GEOMETRICAL OPTICS

KEY CONCEPTS

RAY OPTICS

INTRODUCTION

The branch of Physics called optics deals with the behavior of light and other electromagnetic waves. Under many circumstances, the wavelength of light is negligible compared with the dimensions of the device as in the case of ordinary mirrors and lenses. A light beam can then be treated as a ray whose propagation is governed by simple geometric rules. The part of optics that deals with such phenomenon is known as geometric optics.

PROPAGATION OF LIGHT

Light travels along straight line in a medium or in vacuum. The path of light changes only when there is an object in its path or where the medium changes. We call this rectilinear (straight–line) propagation of light. Light that starts from a point A and passes through another point B in the same medium actually passes through all the points on the straight line AB. Such a straight line path of light is called a ray of light. Light rays start from each point of a source and travel along straight lines till they fall on an object or a surface separating two media (mediums). A bundle of light rays is called a beam of light.

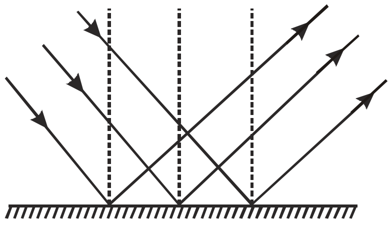
Apart from vacuum and gases, light can travel through some liquids and solids. A medium in which light can travel freely over large distances is called a transparent medium. Water, glycerine, glass and clear plastics are transparent. A medium in which light cannot travel is called opaque. Wood, metals, bricks, etc., are opaque. In materials like oil, light can travel some distance, but its intensity reduces rapidly. Such materials are called translucent.

REFLECTION OF LIGHT

When light rays strike the boundary of two media such as air and glass, a part of light is bounced back into the same medium. This is called **Reflection of light**.

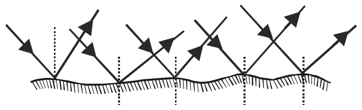
(i) Regular / Specular reflection :

When the reflection takes place from a perfect plane surface then after reflection rays remain parallel.
It is called **Regular reflection**.



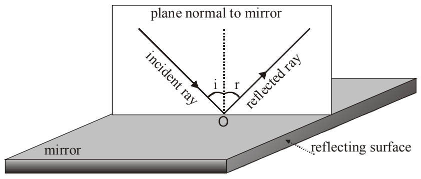
(ii) Diffused reflection

When the surface is rough, light is reflected from the surface from bits of its plane surfaces in irregular directions. This is called **diffused reflection**. This process enables us to see an object from any position.

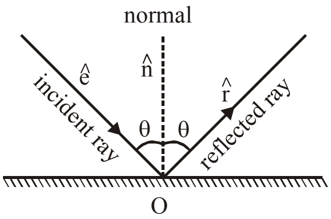


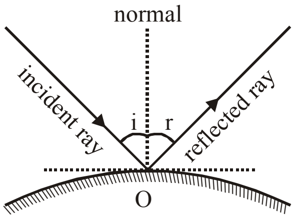
LAWS OF REFLECTION

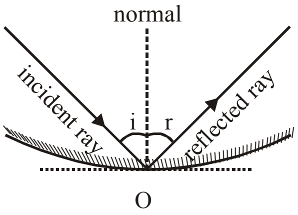
(1) Incident ray, reflected ray and normal lies in the same plane.



(2) The angle of reflection is equal to the angle of incident i.e. ∠ i = ∠r.



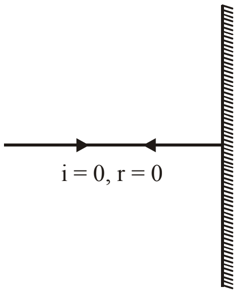




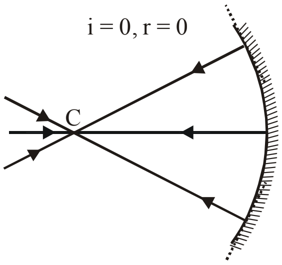
In vector form $\boxed{\hat{r} = \hat{e} - 2(\hat{e}.\hat{n})\hat{n}}$

KEY POINTS

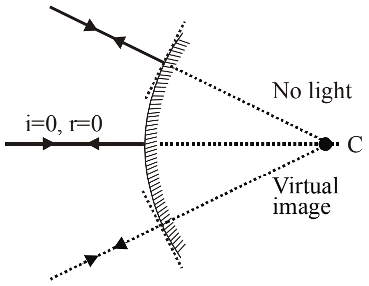
- **Rectilinear propagation of light** : In a homogeneous transparent medium light travels in straight line.
- When a ray is incident normally on a boundary after reflection it retraces its path.



plane mirror



concave mirror



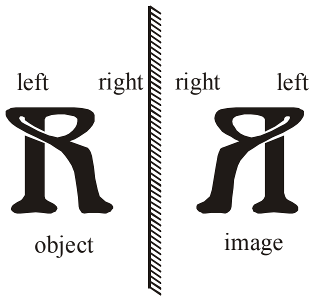
convex mirror

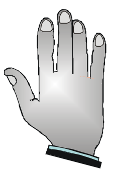
- The frequency, wavelength and speed does not change on reflection.
- Eye is mostly sensitive for yellow colour and least sensitive for violet and red colour.
  Due to this reason :
  • Commercial vehicle's are painted with yellow colour.
  • Sodium lamps (yellow colour) are used in road lights.

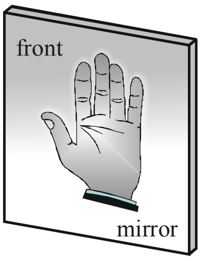
REFLECTION FROM PLANE MIRROR

Plane mirror is the perpendicular bisector of the line joining object and image.

- The image formed by a plane mirror suffers **lateral–inversion,** i.e., in the image formed by a plane mirror left is turned into right and vice–versa with respect to object.







When a watch placed in front of a plane mirror then watch is object and its time is object time and image of watch observed by a person standing in front of mirror then time seen by person.

(i) Object Time = A^H

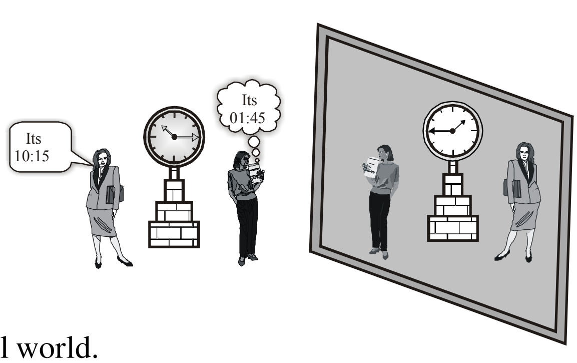
Image Time = $12 - A^H$

(ii) Object Time = $A^H\ B^M$

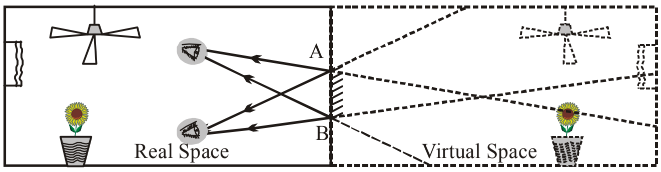
Image Time = $11 - 60' - A^H\ B^M$

(iii) Object Time = $A^H\ B^M C^S$

Image Time = $11 - 59' - 60'' - A^H B^M C^S$



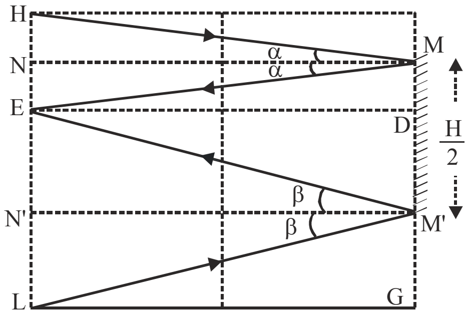
- A plane mirror behaves like a window to virtual world.



AB → Plane mirror

- To see complete image in a plane mirror the minimum length of plane mirror should be half the height of a person.

From figure. ΔHNM and ΔENM are congruent



$\therefore$ EN = HN $\qquad \therefore$ $MD = EN = \frac{1}{2}HE$

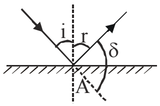
Similarly ΔEN' M' and ΔLN' M' are congruent

Length of the mirror $MM' = MD + M'D = \frac{1}{2}HE + \frac{1}{2}EL$

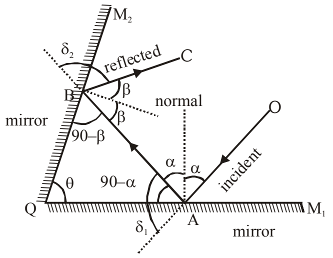
$$= \frac{1}{2}(HE + EL) = \frac{1}{2}HL$$

$\therefore$ Minimum of length of mirror is just half of the person.

- This result does not depend on position of eye (height of the eye from ground).
- This result is independent of distance of person in front of mirror.

- Deviation for a single mirror  $\delta = 180 - (i + r);\ \angle i = \angle r;\ \delta = 180 - 2i$

- Total deviation produced by the combination of two plane mirrors which are inclined at an angle θ from each other.



$\delta = \delta_1 + \delta_2 = 180 - 2\alpha + 180 - 2\beta = 360 - 2(\alpha + \beta)$ ...(i)

From ΔQAB, $\theta + 90 - \alpha + 90 - \beta = 180 \Rightarrow \theta = \alpha + \beta$ ...(ii)

Putting the value of θ in (i) from (ii), $\delta = 360 - 2\theta$

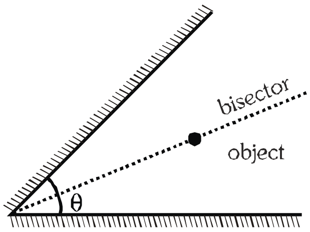
- If there are two plane mirror inclined to each other at an angle θ the number of image (n) of a point object formed are determined as follows.

(a) If $\frac{360°}{\theta} = m$ is even then number of images n = m – 1

(b) If $\frac{360°}{\theta} = m$ is odd. There will be two case.

(i) When object is not on bisector, then number of images n = m

(ii) When object is at bisector, then number of images n = m – 1

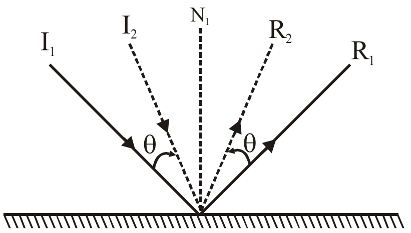


(c) If $\frac{360°}{\theta} = m$ is a fraction, and the object is placed symmetrically then no. of images n =nearest even integer

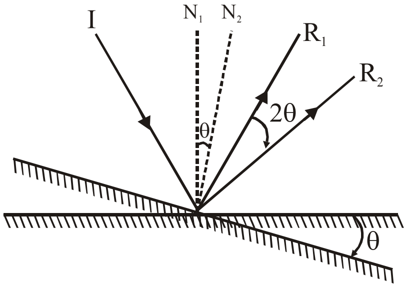
S.No.	**θ in degree**	$m = \frac{360°}{\theta}$	**Number of images formed if object is placed**	
			asymmetrically	**symmetrically**
1.	0	∞	∞	∞
2.	30	12	11	11
3.	45	8	7	7
4.	60	6	5	5
5.	72	5	5	4
6.	75	4.8	–	4
7.	90	4	3	3
8.	112.5	3.2	–	4
9.	120	3	3	2

- If the object is placed between two plane mirrors then images are formed due to multiple reflections. At each reflection, a part of light energy is absorbed. Therefore, distant images get fainter.
- Keeping the mirror fixed if the incident ray is rotated by some angle, the reflected ray is also rotated by the same angle but in opposite sense. (See Fig. 1)

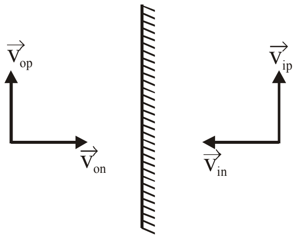
(Fig. 1)



(Fig. 2)



- Keeping the incident ray fixed, if the mirror is rotated by some angle, then the reflected ray rotates by double the angle in the same sense. (See Fig. 2)

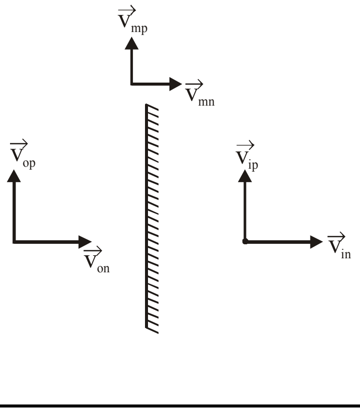
- 

  Stationary Plane Mirror

  $\vec{v}_{on} = -\vec{v}_{in}$, $\vec{v}_{op} = \vec{v}_{ip}$

  though speed of object and image are the same

  v_{op} = component of velocity of object along parallel to mirror.
  v_{on} = component of velocity of object along normal to mirror.
  v_{ip} = component of velocity of image along parallel to mirror.
  v_{in} = component of velocity of image along normal to mirror.

