown in figure
(i) and figure
(ii) below. The value of the angle θ in the case of refraction as shown in figure
(iii) will be



(a) 30^0 (b) 35^0
(c) 60^0 (d) 41^0

Q4. A fish looking up through the water sees the outside world contained in a circular horizon. If the refractive index of water is $\frac{4}{3}$ and the fish is 12 cm below the surface, the radius of this circle in cm is
(a) $36\sqrt{5}$ (b) $4\sqrt{5}$
(c) $36\sqrt{7}$ (d) $36\sqrt{7}$

Q5. A rod of length 10 cm lies along the principal axis of a concave mirror of focal 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 :
(a) 10 cm (b) 15 cm
(c) 2.5 cm (d) 5 cm

Q6. A man's near point is 0.5m and far point is 3 m. Power of spectacle lenses required for (i) reading purposes, (ii) seeing distant objects, respectively, are
(a) -2 D and +3D (b) +2 D and -3 D
(c) +2 D and -0.33 D (d) -2 D and +0.33 D

Q7. A lens made of glass whose index of refraction is 1.60 has a focal length of + 20 cm in air. Its focal length in water, whose refractive index is 1.33, will be
(a) three times longer than in air
(b) two times longer than in air
(c) same as in air
(d) None of these

Q8. A compound microscope has an eye piece of focal length 10 cm and an objective of focal length 4 cm. Calculate the magnification, if an object is kept at a distance of 5cm from the objective so that final image is formed at the least distance vision (20 cm) :
(a) 12 (b) 11
(c) 10 (d) 13

Q9. For a prism kept in air it is found that for an angle of incidence 60^0, the angle of Prism A, angle of deviation δ and angle of emergence 'e' become equal. Then the refractive index of the prism is
(a) 1.73 (b) 1.15
(c) 1.5 (d) 1.33

Q10. The speed of light in media M_1 and M_2 are 1.5×10^8 m/s and 2.0×10^8 m/s respectively. A ray of light enters from medium M_1 to M_2 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 $\sin^{-1}\left(\frac{2}{3}\right)$

Q11. A beam of light composed of red and green ray is incident obliquely at a point on the face of rectangular glass slab. When coming out on the opposite parallel face, the red and green ray emerge from
(a) two points propagating in two different non parallel directions
(b) two points propagating in two different parallel directions
(c) one point propagating in two different directions
(d) one point propagating in the same directions.

Q12. An object is placed at a distance of 40 cm from a concave mirror of focal length 15 cm. If the object is displaced through a distance of 20 cm towards the mirror, the displacement of the image will be
(a) 30 cm away from the mirror
(b) 36 cm away from the mirror
(c) 30 cm towards the mirror
(d) 36 cm towards the mirror

Q13. 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
(a) $\frac{y}{x}$ (b) $\frac{x}{2y}$
(c) $\frac{x}{y}$ (d) $\frac{y}{2x}$

Q14. 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

(a) 45° (b) 30°
(c) 55° (d) 50°

Q15. Which of the following is not due to total internal reflection?

(a) Working of optical fibre
(b) Difference between apparent and real depth of a pond
(c) Mirage on hot summer days
(d) Brilliance of diamond

Q16. 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

(a) +15 cm (b) +150 cm
(c) –150 cm (d) –15 cm

Q17. Exposure time of camera lens at $f/2.8$ setting is 1/200 second. The correct time of exposure at $f/5.6$ is

(a) 0.20 second (b) 0.40 second
(c) 0.02 second (d) 0.04 second.

Q18. The reddish appearance of the sun at sunrise and sunset is due to

(a) the scattering of light
(b) the polarization of light
(c) the color of the sun
(d) the color of the sky

Q19. Rainbow is formed due to

(a) scattering and refraction
(b) internal reflection and dispersion
(c) reflection only
(d) diffraction and dispersion.

Q20. 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

(a) $45°; \sqrt{2}$ (b) $30°; \frac{1}{\sqrt{2}}$
(c) $45°; \frac{1}{\sqrt{2}}$ (d) $30°; \sqrt{2}$

ASSERTION AND REASONING

Directions: These questions consist of two statements, each printed as Assertion and Reason. While answering these questions, you are required to choose any one of the following four responses.

(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.

Q1. Assertion: Diamond glitters brilliantly.
Reason: Diamond does not absorb sunlight.

Q2. Assertion: Resolving power of a telescope is more if the diameter of the objective lens is more. Reason: Objective lens of large diameter collects more light

Q3. Assertion: If objective and eyepiece of a microscope are interchanged, then it can work as a telescope.
Reason: The objective lens of the telescope has small focal length.

Q4. Assertion: Light travels faster in glass than in air.
Reason: Glass medium is rarer than air.

Q5. Assertion: For observing traffic at back, the driver mirror is convex mirror.
Reason: A convex mirror has much larger field of view than a plane mirror.

VERY SHORT ANSWER QUESTIONS

Q1. Why can't we see clearly through fog? Name the phenomenon responsible for it.

Q2. Out of blue and red light which is deviated more by a prism? Give reason.

Q3. Under what condition does a biconvex lens of glass having a certain refractive index act as a plane glass sheet when immersed in a liquid?

NUMERICAL TYPE QUESTIONS

Q1. A converging and a diverging lens of equal focal lengths are placed co-axially in contact. Find the power and the focal length of the combination.

Q2. An object is kept in front of a concave mirror of focal length 15 cm. The image formed is real and three times the size of the object. Calculate the distance of the object from the mirror.
$\Rightarrow\ u = -20$ cm

Q3. Calculate the speed of light in a medium whose critical angle is 45°. Does critical angle for a given pair of media depend on wave length of incident light?