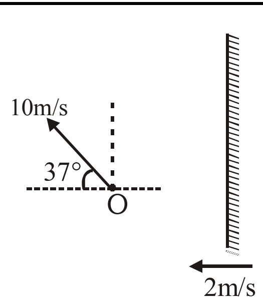
- 

  If mirror is moving $\vec{v}_{ip} = \vec{v}_{op}$ and $(\vec{v}_{im})_n = -(\vec{v}_{om})_n$

  $\Rightarrow \vec{v}_{in} - \vec{v}_{mn} = -(\vec{v}_{on} - \vec{v}_{mn}) \Rightarrow \vec{v}_{in} = 2\vec{v}_{mn} - \vec{v}_{on}$

  $\vec{v}_{mn}$ = component of velocity of mirror along normal.
  $\vec{v}_{op}$ = component of velocity of object along mirror.
  $\vec{v}_{on}$ = component of velocity of object along normal
  $\vec{v}_{ip}$ = component of velocity of image along mirror.
  $\vec{v}_{in}$ = component of velocity of image along normal.

Ex. Find the velocity of the image.



Sol. $\vec{v}_{ox} = (-10\cos 37°)\,\hat{i} = -8\hat{i}$ and

$\vec{v}_{oy} = (10\sin 37°)\,\hat{j} = 6\hat{j}$

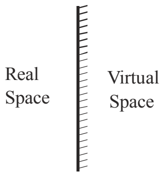
$\vec{v}_{ix} = 2\vec{v}_{mx} - \vec{v}_{ox} = 2\,(-2i) - \left(-8\hat{i}\right) = 4\hat{i}$ and $\vec{v}_{iy} = \vec{v}_{oy} = 6\hat{j}$

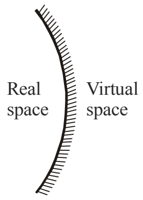
REAL AND VIRTUAL SPACES

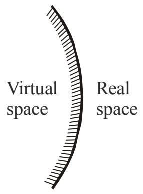
A mirror, plane or spherical divides the space into two ;

(a) Real space, a side where the reflected rays exist.

(b) Virtual space is on the other side where the reflected rays do not exist.

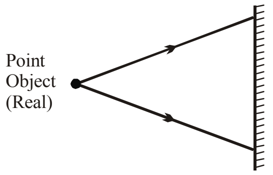


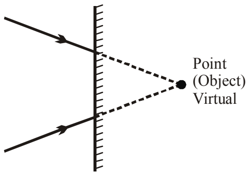


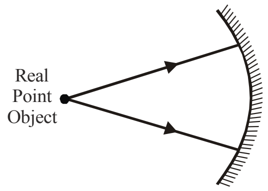


OBJECT

Object is decided by incident rays only. The point object is that point from which the incident rays actually diverge (Real object) or towards which the incident rays appear to converge (virtual object).

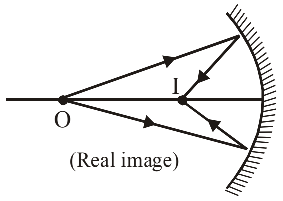


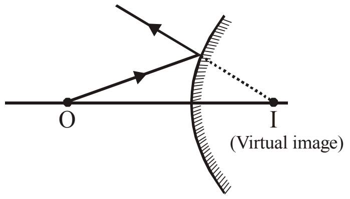




IMAGE

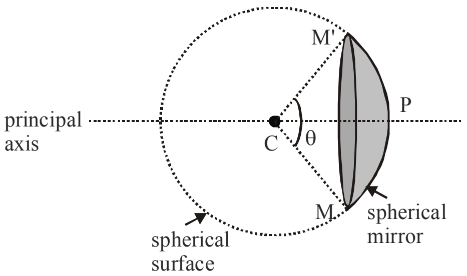
Image is decided by reflected or refracted rays only. The point image is that point at which the refracted / reflected rays reflected from the mirror, actually converge (real image) or from which the refracted /reflected rays appear to diverge (virtual image).

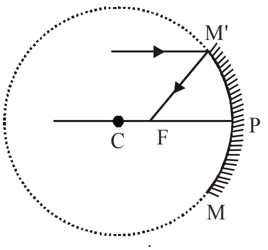




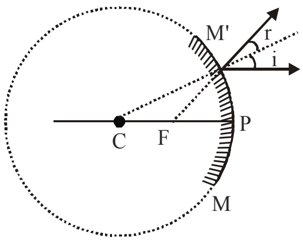
SPHERICAL (CURVED) MIRROR

Curved mirror is part of a hollow sphere. If reflection takes place from the inner surface then The mirror is called concave and if its outer surface acts as reflector it is convex.





concave mirror



convex mirror

DEFINITIONS FOR THIN SPHERICAL MIRRORS

(i) **Pole** is any point on the reflecting surface of the mirror. For convenience we take it as the midpoint P of the mirror (as shown).

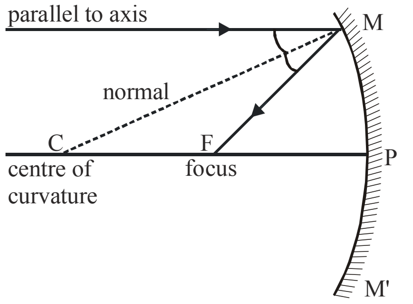
(ii) **Principal–section** is any section of the mirror such as MM' passing through the pole is called principal–section.

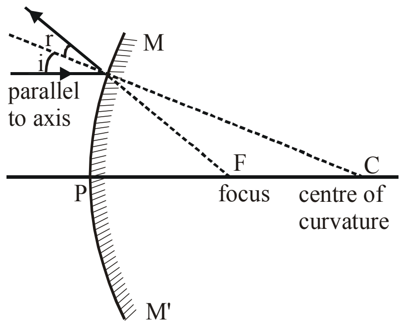
(iii) **Centre of curvature** is the centre C of the sphere of which the mirror is a part.

(iv) **Radius of curvature** is the radius R of the sphere of which the mirror is a part.

(v) **Principal–axis** is the line CP, joining the pole and centre of curvature of the mirror.

(vi) **Principal– focus** is an image point F on principal axis for which object is at infinity.

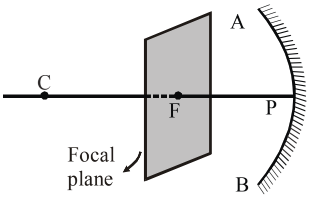


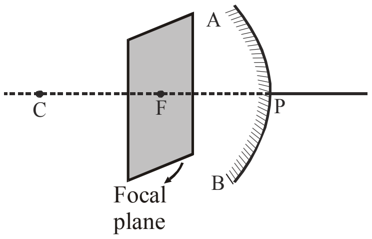


(vii) **Focal–length** is the distance PF between pole P and focus F along principal axis.

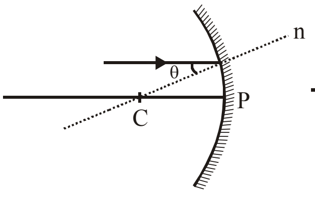
(viii) **Aperture,** in reference to a mirror, means the effective diameter of the light reflecting area of the mirror.

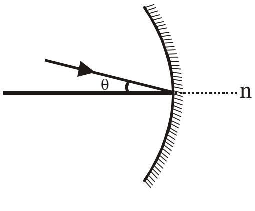
(ix) **Focal Plane** is the plane passing through focus and perpendicular to principal axis.



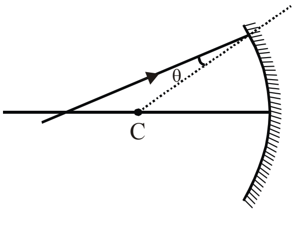


(x) **Paraxial Rays** Those rays which make small angle with normal at point of incidence and hence are close to principal axis.



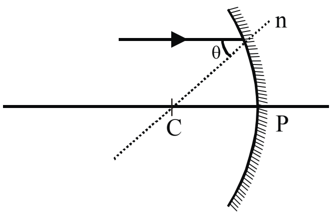


(θ is very small)



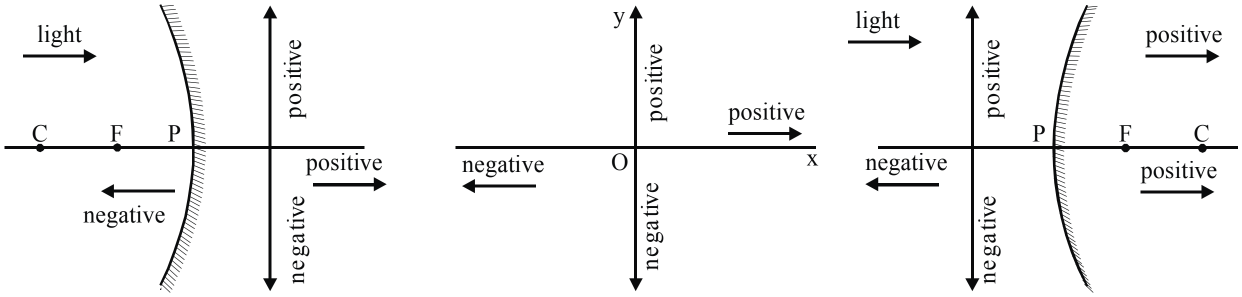
(xi) **Marginal rays :**

Rays having a large angle of incidence



(θ is large)

SIGN– CONVENTION

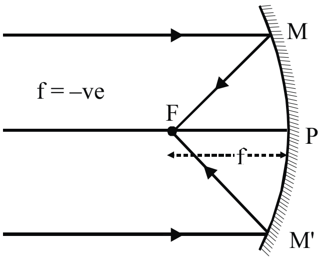


- Along principal axis, distances are measured from the pole (pole is taken as the origin).
- Distance in the direction of light are taken to be positive while opposite to be negative.
- The distances above principal axis are taken to be positive while below it negative.
- Whenever and wherever possible the ray of light is taken to travel from left to right.

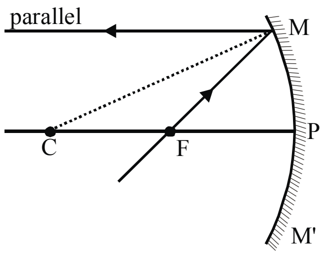
RULES FOR IMAGE FORMATION (FOR PARAXIAL RAYS ONLY)

(These rules are based on the laws of reflection $\angle i = \angle r$)

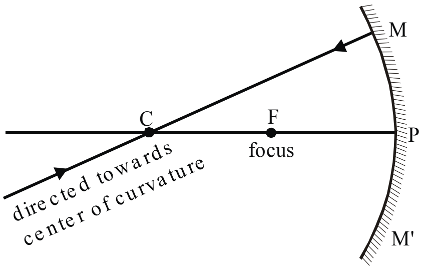
- A ray parallel to principal axis after reflection from the mirror passes or appears to pass through its focus (by definition of focus).