Q4. Calculate the radius of curvature of an equi-concave lens of refractive index 1.5, when it is kept in a medium of refractive index 1.4, to have a power of -5D ?

Q5. A ray of light passing from air through an equilateral glass prism undergoes minimum deviation when the angle of incidence is $\frac{3}{4}$th of the angle of prism. Calculate the speed of light in the prism.

Q6. An object 2 cm high is placed at a distance of 16 cm from a concave mirror, which produces a real image 3 cm high. What is the focal length of the mirror?

Q7. Rear view mirror of a car is of radius of curvature R = 2 m. A jogger approaches car (from behind) at a speed of 5

ms^{-1}. Then find the speed of image, when jogger is 39 m from the mirror.

Q8. When a light ray enters from oil to glass, then on oil-glass interface, the velocity of light changes by which factor. [given, $n_{\text{oil}} = 2, n_{\text{glass}} = 3 / 2$]

Q9. A double convex lens has focal length 25 cm. The radius of curvature of one of the surfaces is double of the other. Find the radii, if the refractive index of the material of the lens is 1.5.

Q10. The refractive index of the material of a prism is $\sqrt{2}$ and the angle of the prism is 30°. One of the two refracting surfaces of the prism is made a mirror inward, by silver coating. A beam of monochromatic light entering the prism from the other face will retrace its path (after reflection from the silvered surface), find its angle of incidence on the prism.

HOMEWORK EXERCISE

MCQ

Q1. An object is placed at a distance of 40 cm in front of a concave mirror of focal length 20 cm. The image produced is
(a) real, inverted and smaller in size
(b) real, inverted and of same size
(c) real and erect
(d) virtual and inverted

Q2. Light travels in two media 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
(a) $\sin^{-1}\left(\frac{2}{3}\right)$ (b) $\tan^{-1}\left(\frac{3}{4}\right)$
(c) $\tan^{-1}\left(\frac{2}{3}\right)$ (d) $\sin^{-1}\left(\frac{3}{4}\right)$

Q3. 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 $\frac{3}{4}$th of angle of prism. The angle of deviation is
(a) 25^0 (b) 30^0
(c) 45^0 (d) 35^0

Q4. The power of a biconvex lens is 10 diopter and the radius of curvature of each surface is 10 cm. Then the refractive index of the material of the lens is
(a) $\frac{3}{2}$ (b) $\frac{4}{3}$
(c) $\frac{9}{8}$ (d) $\frac{5}{3}$

Q5. A microscope is focused on a mark on a piece of paper and then a slab of glass of thickness 3 cm and refractive index 1.5 is placed over the mark. How should the microscope be moved to get the mark in focus again?
(a) 4.5 cm downward (b) 1 cm downward
(c) 2 cm upward (d) 1 cm upward

Q6. If a glass prism is dipped in water, its dispersive power
(a) increases
(b) decreases
(c) does not change
(d) may increase or decrease depending on whether the angle of the prism is less than or greater than 60^0

Q7. To get three images of a single object, one should have two plane mirrors at an angle
(a) 60^0 (b) 90^0
(c) 120^0 (d) 30^0

Q8. A thin convergent glass lens $\left(\mu_g = 1.5\right)$ has a power of + 5.0 D. When this lens is immersed in a liquid of refractive index μ, it acts as a divergent lens of focal length 100 cm. The value of μ must be
(a) $\frac{4}{3}$ (b) $\frac{5}{3}$
(c) $\frac{5}{4}$ (d) $\frac{6}{5}$

Q9. A ray PQ incident on the refracting face BA is refracted in the prism BAC as shown in the figure and emerges from the other refracting face AC as RS such that AQ = AR. If the angle of prism A = 60^0 and the refractive index of the material of prism is $\sqrt{3}$, then the angle of deviation of the ray is
(a) 60^0 (b) 45^0
(c) 30^0 (d) None of these

Q10. 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.
(a) equal to that of glass (b) less than one
(c) greater than that of glass (d) less than that of glass

Q11. If a thin prism of glass is dipped in water, then minimum deviation (with respect to air) of light produced by prism will be $\left(\text{w}\,\mu_g = \frac{3}{2}, a\,\mu_w\right) = \frac{4}{3}$
(a) $\frac{1}{5}$ (b) $\frac{1}{4}$
(c) $\frac{1}{2}$ (d) $\frac{1}{3}$

Q12. Two similar thin equi-convex lenses, of focal length f each, are kept coaxially in contact with each other such that the focal length of the combination is F_1. When the space between the two lenses is filled with glycerin (which has the same refractive index (μ = 1.5) as that of glass) then the equivalent focal length is F_2. The ratio F_1 : F_2 will be
(a) 3 : 4 (b) 2 : 1
(c) 1 : 2 (d) 2 : 3

Q13. 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
(a) equal to that of glass (b) less than one
(c) greater than that of glass (d) less than that of glass.

Q14. A convex lens and a concave lens, each having same focal length of 25 cm, are put in contact to form a combination of lenses. The power in diopters of the combination is
(a) zero (b) 25
(c) 50 (d) infinite.

Q15. A convex lens is dipped in a liquid whose refractive index is equal to the refractive index of the lens. Then its focal length will
(a) become zero
(b) become infinite
(c) become small, but non-zero
(d) remain unchanged.

ASSERTION AND REASONING

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(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.

Q1. Assertion: The focal length of the objective in a telescope is larger than that of eyepiece.
Reason: Magnifying power of telescope increases when the aperture is large

Q2. Assertion: If a convex lens is kept in water its convergent power decreases.
Reason: Focal length of convex lens in water increases.