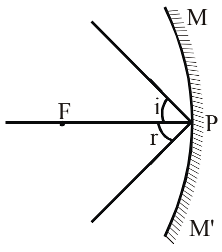
- A ray passing through or directed towards focus, after reflection from the mirror, becomes parallel to the principal axis.



- A ray passing through or directed towards centre of curvature, after reflection from the mirror, retraces its path (as for it $\angle i = 0$ and so $\angle r = 0$).



- Incident and reflected rays at the pole of a mirror are symmetrical about the principal axis $\angle i = \angle r$.



RELATIONS FOR SPHERICAL MIRRORS

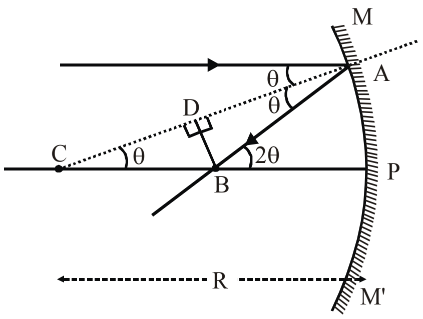
Relation between f and R for the spherical mirror

- **For Marginal rays**

In $\Delta ABC,\ AB = BC$

$AC = CD + DA = 2BC\cos\theta \Rightarrow R = 2BC\cos\theta$

$$\Rightarrow BC = \frac{R}{2\cos\theta} \text{ and } BP = PC - BC = R - \frac{R}{2\cos\theta}$$



Note : B is not the focus ; it is just a point where a marginal ray after reflection meets.

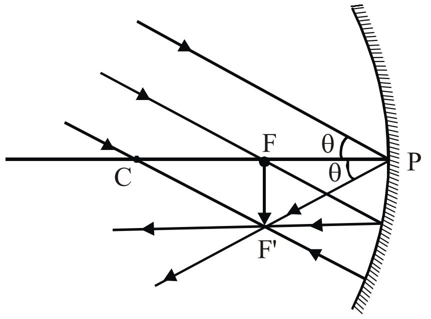
- **For paraxial rays (parallel to principal axis)**

  (θ small so $\sin\theta \simeq \theta$, $\cos\theta \simeq 1$, $\tan\theta \simeq \theta$) Hence $BC = \frac{R}{2}$ and $BP = \frac{R}{2}$

Thus, point B is the midpoint of PC (i.e. radius of curvature) and is defined as FOCUS so $BP = f = \frac{R}{2}$

(**Definition :** Paraxial rays parallel to the principal axis after reflection from the mirror meet the principal axis at focus)

- BP is the focal length (f) $\boxed{\mathbf{f = \frac{R}{2}}}$

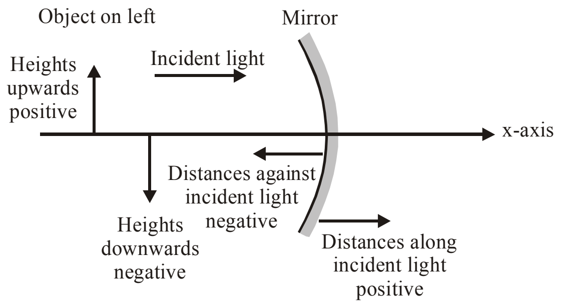


- **Paraxial rays (not parallel to principal axis)**

Such rays after reflection meet at a point in the focal plane (F'), such that

$$\frac{FF'}{FP} = \tan\theta \approx \theta \Rightarrow \frac{FF'}{f} = \theta \Rightarrow FF' = f\theta$$

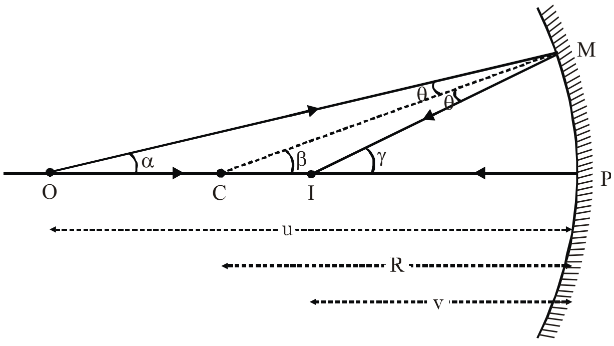
Sign convention


Object on left
Mirror
Heights upwards positive
Incident light
x-axis
Distances against incident light negative
Heights downwards negative
Distances along incident light positive

<u>Relation between u,v and f for curved mirror</u>

An object is placed at a distance u from the pole of a mirror and its image is formed at a distance v (from the pole)

If angle is very small : $\alpha = \frac{MP}{u}$, $\beta = \frac{MP}{R}$, $\gamma = \frac{MP}{v}$



from ΔCMO, $\beta = \alpha + \theta \Rightarrow \theta = \beta - \alpha$

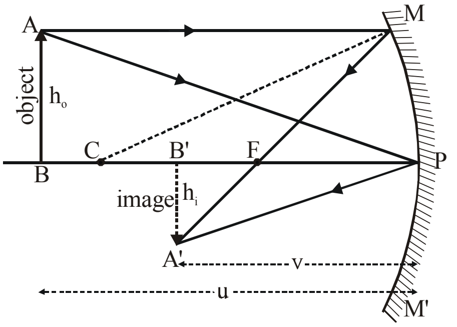
from ΔCMI, $\gamma = \beta + \theta \Rightarrow \theta = \gamma - \beta$

so we can write $\beta - \alpha = \gamma - \beta \Rightarrow 2\beta = \gamma + \alpha$

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

MAGNIFICATION

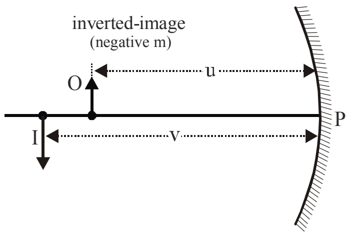
Transverse or lateral magnification

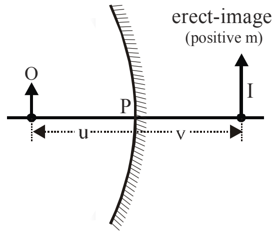


Linear magnification $m = \dfrac{\text{height of image}}{\text{height of object}} = \dfrac{h_i}{h_o}$

ΔABP and ΔA'B'P are similar so $\dfrac{-h_i}{h_o} = \dfrac{-v}{-u} \Rightarrow \dfrac{h_i}{h_o} = -\dfrac{v}{u}$

Magnification $m = -\dfrac{v}{u}$; $m = -\dfrac{v}{u} = \dfrac{f}{f-u} = \dfrac{f-v}{f} = \dfrac{h_i}{h_o}$



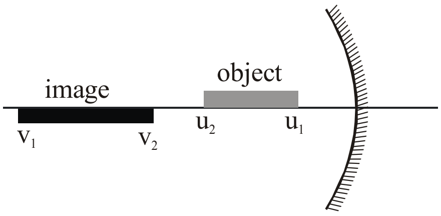


If one dimensional object is placed perpendicular to the principal axis then linear magnification is called transverse or lateral magnification. $\boxed{m = \dfrac{h_i}{h_o} = -\dfrac{v}{u}}$

Magnification	**Image**	**Magnification**	**Image**
$\lvert m\rvert > 1$	enlarged	$\lvert m\rvert < 1$	diminished
$m < 0$	inverted	$m > 0$	erect

- **Longitudinal magnification**

If one dimensional object is placed with its length along the principal axis then linear magnification is called longitudinal magnification.



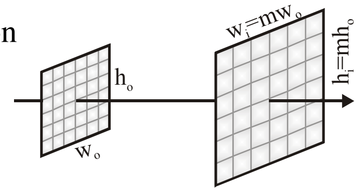
Longitudinal magnification $m_L = \dfrac{\text{length of image}}{\text{length of object}} = \dfrac{|v_2 - v_1|}{|u_2 - u_1|}$

For small objects only : $m_L = -\dfrac{dv}{du}$

differentiation of $\dfrac{1}{v} + \dfrac{1}{u} = \dfrac{1}{f}$ gives us $-\dfrac{dv}{v^2} - \dfrac{du}{u^2} = 0 \Rightarrow -\dfrac{dv}{du} = \left[\dfrac{v}{u}\right]^2$ so $m_L = -\dfrac{dv}{du} = \left[\dfrac{v}{u}\right]^2 = m^2$

- **Superficial magnification**

If two dimensional object placed with its plane perpendicular to principal axis its magnification is known as superficial magnification



Linear magnification $m = \dfrac{h_i}{h_o} = \dfrac{w_i}{w_o}$

$h_i = mh_o$, $w_i = mw_o$ and $A_{obj} = h_o \times w_o$

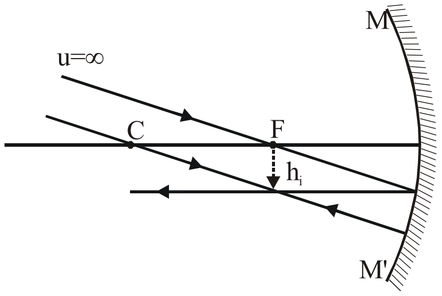
Area of image : $A_{image} = h_i \times w_i = mh_o \times mw_o = m^2 A_{obj}$

superficial magnification $m_s = \dfrac{\text{area of image}}{\text{area of object}} = \dfrac{(ma)\times(mb)}{(a \times b)} = m^2$

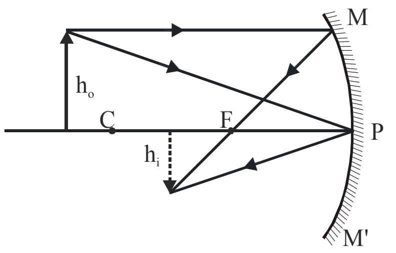
IMAGE FORMATION BY SPHERICAL MIRRORS

Concave mirror

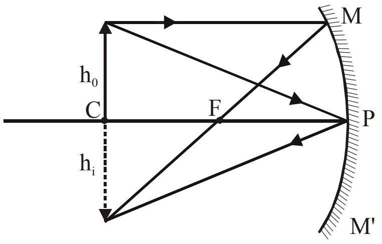
(i) **Object :** Placed at infinity
Image : real, inverted, diminished at F
$|m| << 1$ & $m<0$



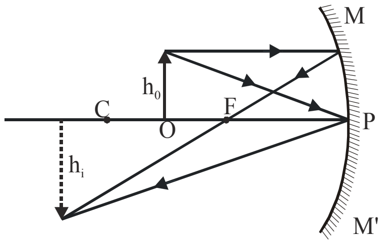
(ii) **Object :** Placed in between infinity and C
Image : real, inverted, diminished in between C and F
$|m| < 1$ & $m<0$



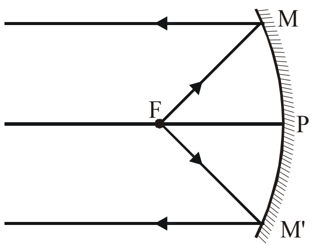
(iii) **Object :** Placed at C
Image : real, inverted, equal at C
$(m = -1)$



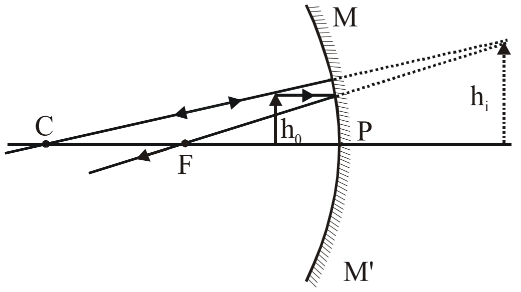
(iv) **Object :** Placed in between F and C
Image : real, inverted, enlarged beyond C
$|m| > 1$ & $m<0$



(v) **Object :** Placed at F
Image : real, inverted, very large (assumed) at infinity $(m<<-1)$



(vi) **Object :** Placed between F and P
Image : virtual, erect, enlarged and behind the mirror $(m > +1)$

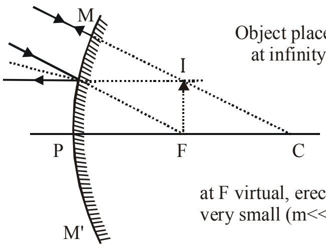


For concave mirror

Object	Image	Magnification
$-\infty$	F	$\|m\| << 1$ & $m<0$
$-\infty - C$	C – F	$\|m\| < 1$ & $m<0$
C	C	$m = -1$
C – F	$-\infty - C$	$\|m\| > 1$ & $m<0$
Just before F towards C	$-\infty$	$m << -1$
Just after F towards P	$+\infty$	$m >> 1$

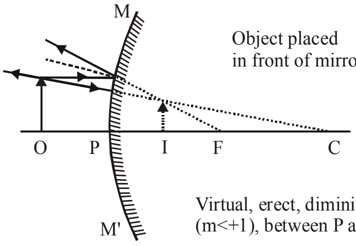
Convex mirror

Image is always virtual and erect, whatever be the position of the object and m is always positive.