Q3. Assertion (A): The speed of light in glass depends on color of light.
Reason (R): The speed of light in glass $v_g = \frac{c}{n_g}$, the refractive index (n_g) of glass is different for different for different colors.

Q4. Assertion (A): If objective and eye lenses of a microscope are interchanged then it can work as telescope.
Reason (R): The objective of telescope has small focal length.

Q5. Assertion: The image formed by a concave mirror is certainly real if the object is virtual.
Reason: The image formed by a concave mirror is certainly virtual if the object is real.

VERY SHORT ANSWER QUESTIONS

Q1. Consider a point at the focal point of a convergent lens. Another convergent lens of short focal length is placed on the other side. What is the nature of the wavefronts emerging from the final image?

Q2. State the condition under which a large magnification can be achieved in an astronomical telescope.

Q3. Will the focal length of a lens for red light be more, same or less than that for blue light?

NUMERICAL TYPE QUESTIONS

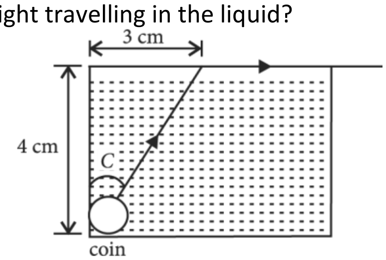
Q1. The far point of a myopic person is 80 cm in front of the eye. What is the power of the lens required to enable him to see very distant objects clearly?

Q2. The nearer point of hypermetropic eye is 20 cm. Find the power of lens which can be used for its correction.

Q3. An 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, then find the distance between lenses.

Q4. 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. Then find the thickness (in cm) of the slab.

Q5. 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?



PRACTICE EXERCISE SOLUTIONS

MCQ

S1. (b) $\frac{1}{f_R} = (1.5-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

$\frac{1}{f_V} = (1.45-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

$\frac{f_V}{f_R} = \frac{0.5}{0.45} = \frac{10}{9}$

$\frac{f}{R} = \frac{9}{10} f_v = \frac{9}{10} \times 20\ cm = 18\ cm.$

S2. (a) Let the distance between the lenses be d. Then, equivalent power is

P = $P_1 + P_2 - d\,P_1\,P_2$

Given $P_1 = P_2 = +5\ D$

∴ P = $(10 - 25d)D$

For P to be -ve,

10 – 25d < 0 ⟹ d > $\frac{2}{5}$m

Or, $d < 0.4m$ or d > 40 cm

S3. (b) $\alpha\mu_g = \frac{\sin 60^0}{\sin 35^0}$ … (i)

$\alpha\mu_w = \frac{\sin 60^0}{\sin 41^0}$….(ii)

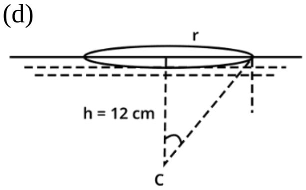
$\alpha\mu_g = \frac{\sin 41^0}{\sin\theta}$…..(iii)

$\alpha\mu_w \times w\mu_g = \alpha\mu_g$

$\frac{\sin 60^0}{\sin 41^0} \times \frac{\sin 41^0}{\sin\theta} = \frac{\sin 60^0}{\sin 35^0}$

(Using (i), (ii) and (iii)

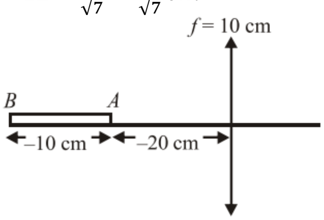
S4. (d)



Sin C = $\frac{1}{\mu} = \frac{1}{4/3} = \frac{3}{4}$

Now r = h tan C

= 12 × $\frac{3}{\sqrt{7}} = \frac{36}{\sqrt{7}} cm$



S5. (d) The Focal length of the mirror

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

For A end of the rod the image distance

When $u_1 = -20\ cm$

$\Rightarrow \frac{-1}{10} = \frac{1}{v_1} - \frac{1}{20}$

$\frac{1}{v_1} = \frac{-1}{10} + \frac{1}{20} = \frac{-2+1}{20}$

$v_1 = -20cm$

For When $u_2 = -30\ cm$

$\frac{1}{f} = \frac{1}{v_2} - \frac{1}{30}$

$\frac{1}{v_2} = \frac{-1}{10} + \frac{1}{30} = \frac{-30+10}{300} = \frac{-20}{300}$

$v_2 = -15\ cm$

$L = v_2 - v_1 = -15 - (-20)$

$L = 5cm$

S6. (c) For reading purposes:

u = -25 cm, v = -50 cm, f = ?

$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = -\frac{1}{50} + \frac{1}{25} = \frac{1}{50}$;

$P = \frac{100}{f} = +2D$

For distant vision, f' = distance of far point = -3 m

P = $\frac{1}{f'} = -\frac{1}{3}D = -0.33\ D$

S7. (a) an_ℓ = 1.6, an_w = 1.33 f = 20 cm

We have,

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

$\frac{1}{20} = (1.6-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$ …….(1)

Also, $\frac{1}{f'} = (wn_\ell - 1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

$= \left(\frac{an_\ell}{a\,n_w} - 1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

$\frac{1}{f'} = \left(\frac{1.6}{1.33} - 1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$ ……(2)

Dividing equation (1) by (2)

$\Rightarrow \frac{f'}{20} = \frac{0.6}{(1.2-1)}$

f'= $\frac{0.6\times 20}{0.2} = 60\ cm.$

Hence it's focal length is three times longer than in air.

S8. (a) m = $\frac{v_0}{|u_0|}\left(1+\frac{d}{f_e}\right) = \frac{20}{5}\left(1+\frac{20}{10}\right)$

$= 4\left(\frac{10+20}{10}\right) = \frac{4\times 30}{10} = 12$

S9. (a) Given i = 60^0

$A = \delta = e$

$\delta = i + e - A \Rightarrow \delta = i\ (\because e = A)$

$\frac{\sin\left(\frac{A+\delta m}{2}\right.}{\sin\frac{A}{2}}$

Here angle of deviation is min. ($\because i = e$)

$\mu = \frac{\sin\left(\frac{60^0+60^0}{2}\right.}{\sin\frac{60^0}{2}} = 1.73$

S10. (c) Refractive index for medium M_1 is

$\mu_1 = \frac{c}{v_1} = \frac{3\times 10^8}{1.5\times 10^8} = 2$

Refractive index for medium M_2 is

$\mu_2 = \frac{c}{v_2} = \frac{3\times 10^8}{2.0\times 10^8} = \frac{3}{2}$

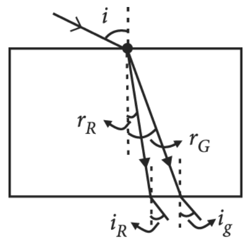
For total internal reflection, $\sin i \geq \sin C$

where i = angle of incidence, C = critical angle

But $\sin C = \frac{\mu_2}{\mu_1}$

∴ $\sin i \geq \frac{\mu_2}{\mu_1} \geq \frac{3/2}{2} \Rightarrow i \geq \sin^{-1}\left(\frac{3}{4}\right)$

S11. (b) The velocities of different colours is different in a given medium. Red and green are refracted at different angle of refraction.



$\frac{\sin i}{\sin r_R} = \mu$ ...(i)

$\frac{\sin i}{\sin r_G} = \mu$ ...(ii)

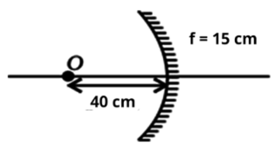
$\frac{\sin r_p}{\sin i_p} = \mu$ ...(iii)

From equations (i), (ii) and (iii), we get

$i = i_R = i_G$

Thus, two point propagation in two different parallel direction.

S12. (b)



Using mirror formula,

$\frac{1}{f} = \frac{1}{v_1} + \frac{1}{u_1}; -\frac{1}{15} = \frac{1}{v_1} - \frac{1}{40} \Rightarrow \frac{1}{v_1} = \frac{1}{-15} + \frac{1}{40}$

$v_1 = -24$ cm

When object is displaced by 20 cm towards mirror.

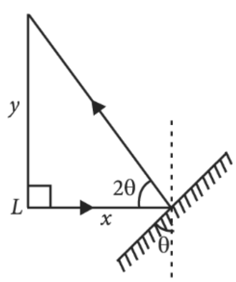
Now, $u_2 = -20$ cm

$\frac{1}{f} = \frac{1}{v_2} + \frac{1}{u_2}; \frac{1}{-15} = \frac{1}{v_2} - \frac{1}{20} \Rightarrow \frac{1}{v_2} = \frac{1}{20} - \frac{1}{15};$

$v_2 = -60$ cm

So, the image will be shift away from mirror by (60 – 24) cm = 36 cm.

S13 . (d)



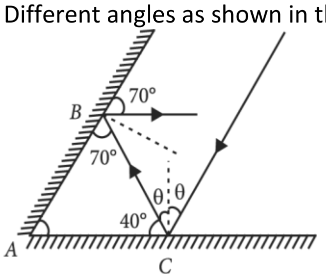
When mirror is rotated by θ angle reflected ray will be rotated by 2θ.

For small angle θ,

$\tan 2\theta \approx 2\theta = \frac{y}{x}$

$\therefore$ $\theta = \frac{y}{2x}$

S14. (d) Different angles as shown in the figure.



θ + 40° = 90°

∴ θ = 90° – 40° = 50°

S15. (b) Difference between apparent and real depth of a pond is due to refraction. Other three are due to total internal reflection.

S16. (a) Magnifying power of telescope,

$M = f_0/f_e$

To produce largest magnifications $f_0 > f_e$ and f_0 and f_e both should be positive (convex lens).

Therefore f_e = +15 cm.

S17. (c) Time of exposure $t \propto (f - \text{number})^2$

$\therefore \frac{t}{\left(\frac{1}{200}\right)} = \left(\frac{5.6}{2.8}\right)^2 = 4$ or $t = 0.02$ s

S18. (a) The reddish appearance of the sun at sunrise and sunset is due to the scattering of light.

S19. (b) The rainbow is an example of the dispersion of sunlight by the water drops in the atmosphere. This is a phenomenon due to a combination of the refraction of sunlight by spherical water droplets and of internal (not total) reflection.

S20. (d) Given, $i = 45°, A = 60°$

Since the ray undergoes minimum deviation, therefore, angle of emergence from second face, e = i = 45°

$\therefore \delta_m = i + e - A = 45° + 45° - 60° = 30°$

$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \frac{\sin\left(\frac{60°+30°}{2}\right)}{\sin\left(\frac{60°}{2}\right)}$

$= \frac{\sin 45°}{\sin 30°} = \frac{1}{\sqrt{2}} \times \frac{2}{1} = \sqrt{2}$

ASSERTION AND REASONING

S1. (b) Diamond glitters brilliantly due to total internal reflection o0iccuring multiple times to the light rays entering the diamond.

S2. (b) Resolving power of a telescope is more if the diameter of the objective lens is more because R= a / 1.22λ where, a is diameter of the objective. objective lens of large diameter collects more light but does not increase the resolving power of the telescope because resolving power increases when angular separation increases.