Object placed at infinity

at F virtual, erect and very small (m<<+1)



Object placed in front of mirror

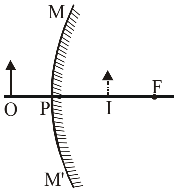
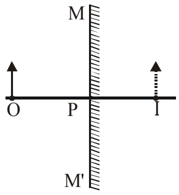
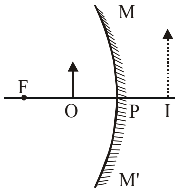
Virtual, erect, diminished (m<+1), between P and F

KEY POINTS

- **Differences in real & virtual image for spherical mirror**

Real Image	Virtual Image
(i) Inverted w.r.t. object	(i) Erect w.r.t. object
(ii) Can be obtained on screen	(ii) Can not be obtained on screen
(iii) Its magnification is negative	(iii) Its magnification is positive
(iv) Forms in front of mirror	(iv) Forms behind the mirror

- For real extended object, if the image formed by a single mirror is erect it is always virtual (i.e.,m is + ve) and in this situation if the size of image is :

Smaller than object the mirror is convex	Equal to object the mirror is plane	Larger than object the mirror is concave
m<+1 	m=+1 	m>+1 

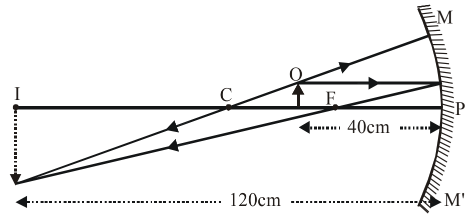
Ex. The focal length of a concave mirror is 30cm. Find the position of the object in front of the mirror, so that the image is three times the size of the object.

Sol. As the object is in front of the mirror it is real and for real object the magnified image formed by concave mirror can be inverted (i.e.,real) or erect (i.e.,virtual), so there are two possibilities.

(a) If the image is inverted (i.e., real)

$$m = \frac{f}{f-u} \Rightarrow -3 = \frac{-30}{-30-u} \Rightarrow \; u = -40 \text{ cm}$$

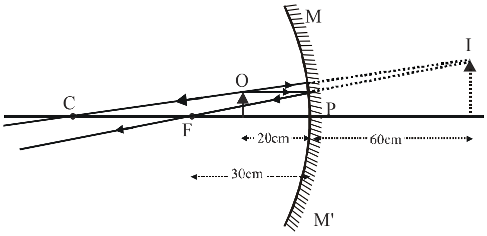
Object must be at a distance of 40 cm in front of the mirror (in between C and F).



(b) If the image is erect (i.e., virtual)

$$m = \frac{f}{f-u} \Rightarrow 3 = \frac{-30}{-30-u} \Rightarrow u = -20 \text{ cm}$$

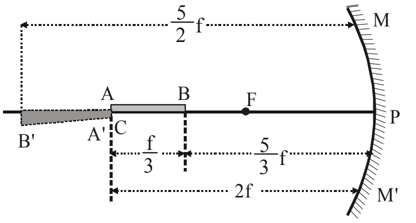
Object must be at a distance of 20 cm in front of the mirror (in between F and P).



Ex. A thin rod of length $\frac{f}{3}$ is placed along the principal axis of a concave mirror of focal length f such that its image which is real and elongated, just touches the rod. What is magnification ?

Sol. Image is real and enlarged, the object must be between C and F. One end A' of the image coincides with the end A of rod itself, so

$$v_A = u_A, \frac{1}{v_A} + \frac{1}{v_A} = \frac{1}{-f} \text{ i.e., } v_A = u_A = -2f$$



so it clear that the end A is at C. ∵ the length of rod is $\frac{f}{3}$

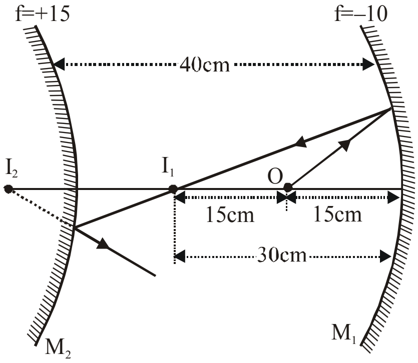
∴ distance of the other end B from P is $u_B = 2f - \frac{f}{3} = \frac{5}{3}f$

if the distance of image of end B from P is v_B then $\frac{1}{v_B} + \frac{1}{-\frac{5}{3}f} = \frac{1}{-f} \Rightarrow v_B = -\frac{5}{2}f$

∴ the length of the image $|v_B| - |v_A| = \frac{5}{2}f - 2f = \frac{1}{2}f$ and magnification $m = \frac{|v_B| - |v_A|}{|u_B| - |u_A|} = \frac{\frac{1}{2}f}{-\frac{1}{3}f} = -\frac{3}{2}$

Negative sign implies that image is inverted with respect to object and so it is real.

Ex A concave mirror of focal length 10 cm and convex mirror of focal length 15 cm are placed facing each other 40 cm apart. A point object is placed between the mirror on their common axis and 15 cm from the concave mirror. Find the position of image produced by the reflection first at concave mirror and then at convex mirror.



Sol. For M_1 mirror O act as a object, let its image is I_1 then,

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

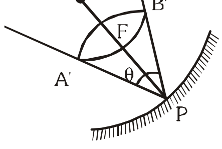
Image I_1 will act as a object for mirror M_2 its distance from mirror M_2.

$u_1 = -(40 - 30)$ cm $= -10$ cm

$$\text{so } \frac{1}{v_1} + \frac{1}{u_1} = \frac{1}{f} \Rightarrow \frac{1}{v_1} - \frac{1}{10} = \frac{1}{15} \Rightarrow v_1 = +6\text{cm}$$

So final image I_2 is formed at a distance 6 cm behind the convex mirror and is virtual.

Ex. The sun subtends an angle θ radians at the pole of a concave mirror of focal length f. What is the diameter of the image of the sun formed by the mirror.



Sol. Since the sun is at large distance very distant, u is very large and so $\frac{1}{u} \approx 0$

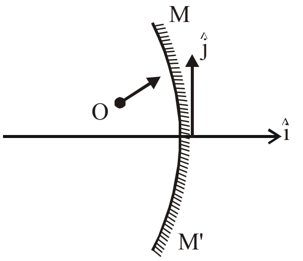
$$\therefore \frac{1}{v} + \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{v} = -\frac{1}{f} \Rightarrow v = -f$$

The image of sun will be formed at the focus and will be real, inverted and diminished

$$A'B' = \text{height of image and } \theta = \frac{\text{Arc}}{\text{Radius}} = \frac{A'B'}{FP} \Rightarrow \theta = \frac{d}{f} \Rightarrow d = f\theta$$

VELOCITY OF IMAGE OF MOVING OBJECT (SPHERICAL MIRROR)

(a) Velocity component along axis (Longitudinal velocity)



When an object is coming from infinite towards the focus of concave mirror

$$\because \frac{1}{v}+\frac{1}{u}=\frac{1}{f} \Rightarrow -\frac{1}{v^2}\frac{dv}{dt}-\frac{1}{u^2}\frac{du}{dt}=0 \Rightarrow \vec{v}_{ix}=-\frac{v^2}{u^2}\vec{v}_{ox}=-m^2\vec{v}_{ox}$$

$$\left[v_{ix}=\frac{dv}{dt}=\text{velocity of image along principal-axis; } v_{ox}=\frac{du}{dt}=\text{velocity of object along principal-axis}\right]$$

(b) Velocity component perpendicular to axis (Transverse velocity)

$$m=\frac{h_I}{h_0}=-\frac{v}{u}=\frac{f}{f-u} \Rightarrow h_I=\left(\frac{f}{f-u}\right)h_0$$

$$\frac{dh_I}{dt}=\left(\frac{f}{f-u}\right)\frac{dh_0}{dt}+\frac{f\,h_0}{(f-u)^2}\frac{du}{dt}\ ;\ \vec{v}_{iy}=\left[m\vec{v}_{oy}+\frac{m^2h_0}{f}\vec{v}_{ox}\right]\hat{j}$$

$$\left[\begin{array}{l}\dfrac{dh_I}{dt}=\text{velocity of image} \perp^r \text{ to principal-axis}\\ \dfrac{dh_o}{dt}=\text{velocity of object } \perp^r \text{ to principal-axis}\end{array}\right]$$

Note : Here principal axis has been taken to be along x–axis.

POWER OF A MIRROR

The power of a mirror is defined as $P=-\frac{1}{f(m)}=-\frac{100}{f(cm)}$

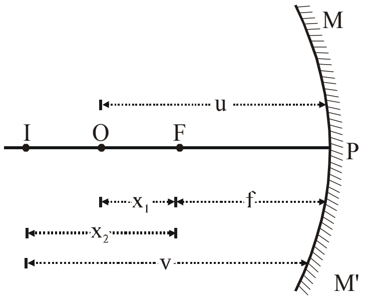
NEWTON'S FORMULA

In case if spherical mirrors if object distance (x_1) and image distance (x_2) are measured from focus instead of pole,

$u=-(f+x_1)$ and $v=-(f+x_2)$,

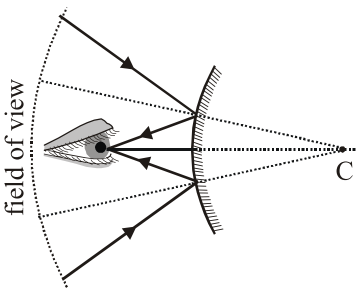
by $\frac{1}{v}+\frac{1}{u}=\frac{1}{f} \Rightarrow -\frac{1}{(f+x_2)}-\frac{1}{(f+x_1)}=-\frac{1}{f}$

on solving $\boxed{x_1x_2=f^2}$ This is Newton's formula.



POINTS

- **Convex mirrors** gives erect, virtual and diminished image. In convex mirror the field of view is increased as compared to plane mirror. It is used as rear–view mirror in vehicles.
- **Concave mirrors** give enlarged, erect and virtual image, so these are used by dentists for examining teeth. Due to their converging property concave mirrors are also used as reflectors in automobile head lights and search lights

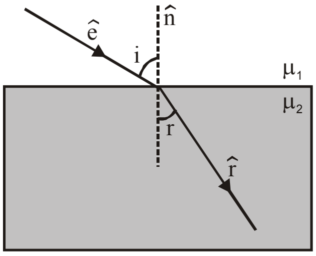


- As focal length of a spherical mirror f = R/2 depends only on the radius of mirror and is independent of wavelength of light and refractive index of medium so the focal length of a spherical mirror in air or water and for red or blue light is same.