S3. (d) We cannot interchange the objective and eye lenses of a microscope to make a telescope because focal length of lenses are very small in compound microscope and hence their difference ($f_o - f_e$) is also very small. Whereas in telescope, objective has a very large focal length as compared to eye lens. So, difference between focal length of objective and eye piece is large in telescope as compared to the same in case of microscope.

S4. (d) Light travels faster in air than in glass, because glass is denser than air.

S5. (a) A convex mirror bends light as it reflects the light, and the farther away a point is from the center, the more the light is bent. As a result, an image formed in a convex mirror is smaller than an image in a plane (flat) mirror. Because the image is smaller, more images can fit onto the mirror, so a convex mirror provides for a larger field of view than a plane mirror. They are used whenever a mirror with a large field of view is needed to observe traffic.

VERY SHORT ANSWER QUESTIONS

S1. Scattering of light: When light falls on fog then scattering takes place so the particles of fog become visible. Visible light cannot pass through fog.

S2. Blue is deviated more than red. Reason: Deviation caused by a prism δ= (n – 1) A and Refractive index (n) is more for blue than red.

S3. When $n_L = n_g$ where n_L = Refractive index of liquid and n_g = Refractive index of glass.

NUMERICAL TYPE QUESTIONS

S1. Let focal length of converging and diverging lenses be $+f$ and $-f$ respectively.

Power of converging lens $P_1 = \frac{1}{f}$ Power of diverging lens $P_2 = -\frac{1}{f}$

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∴ Power of combination $P = P_1 + P_2 = \frac{1}{f} - \frac{1}{f} = 0$

∴ Focal length of combination $F = \frac{1}{P} = \frac{1}{0} = \infty$ (infinite)

S2. Here, $m = -3$ and $f = -15$ cm

$m = -\frac{v}{u} = -3 \ \therefore \ v = 3u$

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

$\frac{1}{-15} = \frac{1}{3u} + \frac{1}{u}$

S3. Critical angle in the medium, $i_C = 45°$

So, refractive index, $n = \frac{1}{\sin i_C} = \frac{1}{\sin 45°}$

$\Rightarrow \ n = \sqrt{2}$

Refractive index, $n = \frac{c_0}{c_m}$

$\sqrt{2} = \frac{3\times10^8}{c_m}$

$c_w = \frac{3\times10^8}{\sqrt{2}} = 2.1 \times 10^8 \text{ m/s}$

Yes, critical angle for a pair of media depends on wavelength, because $n = a + \frac{b}{\lambda^2}$, where a and b are constants of the media.

S4. We know that

$P = \frac{1}{f} = \left(\frac{n_2 - n_1}{n_1}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

According to question $P = -5\text{D}$,

$n_2 = 1.5, n_1 = 1.4$

also, lens is equiconvex $R_1 = -R, R_2 = R$

$-5 = \left(\frac{1.5-1.4}{1.4}\right)\left(-\frac{1}{R} - \frac{1}{R}\right)$

$-5 = -\frac{0.1}{1.4} \times \frac{2}{R} \ \Rightarrow \ 5 = \frac{1}{14} \times \frac{2}{R}$

$\Rightarrow \frac{1}{R} = 35 \Rightarrow R = \frac{1}{35} \text{ m} = \frac{100}{35} \text{ cm} = \frac{20}{7} \text{ cm} =$ $\mathbf{2.86}$cm

S5. Angle of prism, $A = 60°$ (Since prism is an equilateral glass prism)

We are given that

$\text{i} = \frac{3}{4}A = \frac{3}{4} \times 60°$

$i = 40°$

At minimum deviation,

$\text{r} = \frac{A}{2} = 30°$

$\text{n} = \frac{\sin i}{\sin r} = \frac{\sin 45°}{\sin 30°} = \frac{\frac{1}{\sqrt{2}}}{\frac{1}{2}} = \frac{2}{\sqrt{2}} = \sqrt{2}$

∴ Speed of light in the prism is given by

$v = \frac{c}{n} = \frac{3\times10^8}{\sqrt{2}} = 2.1 \times 10^8 \text{ m/s}$

S6. Given, size (height) of the object, h_1 = 2 cm, object distance, $u = -16$ cm and size (height) of the image, $h_2 = -3$ cm (since the image is real and inverted)

As, linear magnification, $m = \frac{-h_2}{h_1} = \frac{v}{u}$

where, *v* is image distance.

$\Rightarrow \quad v = \frac{-h_2}{h_1} \times u = -\frac{(-3)}{2} \times (-16) = -24 \text{ cm}$

Now, using mirror formula,

$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} = -\frac{1}{24} - \frac{1}{16} = \frac{-2-3}{48} = \frac{-5}{48}$

$\Rightarrow \quad f = \frac{-48}{5} = -9.6 \text{ cm}$

S7. Since, rear view mirror of a car is convex in nature, so the radius of curvature of convex mirror, *R* = 2 m (given).

Focal length of the mirror, $f = \frac{R}{2} = \frac{2}{2} = 1 \text{ m}$

Also, image distance, $u = -39$ m

From the mirror equation, we get $v = \frac{f\,u}{u-f}$

Substituting the given values in Eq. (i), we get

$v = \frac{(-39)\times1}{-39-1} = \frac{39}{40}$ m

Since, the jogger moves at a constant speed of 5 ms^{-1}, after 1 s the position of the jogger will be

$u = -39 + (5 \times 1)$

$= -39 + 5 = -34$ m

So, now the image position of the jogger will

$v = \frac{(-34)\times1}{-34-1} = \frac{34}{35}$ m.