REFRACTION

Refraction is the phenomenon in which direction of propagation of light changes at the boundary when it passes from one medium to the other. In case of refraction frequency does not change.

◎ Laws of Refraction



(i) Incident ray, refracted ray and normal always lie in the same plane.

In vector form $\boxed{(\hat{e}\times\hat{n}).\hat{r}=0}$

(ii) The product of refractive index and sine of angle of incidence at a point in a medium is constant. $\mu_1 \sin i = \mu_2 \sin r$ (Snell's law)

In vector form $\boxed{\mu_1\left|\hat{e}\times\hat{n}\right| = \mu_2\left|\hat{r}\times\hat{n}\right|}$

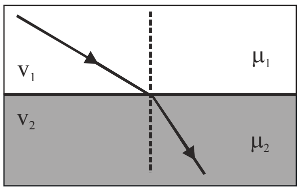
Absolute refractive index

It is defined as the ratio of speed of light in free space 'c' to that in a given medium v. μ or $n = \frac{c}{v}$

Denser is the medium, lesser will be the speed of light and so greater will be the refractive index,

$$\because v_{glass} < v_{water}, \qquad \therefore \mu_G > \mu_W$$

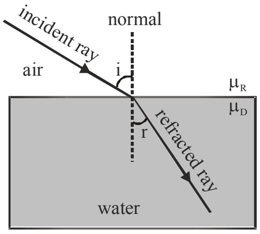
Relative refractive index



When light passes from one medium to the other, the refractive index of medium 2 relative to 1 is written as ${}_1\mu_2$ and is defined as

$${}_1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{(c/v_2)}{(c/v_1)} = \frac{v_1}{v_2}$$

◎ Bending of light ray

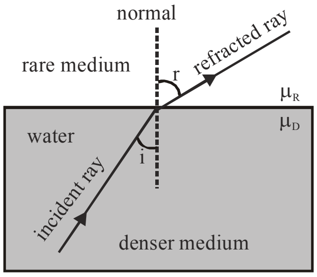


According to Snell's law, $\mu_1 \sin i = \mu_2 \sin r$

(i) If light passes from rarer to denser medium $\mu_1 = \mu_R$ and $\mu_2 = \mu_D$

so that $\frac{\sin i}{\sin r} = \frac{\mu_D}{\mu_R} > 1 \Rightarrow \angle i > \angle r$

In passing from rarer to denser medium, the ray bends towards the normal.



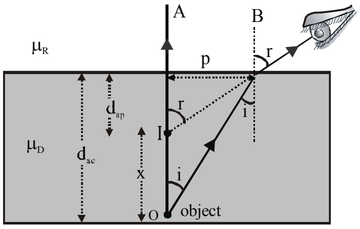
(ii) If light passes from denser to rarer medium $\mu_1 = \mu_D$ and $\mu_2 = \mu_R$

$$\frac{\sin i}{\sin r} = \frac{\mu_R}{\mu_D} < 1 \Rightarrow \angle i < \angle r$$

In passing from denser to rarer medium, the ray bends away from the normal

APPARENT DEPTH AND NORMAL SHIFT

If a point object in denser medium is observed from rarer medium and boundary is plane, then from Snell's law we have $\mu_D \sin i = \mu_R \sin r$...(i)
If the rays OA and OB are close enough to reach the eye.



$$\sin i \simeq \tan i = \frac{p}{d_{ac}} \text{ and } \sin r \simeq \tan r = \frac{p}{d_{ap}}$$

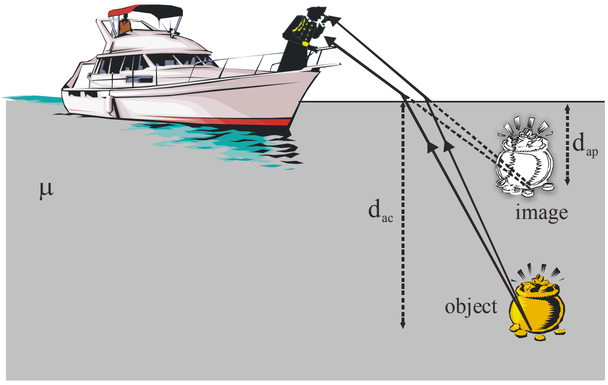
here d_{ac} = actual depth, d_{ap} = apparent depth

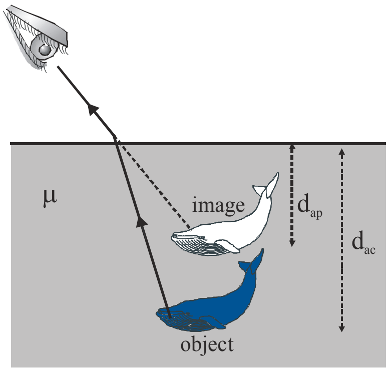
So that equation (i) becomes $\mu_D \dfrac{p}{d_{ac}} = \mu_R \dfrac{p}{d_{ap}} \Rightarrow \dfrac{d_{ac}}{d_{ap}} = \dfrac{\mu_D}{\mu_R} = \dfrac{\mu_1}{\mu_2}$

(If $\mu_R = 1$, $\mu_D = \mu$) then $d_{ap} = \dfrac{d_{ac}}{\mu}$ so $d_{ap} < d_{ac}$ ...(ii)

The distance between object and its image, called normal shift (x)

$$x = d_{ac} - d_{ap}\left[\because d_{ap} = \frac{d_{ac}}{\mu}\right];\ x = d_{ac} - \frac{d_{ac}}{\mu} = d_{ac}\left[1 - \frac{1}{\mu}\right] \text{...(iii)} \qquad \text{If } d_{ac} = d \text{ then } \boxed{x = d\left[1 - \frac{1}{\mu}\right]}$$

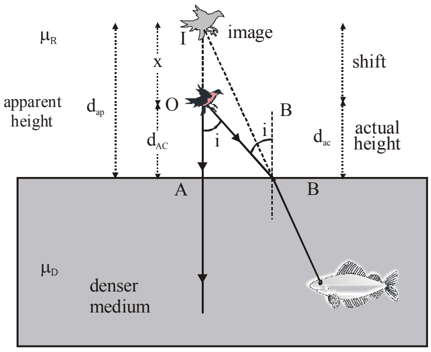




Object in a rarer medium is seen from a denser medium

$$\frac{d_{ac}}{d_{ap}} = \frac{\mu_1}{\mu_2} = \frac{\mu_R}{\mu_D} = \frac{1}{\mu}(<1)$$

$d_{ap} = \mu\, d_{ac}$ i.e., $d_{ap} > d_{ac}$

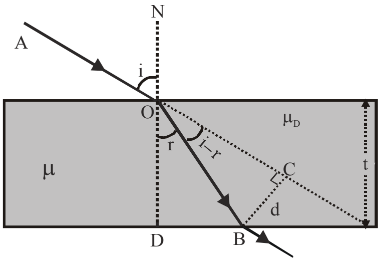


A high flying object appears to be higher than in reality.

$x = d_{ap} - d_{ac} \Rightarrow x = [\mu - 1]\, d_{ac}$

LATERAL SHIFT

The perpendicular distance between incident and emergent ray is known as lateral shift.
Lateral shift d = BC and t = thickness of slab

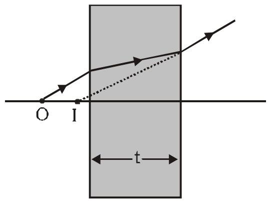


In Δ BOC $\sin(i-r) \dfrac{BC}{OB} = \dfrac{d}{OB} \Rightarrow d = OB \sin(i-r)$ ...(i)

In Δ OBD $\cos r = \dfrac{OD}{OB} = \dfrac{t}{OB} \Rightarrow OB = \dfrac{t}{\cos r}$ ...(ii)

From (i) and (ii) $d = \dfrac{t}{\cos r}\sin(i-r)$

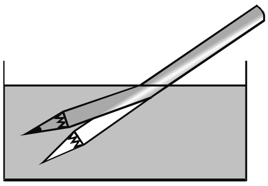
TRANSPARENT GLASS SLAB (Normal shift)



When an object is placed infront of a glass slab, it shift the object in the direction of incident light and form a image at a distance x.

$$x = t\left[1-\frac{1}{\mu}\right]$$

SOME ILLUSTRATIONS OF REFRACTION



- **Bending of an object**

  When a point object in a denser medium is seen from a rarer medium it appears to bend by $\frac{d}{\mu}$

- **Twinkling of stars**

  Due to fluctuations in refractive index of atmosphere the refraction becomes irregular and the light sometimes reaches the eye and sometimes it does not. This gives rise to twinkling of stars.

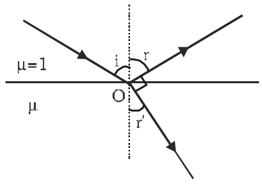
KEY POINTS

- μ is a scalar and has no units and dimensions.
- If ε_0 and μ_0 are electric permittivity and magnetic permeability respectively of free space while ε and μ those of a given medium, then according to electromagnetic theory.

$$c = \frac{1}{\sqrt{\varepsilon_0\mu_0}} \text{ and } v_m = \frac{1}{\sqrt{\varepsilon\mu}} \Rightarrow n_m = \frac{c}{v} = \sqrt{\frac{\varepsilon\mu}{\varepsilon_0\mu_0}} = \sqrt{\varepsilon_r\mu_r}$$

- As in vacuum or free space, speed of light of all wavelengths is maximum and equal to c so for all wavelengths the refractive index of free space is minimum and is $\mu = \frac{c}{v_m} = \frac{c}{c} = 1$

Ex. A ray of light is incident on a transparent glass slab of refractive index 1.62. If the reflected and refracted rays are mutually perpendicular, what is the angle of incidence ? [$\tan^{-1}(1.62) = 58.3°$]



Sol. According to given problem : $r + 90° + r' = 180°$

i.e, $r' = 90° - r \Rightarrow r' = (90° - i)$ [$\because \angle i = \angle r$]

And as according to Snell's law: $1 \sin i = \mu \sin r'$

$\sin i = \mu \sin(90 - i) \Rightarrow \sin i = \mu \cos i$ [$\because \sin(90 - i) = \cos i$]

$\Rightarrow \tan i = \mu \Rightarrow i = \tan^{-1}\mu = \tan^{-1}(1.62) = 58.3°$

Ex. A 20 cm thick glass slab of refractive index 1.5 is kept infront of a plane mirror. An object is kept in air at a distance 40 cm from the mirror. Find the position of image w.r.t an observer near the object. What is effect of separation between glass slab and the mirror on image.

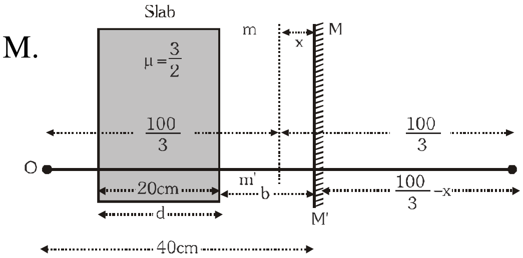
Sol. Shifting in object due to glass slab $x = d\left(1-\frac{1}{\mu}\right) = 20\left[1-\frac{1}{1.5}\right] = \frac{20}{3}$cm

Distance of object from mirror (as seen by mirror) $= 40 - \frac{20}{3} = \frac{100}{3}$cm

Image will be formed at a distance $\frac{100}{3}$cm from mirror M.

Shifting in image due to glass slab $= \frac{20}{3}$ cm

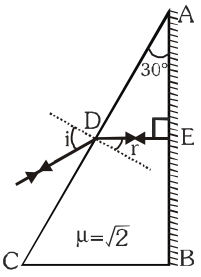
So distance of image from mirror $= \frac{100}{3} - \frac{20}{3} = \frac{80}{3}$ cm



Distance of image from the actual plane mirror is independent of separation b between glass slab and the mirror. If the distance is more then brightness of image will be less.

Ex. If one face of a prism angle 30° and $\mu = \sqrt{2}$ is silvered, the incident ray retraces its initial path. What is the angle of incidence ?

Sol. As incident ray retraces its path the ray is incident normally on the silvere face of the prism as shown in figure.



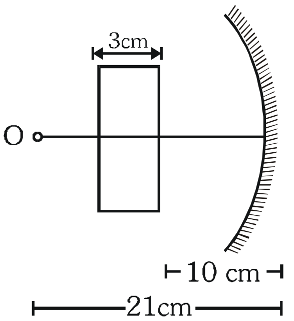
Further, as in ΔAED $30° + 90° + \angle D = 180°$ $\Rightarrow \angle D = 60°$

Now as by construction, $\angle D + \angle r = 90° \Rightarrow \angle r = 90° - 60° = 30°$

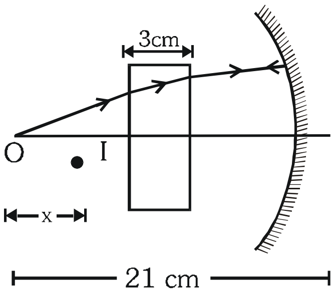
$\therefore$ from Snell's law at surface AC, $1\sin i = \sqrt{2}\sin 30° = \sqrt{2} \times \frac{1}{2} = \frac{1}{\sqrt{2}}$

$\therefore \sin i = \frac{1}{\sqrt{2}}$ so i = 45°

Ex. An object is placed 21 cm infront of a concave mirror of radius of curvature 20 cm. A glass slab of thickness 3 cm and refractive index 1.5 is placed closed to the mirror in space between the object and the mirror. Find the position of final image formed if distance of nearer surface of the slab from the mirror is 10 cm.



Sol. shift by slab $x = d\left(1-\frac{1}{\mu}\right) = 3\left(1-\frac{1}{1.5}\right) = 1\text{cm}$



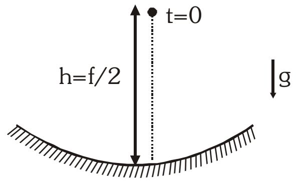
for image formed by mirror u = – (21 – 1) cm = – 20 cm.

$\frac{1}{u}+\frac{1}{v}=\frac{1}{f} \Rightarrow \frac{1}{-20}+\frac{1}{v}=\frac{1}{-10} \Rightarrow v = -20\text{ cm}$

shift in the direction of light v = – (20 + 1) = – 21 cm.

Ex. A particle is dropped along the axis from a height $\frac{f}{2}$ on a concave mirror of focal length f as shown in figure. Find the maximum speed of image.

Sol. $v_{IM} = -m^2 v_{OM} = -m^2(gt)$ where

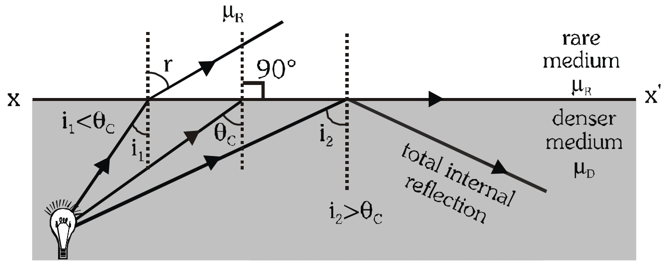


$$m = \frac{f}{f-u} = \frac{-f}{-f+\left(\frac{f}{2}-\frac{gt^2}{2}\right)} = \frac{2f}{f+gt^2} \Rightarrow v_1 = -\left(\frac{2f}{f+gt^2}\right)^2(gt) = \frac{-4f^2gt}{\left(f+gt^2\right)^2}$$

For maximum speed $\frac{dv_I}{dt} = 0 \Rightarrow t = \sqrt{\frac{f}{3g}} \Rightarrow v_{I\max} = \frac{3}{4}\sqrt{3fg}$

TOTAL INTERNAL REFLECTION

When light ray travel from denser to rarer medium it bend away from the normal if the angle of incident is increased, angle of refraction will also increased. At a particular value of angle the refracted ray subtend 90^0 angle with the normal, this angle of incident is known as critical angle (θ_C). If angle of incident further increase the ray come back in the same medium this phenomenon is known as total internal reflection.



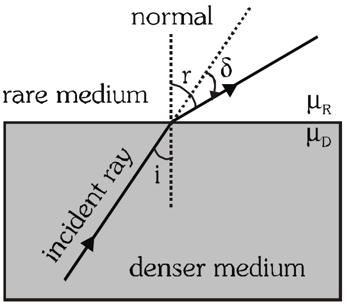
CONDITIONS

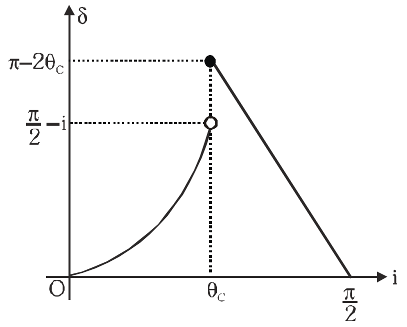
- Angle of incident > critical angle [$i > \theta_c$]
- Light should travel from denser to rare medium $\Rightarrow$ Glass to air, water to air, Glass to water

Snell's Law at boundary xx', $\mu_D \sin\theta_C = \mu_R \sin 90° \Rightarrow \sin\theta_C = \frac{\mu_R}{\mu_D}$

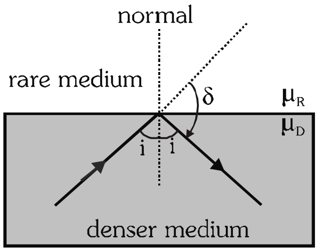
Graph between angle of deviation (δ) and angle of incidence (i) as rays goes from denser to rare medium

- If $i < \theta_c$ $\mu_D \sin i = \mu_R \sin r$; $r = \sin^{-1}\left(\frac{\mu_D}{\mu_R}\sin i\right)$ so $\delta = r - i = \sin^{-1}\left(\frac{\mu_D}{\mu_R}\sin i\right) - i$

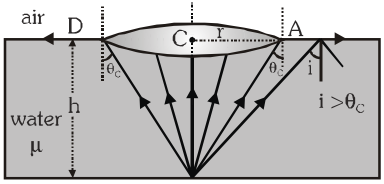


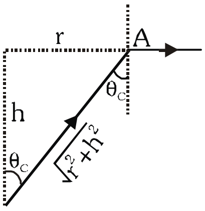


- If $i > \theta_c$; $\delta = \pi - 2i$



- A point object is situated at the bottom of tank filled with a liquid of refractive index μ upto height h. It is found light from the source come out of liquid surface through a circular portion above the object





$$\sin\theta_C = \frac{r}{\sqrt{r^2+h^2}} \quad \& \quad \sin\theta_C = \frac{1}{\mu} \Rightarrow \frac{1}{\mu} = \frac{r}{\sqrt{r^2+h^2}} \Rightarrow \frac{1}{\mu^2} = \frac{r^2}{r^2+h^2}$$

$$\Rightarrow \mu^2 r^2 = r^2 + h^2 \Rightarrow (\mu^2-1)r^2 = h^2 \Rightarrow \text{radius of circular portion}$$

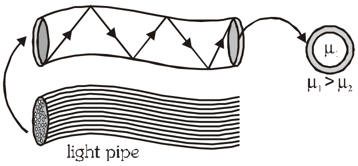
$$r = \frac{h}{\sqrt{\mu^2-1}} \quad \text{and} \quad \text{area} = \pi r^2$$

SOME ILLUSTRATIONS OF TOTAL INTERNAL REFLECTION

- **Sparkling of diamond**

  The sparkling of diamond is due to total internal reflection inside it. As refractive index for diamond is 2.5 so $\theta_c = 24°$. Now the cutting of diamond are such that $i > \theta_C$. So TIR will take place again and again inside it. The light which beams out from a few places in some specific directions makes it sparkle.

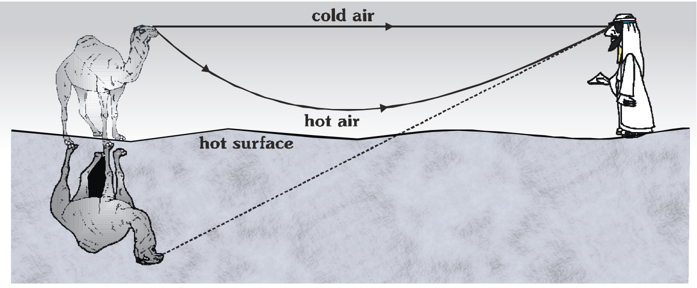
- **Optical Fibre**

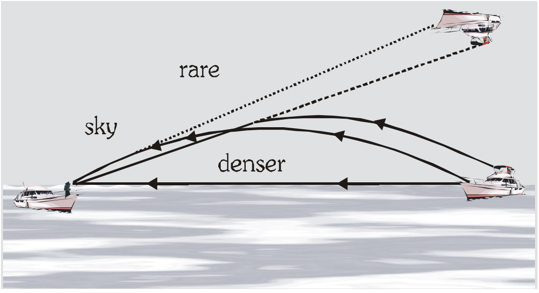
  

  In it light through multiple total internal reflections is propagated along the axis of a glass fibre of radius of few microns in which index of refraction of core is greater than that of surroundings.

- **Mirage and looming**

  Mirage is caused by total internal reflection in deserts where due to heating of the earth, refractive index of air near the surface of earth becomes lesser than above it. Light from distant objects reaches the surface of earth with $i > \theta_C$ so that TIR will take place and we see the image of an object along with the object as shown in figure.





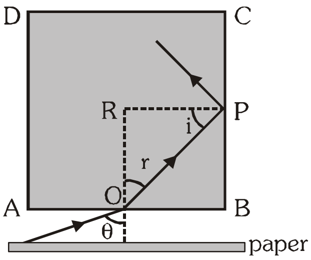
Similar to 'mirage' in deserts, in polar regions 'looming' takes place due to TIR. Here μ decreases with height and so the image of an object is formed in air if $(i > \theta_C)$ as shown in figure.

KEY POINTS

- A diver in water at a depth d sees the world outside through a horizontal circle of radius. $r = d\tan\theta_c$.
- In case of total internal reflection, as all (i.e. 100%) incident light is reflected back into the same medium there is no loss of intensity while in case of reflection from mirror or refraction from lenses there is some loss of intensity as all light can never be reflected or refracted. This is why images formed by TIR are much brighter than formed by mirrors or lenses.

Ex. A rectangular block of glass is placed on a printed page laying on a horizontal surface. Find the minimum value of the refractive index of glass for which the letters on the page are not visible from any of the vertical faces of the block.