The shift in the position of image in 1 s is

$\frac{39}{40} - \frac{34}{35} = \frac{1365-1360}{1400} = \frac{5}{1400} = \frac{1}{280}$ m

Therefore, the average speed of the image when the jogger is between 39 m and 34 m from the mirror, is (1/280) ms^{-1} or 0.3×10^{-2} ms^{-1}.

S8. Given, $n_{\text{oil}} = 2, n_{\text{glass}} = 3/2$

Velocity of light in oil is given by

$v_{\text{oil}} = \frac{\text{Velocity of light}}{n_{\text{oil}}} = \frac{c}{n_{\text{oil}}}$

Similarly, $v_{\text{glass}} = \frac{c}{n_{\text{glass}}}$

$\therefore \quad \frac{v_{glass}}{v_{oil}} = \frac{c / n_{glass}}{c / n_{oil}} = \frac{n_{oil}}{n_{glass}} = \frac{2}{3/2} = \frac{4}{3}$

S9. Using the lens Maker's formula,

$\frac{1}{f} = \left(\frac{n_2 - n_1}{n_1}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad ...(i)$

Given, f = 25 cm

$n_2 = 1.5, n_1 = 1$ (for air)

Let $R_1 = R$ and $R_2 = -2R$

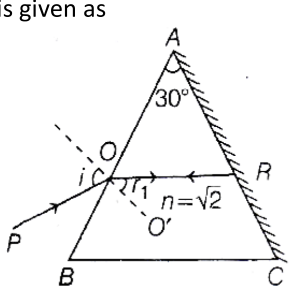
Substituting the given values in Eq. (i), we get

$\Rightarrow \quad \frac{1}{25} = \left(\frac{1.5-1}{1}\right)\left[\frac{1}{R} - \left(-\frac{1}{2R}\right)\right]$

$\frac{1}{25 \times 0.5} = \frac{1}{R} + \frac{1}{2R} \Rightarrow R = \frac{3}{2} \times 25 \times 0.5 = 18.75$ cm

$\therefore \quad R_1 = 18.75$ cm and $R_2 = 2 \times 18.75 = 37.5$ cm

S10. According to the questions, the figure of mentioned prism is given as



(since, there is no refraction at the face *AC*)

Given, refractive index of the material of prism, $n = \sqrt{2}$ and angle of prism, $A = 30°$

If the ray *OR* has to retrace its path after reflection (as per the given condition), then the ray has to fall normally on the surface *AC.*

This means, $\angle ARO = \angle ORC = 90°$

In $\Delta AOR, \angle AOR + \angle ARO + \angle OAR = 180°$

$\Rightarrow \quad \angle AOR + 90° + 30° = 180°$

$\Rightarrow \quad \angle AOR = 180° - 120° = 60° \qquad ...(i)$

From figure, $\angle AOR + \angle r_1 = 90°$

$\Rightarrow \quad \angle r_1 = 90° - 60° = 30° \qquad$ [from Eq. (i)]

Applying Snell's law at the face *AB,* we get

$n = \frac{\sin i}{\sin r_1}$

Substituting the given values, we get

$\sqrt{2} = \frac{\sin i}{\sin 30°}$

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

$= \frac{1}{2} \times \sqrt{2} \qquad \left(\because \sin 30° = \frac{1}{2}\right)$

$= \frac{1}{\sqrt{2}}$ or $i = \sin^{-1}\left(\frac{1}{\sqrt{2}}\right)$

$= 45° \qquad \left(\because \sin 45° = \frac{1}{\sqrt{2}}\right)$

The angle of incidence of the ray on the prism is 45°.

HOMEWORK EXERCISE SOLUTIONS

MCQ

S1. (b) object distance u = - 40 cm Focal length f = -20 cm

According to mirror formula

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

or $\frac{1}{v}+\frac{1}{-20}-\frac{1}{(-40)}=\frac{1}{-20}+\frac{1}{40}$

$\frac{1}{v}=\frac{-2+1}{40}=-\frac{1}{40}$ or v = -40 cm.

Negative sign shows that image in front of concave mirror. The image is real. Magnification,

m = $-\frac{v}{u}=\frac{(-40)}{(-40)}=-1$

The image is of the same size an inverted.

S2. (d) Here, $v_A = 1.8\times10^8\ m\ s^{-1}$

$v_B = 2.4\times10^8\ m\ s^{-1}$

Light travels slower in denser medium. A is a denser medium and medium B is a rarer medium. Here, Light travels from medium B is a rarer medium. Here, Light travels from medium A to medium B. LetC be the critical angle between them.

$\therefore$ sinC = $A\mu_B=\frac{1}{B\mu_A}$

Refractive index of medium B w.r.t. to medium A is

$A\mu_B=\frac{Velocity\ of\ light\ in\ medium\ A}{Velocity\ \ of\ light\ in\ medium\ B}=\frac{v_A}{v_B}$

$\therefore$ sin C = $\frac{v_A}{v_B}=\frac{1.8\times10^8}{2.4\times10^8}=\frac{3}{4}\ or\ C=sin^{-1}\left(\frac{3}{4}\right)$