Sol. The situation is depicted in figure. Light will not emerge out from the vertical face BC if at it



$i > \theta_C$ or $\sin i > \sin\theta_C \Rightarrow \sin i > \frac{1}{\mu}\left[\text{as } \sin\theta_C = \frac{1}{\mu}\right]$ ... (i)

But from Snell's law at O $1 \times \sin\theta = \mu \sin r$
And in Δ OPR, $r + 90 + i = 180 \Rightarrow r + i = 90° \Rightarrow r = 90 - i$

So $\sin\theta = \mu\sin(90 - i) = \mu\cos i \Rightarrow \cos i = \frac{\sin\theta}{\mu}$

so $\sin i = \sqrt{1-\cos^2 i} = \sqrt{1-\left[\frac{\sin\theta}{\mu}\right]^2}$ ... (ii)

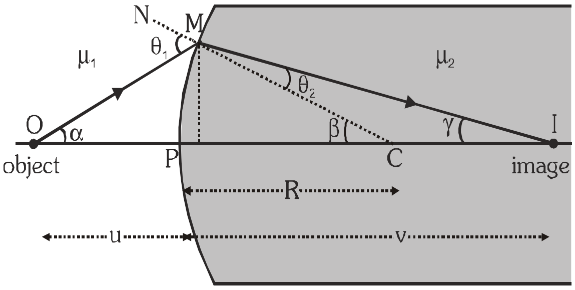
so substituting the value of sin i from equation (ii) in (i),

$\sqrt{1-\frac{\sin^2\theta}{\mu^2}} > \frac{1}{\mu}$ i.e., $\mu^2 > 1 + \sin^2\theta$ ∵ $(\sin^2\theta)_{max} = 1$ ∴ $\mu^2 > 2 \Rightarrow \mu > \sqrt{2}$ ∴

$\mu_{min} = \sqrt{2}$

REFRACTION AT TRANSPARENT CURVED SURFACE

μ_1 = refractive index of the medium in which actual incident ray lies.
m_2 = refractive index of the medium in which actual refractive ray lies.
O = Object
P= pole
C= centre of curvature
R = PC = radius of curvature

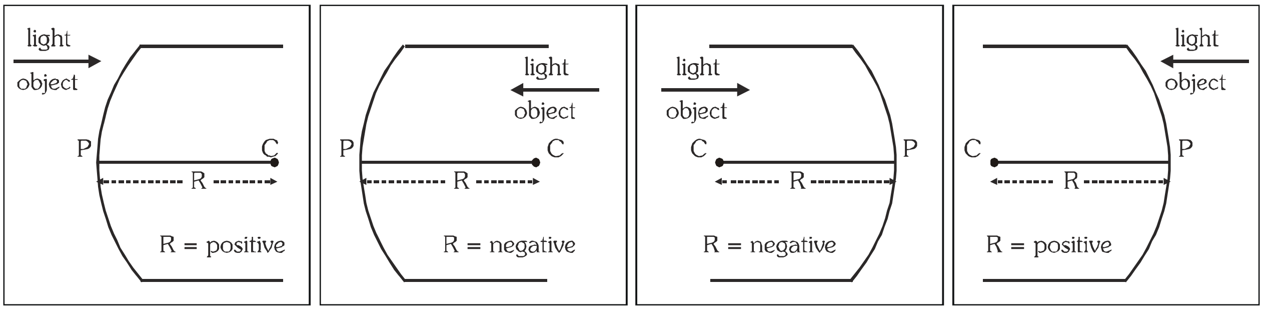


Refraction from curved surface

$\mu_1 \sin\theta_1 = \mu_2 \sin\theta_2$
if angle is very small : $\mu_1\theta_1 = \mu_2\theta_2$...(i)
But $\theta_1 = \alpha + \beta$ ...(ii)
$\beta = \theta_2 + \gamma$ ...(iii)
from (i), (ii) and (iii) $\mu_1(\alpha + \beta) = \mu_2(\beta - \gamma)$
$\Rightarrow \mu_1\alpha + \mu_1\beta = \mu_2\beta - \mu_2\gamma \Rightarrow \mu_1\alpha + \mu_2\gamma = (\mu_2 - \mu_1)\beta$

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

SIGN CONVENTION FOR RADIUS OF CURVATURE

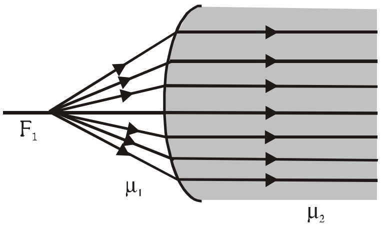


These are valid for all single refraction surfaces – convex, concave or plane. In case of plane refracting surface R → ∞, $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2-\mu_1}{R} \Rightarrow \frac{\mu_2}{v} - \frac{\mu_1}{u} = 0$ i.e. $\frac{u}{v} = \frac{\mu_1}{\mu_2}$ or $\frac{d_{Ac}}{d_{Ap}} = \frac{\mu_1}{\mu_2}$

FOCAL LENGTH OF A SINGLE SPHERICAL SURFACE

A single spherical surface as two principal focus points which are as follows–

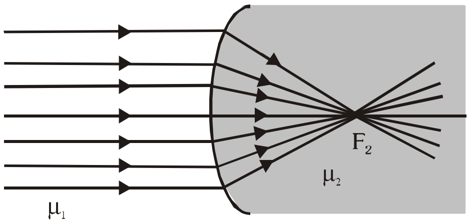
(i) **First focus:** The first principal focus is the point on the axis where when an object is placed, the image is formed at infinity. That is when



u = f_1, v = ∞, then from $-\frac{\mu_1}{u}+\frac{\mu_2}{v}=\left(\frac{\mu_2-\mu_1}{R}\right)$

We get $-\frac{\mu_1}{f_1}=\frac{\mu_2-\mu_1}{R}\Rightarrow f_1=\frac{-\mu_1 R}{(\mu_2-\mu_1)}$

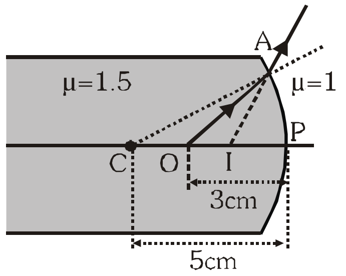
(ii) **Second focus:** Similarly, the second principal focus is the point where parallel rays focus. That is $u_1 = -\infty$, $v_1 = f_2$, then

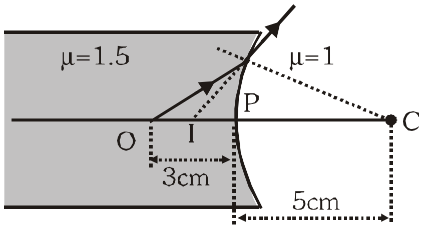


$$\frac{\mu_2}{f_2}=\frac{\mu_2-\mu_1}{R}\ ;\ f_2=\frac{\mu_2 R}{(\mu_2-\mu_1)}$$

(iii) **Ratio of Focal length:** $\boxed{\frac{f_1}{f_2}=-\frac{\mu_1}{\mu_2}}$

Ex An air bubble in glass (μ = 1.5) is situated at a distance 3 cm from a spherical surface of diameter 10 cm as shown in Figure. At what distance from the surface will the bubble appear if the surface is (a) convex (b) concave.





Sol. In case of refraction from curved surface $\frac{\mu_2}{v}-\frac{\mu_1}{u}=\frac{(\mu_2-\mu_1)}{R}$

(a) $\mu_1 = 1.5$, $\mu_2 = 1$, R = – 5 cm and u = –3 cm $\Rightarrow \frac{1}{v}-\frac{(1.5)}{(-3)}=\frac{1-1.5}{(-5)}\Rightarrow v=-2.5$ cm

the bubble will appear at a distance 2.5 cm from the convex curved surface inside the glass.

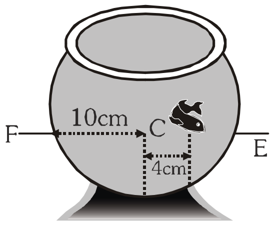
(b) $\mu_1 = 1.5$, $\mu_2 = 1$, R = 5 cm and u = –3 cm $\Rightarrow \frac{1}{v}-\frac{(1.5)}{(-3)}=\frac{1-1.5}{(5)}\Rightarrow v=-1.66$ cm

the bubble will appear at a distance 1.66 cm from the concave curved surface inside the glass.

Note : If the surface is plane then R → ∞

case (a) or (b) would yield $\frac{1}{v}-\frac{(1.5)}{(-3)}=\frac{(1-1.5)}{\infty}\Rightarrow$ v = – 2cm

Ex. In a thin spherical fish bowl of radius 10 cm filled with water of refractive index (4/3), there is a small fish at a distance 4 cm from the centre C as shown in Figure. Where will the fish appear to be, if seen from (a) E and (b) F (neglect the thickness of glass) ?

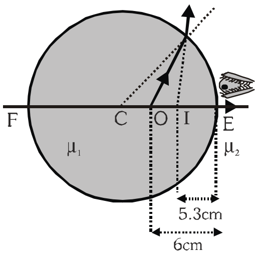


Sol. In the case of refraction from curved surface $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{(\mu_2 - \mu_1)}{R}$

(a) Seen from E $\mu_1 = \frac{4}{3}$, $\mu_2 = 1$, R = – 10 cm & u = –(10 – 4) = –6 cm

$$\Rightarrow \frac{1}{v} - \frac{\frac{4}{3}}{-6} = \frac{1-\frac{4}{3}}{-10} \Rightarrow v == \frac{90}{17} = -5.3\text{cm}$$

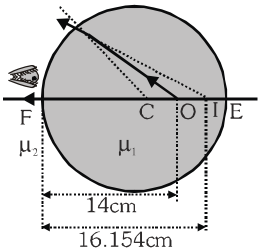
i.e., fish will appear at a distance 5.3 cm from E towards F (lesser than actual distance, i.e., 6 cm)



(b) Seen from F $\mu_1 = \frac{4}{3}$, $\mu_2 = 1$, R = – 10 cm and u= –(10 + 4) = –14 cm

$$\Rightarrow \frac{1}{v} - \frac{\frac{4}{3}}{-14} = \frac{1-\frac{4}{3}}{-10} \quad \Rightarrow v = \frac{-210}{13} = -16.154 \text{ cm}$$

so fish will appear at a distance 16.154 cm from F toward E (more than actual distance, i.e., 14 cm)

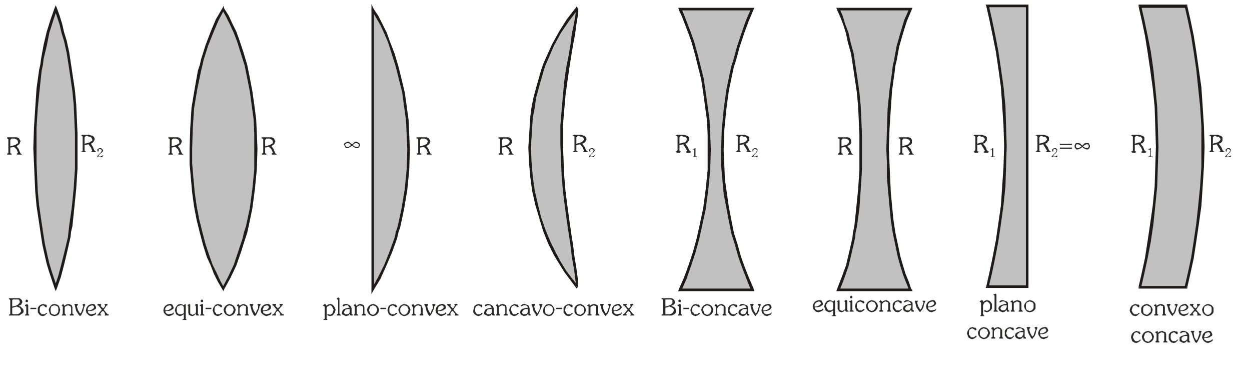


LENS

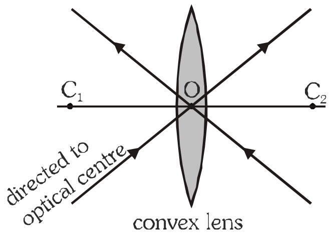
A lens is a piece of transparent material with two refracting surfaces such that at least one is curved and refractive index of its material is different from that of the surroundings.

A thin spherical lens with refractive index greater than that of surroundings behaves as a convergent or convex lens, i.e., converges parallel rays if its central (i.e. paraxial) portion is thicker than marginal one.