S3. (b) From the fig. Angle of deviation,

$\delta=i+e-A$

Here, $e=i$

and $e\frac{3}{4}A$

$\therefore\ \delta=\frac{3}{4}A+\frac{3}{4}A-A=\frac{A}{2}$

For equilateral prism, A = 60^0

$\therefore\ \delta=\frac{60^0}{2}=30^0$

S4. (a) Power of lens, P (in dioptre) = $\frac{100}{focal\ length\ f\ (in\ cm)}$

$\therefore\ f=\frac{100}{10}=10\ cm$

By lens maker's formula,

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

For biconvex lens, $R_1 = +R,$ and $R_2=-R$

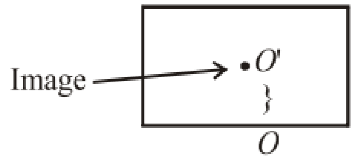
$\therefore\frac{1}{f}=(\mu-1)\left(\frac{1}{R}+\frac{1}{R}\right)$

$\frac{1}{f}=(\mu-)\left(\frac{2}{R}\right)$

$\frac{1}{10}=(\mu-1)\left(\frac{2}{10}\right)$

$(\mu-1)=\frac{1}{2}\ or\ \mu=\frac{1}{2}+1=\frac{3}{2}$

S5. (d) In the latter case microscope will be focused for O'. So, it is required to be lifted by distance OO'. OO' = real depth of O – apparent depth of O.



$=3-\frac{3}{1.5}\left[\mu=\frac{real\ depth}{apparent\ depth}\right]$

$=3\left[\frac{1.5-1}{1.5}\right]=\frac{3\times.5}{1.5}=1cm$

$\therefore B\mu_A=1.5$

S6. (b) Dispersive power of a prism

$\omega=\frac{\mu_V-\mu_R}{\mu_y-1}=\frac{d\mu}{\mu-1},$

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

S7. (b) When $\theta=90^0$ then $\frac{360}{\theta}=\frac{360}{90}=4$ is an even number.

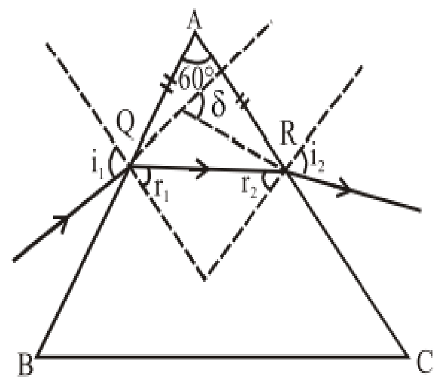
The number of images formed is given by

n = $\frac{360}{\theta}-1=\frac{360}{90}-1=4-1=3$

S8. (b) $\frac{P_a}{P_1}=\frac{\left(\frac{\mu_g}{\mu_a}-1\right)}{\left(\frac{\mu_g}{\mu_1}-1\right)}=\frac{+5}{-100/100}=-5$

$-5\left(\frac{\mu_g}{\mu_1}-1\right)=\frac{\mu_g}{\mu_a}-1$

$\frac{1.5}{\mu_1}-1=\frac{-1}{5}(1.5-1)=0..1\ ;\mu_1=\frac{1.5}{0.9}=\frac{5}{3}$



S9. (a) Given AQ = AR and $\angle A=60^0$

$\therefore\ \angle AQR=\angle ARQ=60^0$

$\therefore\ r_1=r_2=30^0$

Applying Snell's law on face AB.

Sin $i_1=\mu\ sin\ r_1$

$\Rightarrow$ sin $i_1=\sqrt{3}\sin30^0=\sqrt{3}\times\frac{1}{2}=\frac{\sqrt{3}}{2}$

$\therefore\ i_1=60^0$

Similarly, $i_2=60^0$

In a prism, deviation

$\delta=i_1+i_2-A=60^0+60^0-60^0=60^0$

S10. (a) $\frac{1}{f}=\left(\frac{\mu_g}{\mu_m}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

If $\mu_g=\mu_m$, then $\frac{1}{f}=(1-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$

$\Rightarrow\frac{1}{f}=0$

$f=\frac{1}{0}=\infty$

This implies that the liquid must have refractive index equal to glass.

S11. (b) Minimum deviation of the prism when it is dipped in water,

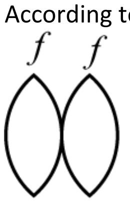
$$\delta'_m = (w\mu_g - 1)A = \left(\frac{a\mu_g}{a\mu_\omega} - 1\right)A = \left(\frac{\frac{3}{2}}{\frac{4}{3}} - 1\right)A = \frac{1}{8}$$

A Minimum deviation of the prism with respect to air

$= \delta_m = (\mu - 1)A = \left(\frac{3}{2} - 1\right)A = \frac{1}{2}A$

$\frac{\delta_{m'}}{\delta_m} = \frac{\frac{1}{8}A}{\frac{1}{2}A} = 1/4$

S12. (c) According to lens maker's formula



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

$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R} - \frac{1}{-R}\right) = (1.5 - 1)\left(\frac{2}{R}\right) = \frac{1}{R}$

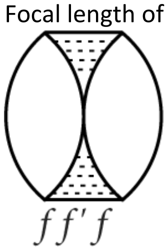
Two similar equi-convex lenses of focal length f each are held in contact with each other.

The focal length F_1 of the combination is given by

$\frac{1}{F_1} = \frac{1}{f} + \frac{1}{f} = \frac{2}{f}; F_1 = \frac{f}{2} = \frac{R}{2}$ ...(i)

For glycerin in between lenses, there are three lenses, one concave and two convex.

Focal length of the concave lens is given by



$\frac{1}{f'} = (1.5 - 1)\left(\frac{-2}{R}\right) = -\frac{1}{R}$

Now, equivalent focal length of the combination is,

$\frac{1}{F_2} = \frac{1}{f} + \frac{1}{f'} + \frac{1}{f}; \frac{1}{F_2} = \frac{1}{R} - \frac{1}{R} + \frac{1}{R} = \frac{1}{R}$

$F_2 = R$ ...(ii)

Dividing equation (i) by (ii), we get $\frac{F_1}{F_2} = \frac{1}{2}$

S13. (a) According to lens maker's formula

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

where μ_g is the refractive index of the material of the lens and μ_L is the refractive index of the liquid in which lens is dipped.

As the biconvex lens dipped in a liquid act as a plane sheet of glass, therefore

$f = \infty \Rightarrow \frac{1}{f} = 0$

$\therefore \frac{\mu_g}{\mu_L} - 1 = 0$ or $\mu_g = \mu_L$

S14. (a) Focal length of convex lens f_1 = 25 cm

Focal length of concave lens f_2 = – 25 cm

Power of combination in diopters,

$P = P_1 + P_2 = \frac{100}{f_1} + \frac{100}{f_2} = \frac{100}{25} - \frac{100}{25} = 0.$

S15. (b) When refractive index of lens is equal to the refractive index of liquid, the lens behave like a plane surface with focal length infinity.

ASSERTION AND REASONING

S1. (c) The focal length of the objective in a telescope is larger than that of eyepiece. The objective is a convex lens of large focal length and large aperture. It usually made of two convex lenses in contact with each other to reduce the chromatic and spherical aberrations. The eye piece is also a convex lens. Its focal length is smaller than that of objective. It is also a combination of two lenses. Magnifying power of telescope increases when the aperture of the objective is large.

S2. (a) Eddy currents are produced when a metal sheet is placed in a changing magnetic field. In the metal sheet, we can consider closed loops as shown in the figure, through which an induced current flow due to a change of magnetic flux. This current is called eddy current and it gives rise to loss of thermal energy.

S3. (a) both assertion and reason are true and reason is correct explanation of assertion

S4. (d) We cannot interchange the objective and eye lens of a microscope to make a telescope. The reason is that the focal length of lenses in microscope are very small. of the order of mm or a few cm and the difference (f_o −f_e) is very small, While the telescope length as compared to eye lens of microscope

S5. (c) The image of real object may be real in case of concave mirror

VERY SHORT ANSWER QUESTIONS

S1. The focal point of a convergent lens is the position of real image formed by this lens, when object is at infinity. When another convergent lens of short focal length is placed on the other side, the combination will form a real point image at the combined focus of the two lenses. The wavefronts emerging from the final image will be spherical.

S2. The condition under which a large magnification can be achieved in an astronomical telescope is $f_o >> f_e$, focal length of objective must be greater than focal length of eyepiece.

S3. As the refractive index for red is less than that for blue$\frac{1}{F} \propto n - 1$, parallel beams of light incident on a lens will be bent more towards the axis for blue light compared to red. Thus the focal length for red light will be more than that for blue.

NUMERICAL TYPE QUESTIONS

S1. For myopic eye, the person should use a concave lens of focal length = – (defected far point)

$= -80\ cm = \frac{-80}{100}\,\text{m}$

i. e. $\quad \text{Power} = \frac{1}{\text{focal length}} = \frac{-100}{80} = -1.25\ \text{D}$

S2. Hypermetropia is corrected by using convex lens. Focal length of lens used, $f = +$ (defected near point)

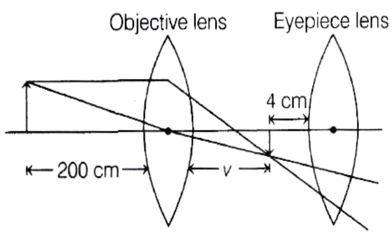
$f = +d = +20\ \text{cm}$

$\therefore \quad \text{Power of lens} = \frac{100}{f(\text{cm})} = \frac{100}{+20} = 5\ D$

S3. According to questions,

Focal length of objective lens, $f_o = 40$ cm

Focal length of eyepiece lens, $f_e = 4$ cm



Object distance for objective lens, $u_o = -200$ cm

Applying lens formula for objective lens

$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \;\Rightarrow\; \frac{1}{v} - \frac{1}{-200} = \frac{1}{40}$

$\Rightarrow \qquad \frac{1}{v} = \frac{1}{40} - \frac{1}{200} = \frac{5-1}{200} = \frac{4}{200}$

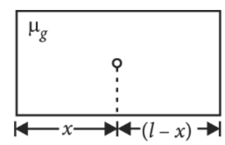
$\Rightarrow \qquad v = 50\ \text{cm}$

Image will be formed at first focus of eyepiece lens.

So, for normal adjustment distance between objective and eyepiece lens (length of tube) will be

$v + f_e = 50 + 4 = 54$ cm

S4.



Here μ = 1.5

l = length of the slab

x = position of air bubble from one side

As per question, total apparent length of slab = 5 + 3

Or $\frac{x}{\mu} + \frac{(l-x)}{\mu} = 8$ or $\frac{l}{\mu} = 8$

$\therefore\ l = 8\mu = 8 \times 1.5 = 12$ cm

S5. From figure, $\sin C = \frac{3}{\sqrt{(4)^2+(3)^2}} = \frac{3}{5}$

where C is the critical angle.

Also, $\sin C = {}^{l}\mu_a$

$\sin C = \frac{1}{{}^{a}\mu_l}\left[\text{since } {}^{l}\mu_a = \frac{1}{{}^{a}\mu_l}\right]$

Also ${}^{a}\mu_l = \frac{\text{velocity of light in air }(c)}{\text{velocity of light in liquid }(v)}$

$\therefore\ \sin C = \frac{v}{c} = \frac{v}{3\times10^8}$

or, $\quad v = 3 \times 10^8 \times \frac{3}{5} = 1.8 \times 10^8\ \text{m s}^{-1}$.