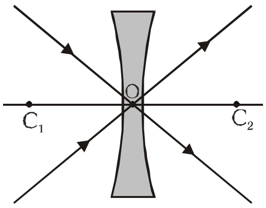
However if the central portion of a lens is thinner than marginal, it diverges parallel rays and behaves as divergent or concave lens. This is how wse and classify identify convergent and divergent lenses.



- **Optical Centre :** O is a point for a given lens through which any ray passes undeviated

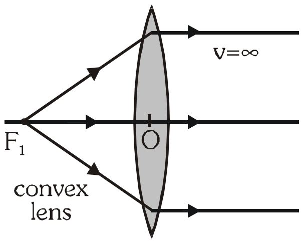


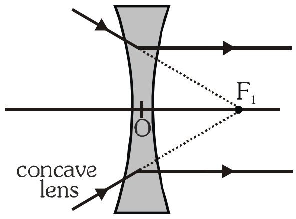
convex lens



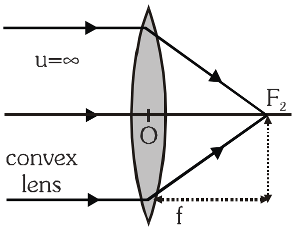
concave lens

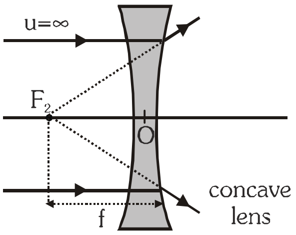
- **Principal Axis : C_1C_2** is a line passing through optical centre and perpendicular to the lens.
- **Principal Focus :** A lens has two surfaces and hence two focal points. First focal point is an object point on the principal axis for which image is formed at infinity.





While second focal point is an image point on the principal axis for which object lies at infinity



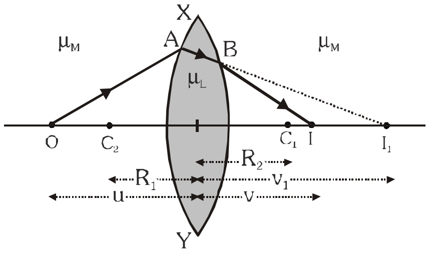


- **Focal Length f** is defined as the distance between optical centre of a lens and the point where the parallel beam of light converges or appears to converge.
- **Aperture :** In reference to a lens, aperture means the effective diameter. Intensity of image formed by a lens which depends on the light passing through the lens will depend on the square of aperture, i.e., Intensity $\propto$ (Aperture)^2

LENS–MAKER'S FORMULA

In case of image formation by a lens

Image formed by first surface acts as object for the second.
So, from the formula of refraction at curved surface.



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

For first surface A $\frac{\mu_L}{v_1}-\frac{\mu_M}{u}=\frac{\mu_L-\mu_M}{R_1}$ ...(i) $[\because \mu_2=\mu_L, \mu_1=\mu_M]$

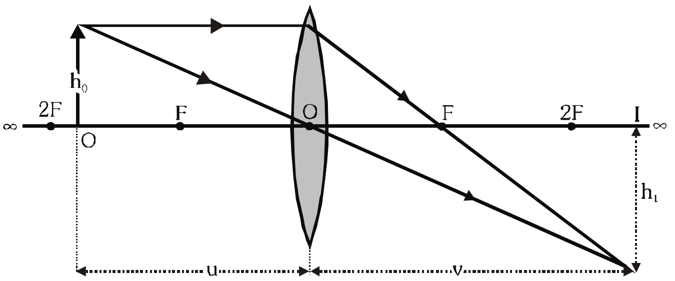
For second surface B $\frac{\mu_M}{v}-\frac{\mu_L}{v_1}=\frac{\mu_M-\mu_L}{R_2}=-\frac{\mu_L-\mu_M}{R_2}$ ...(ii) $[\because \mu_2=\mu_M, \mu_1=\mu_L, \mu_1=\mu_2, u\rightarrow v_1]$

By adding (i) and (ii)

$$\mu_M\left[\frac{1}{v}-\frac{1}{u}\right]=(\mu_L-\mu_M)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]\Rightarrow\frac{1}{v}-\frac{1}{u}=\frac{\mu_L-\mu_M}{\mu_M}\left[\frac{1}{R_1}-\frac{1}{R_2}\right]=(\mu-1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]\text{...(iii)}\quad\left(\because\ \mu=\frac{\mu_L}{\mu_M}\right)$$

Now if object is at infinity, Image will be formed at the focus, u = –∞, v = f

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



This is known as lens makers formula by equating (iii) and (iv) $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$

this is known as lens formula

Magnification : $m=\frac{\text{height of image}}{\text{height of object}}=\frac{h_1}{h_0}=\frac{v}{u}=\frac{f}{f+u}=\frac{f-v}{f}$

RULES FOR IMAGE FORMATION

- A ray passing through optical centre proceeds undeviated through the lens
- A ray passing through first focus or directed towards it, after refraction from the lens, becomes parallel to the principal axis.
- A ray passing parallel to the principal axis after refraction through the lens passes or appears to pass through F_2

For Convergent or convex lens

Object	Image	Magnification
$-\infty$	F	$\lvert m\rvert << 1$ & $m<0$
$-\infty - 2F$	F–2F	$\lvert m\rvert < 1$ & $m<0$
2F	2F	$m = -1$
F – 2F	∞–2F	$\lvert m\rvert > 1$ & $m<0$
Just before F towards C	$+\infty$	$m <<-1$
Just before F towards P	$-\infty$	$m >>1$
F – O	In front of lens	$m >1$

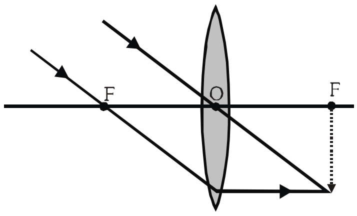
IMAGE FORMATION FOR CONVEX LENS (CONVERGENT LENS)

(i) Object is placed at infinity

Image :

at F real inverted very small in size

$\lvert m\rvert << 1$ & $m<0$

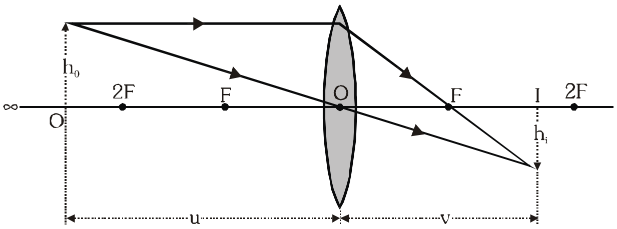


(ii) Object is placed in between ∞ – 2F

Image :

real (F – 2F) inverted small in size (diminished)

$\lvert m\rvert < 1$ & $m<0$

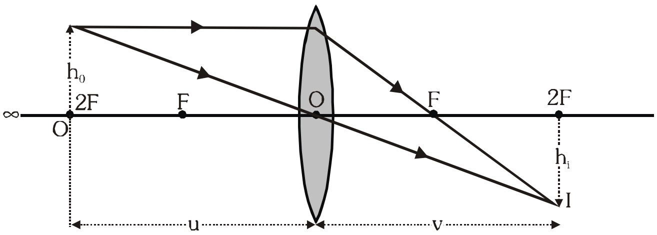


(iii) Object is placed at 2F

Image :

real (at 2F) inverted equal (of same size)

($m = -1$)

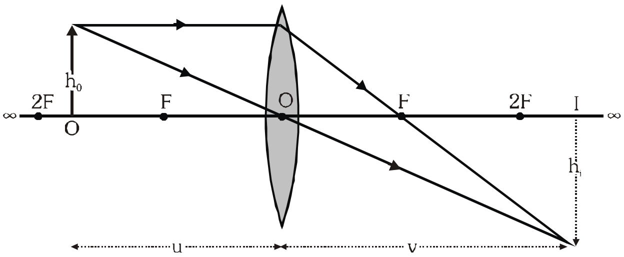


(iv) Object is placed in between 2F – F

Image :

real (2F – ∞) inverted enlarged

$|m| > 1$ & $m<0$



(v) Object is placed in between F – O

Image :

virtual (in front of lens) erected enlarge

($m > +1$)

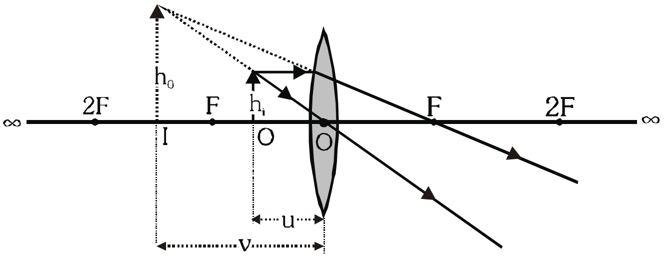


IMAGE FORMATION FOR CONCAVE LENS (DIVERGENT LENS)

Imge is virtual, diminished, erect, towards the object, m = **+ve**

(i) Object is placed at infinity

Image :

At F virtual erected

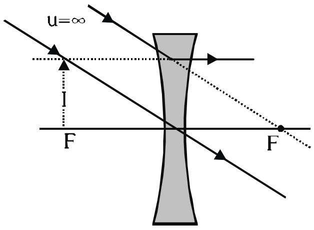
diminished ($m << +1$)

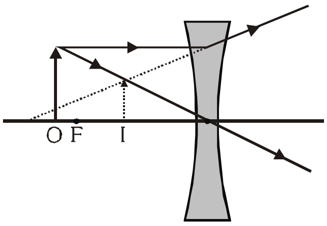
(ii) Object is placed infront of lens

Image :

between F and optical centre

virtual erected diminished ($m < +1$)





Sign convention for object/image for lens

Real object	u – ve
Real image	v + ve
Virtual object	u + ve
Virtual image	v – ve

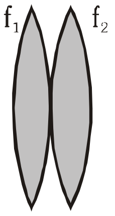
POWER OF LENS

Reciprocal of focal length in meter is known as power of lens.

SI UNIT : dioptre (D) **Power of lens :** $P = \frac{1}{f(m)} = \frac{100}{f(cm)}$ dioptre [in air]

COMBINATION OF LENSES

Two thin lens are placed in contact to each other

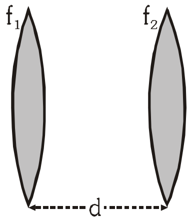


power of combination. $P = P_1 + P_2 \Rightarrow \frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$

Use sign convention when solve numericals

Two thin lens are placed in at a small distance d

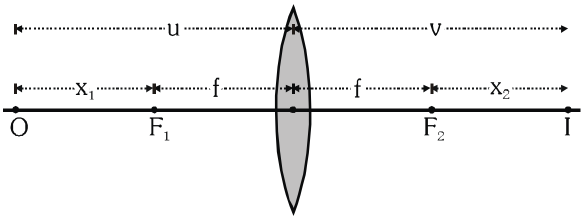
(provided incident rays are parallel to principal axis).



$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2} \Rightarrow P = P_1 + P_2 - d\ P_1 P_2$$

Use sign convention when solving numericals

- **Newton's Formula**



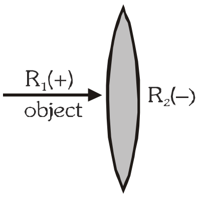
$f = \sqrt{x_1 x_2}$

x_1 = distance of object from focus.

x_2 = distance of image from focus.

SOME SPECIAL CASES

(i) The focal length of equiconvex lens placed in air

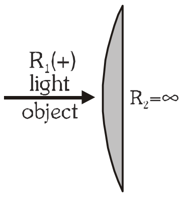


refractive index of lens $\mu_L = \mu$ refractive index of medium $\mu_M = 1$

$R_1 = +R$, $R_2 = -R$

$$\frac{1}{f} = (\mu - 1)\left[\frac{1}{R} - \left(-\frac{1}{R}\right)\right] \Rightarrow \text{Focal length } f = \frac{R}{2(\mu - 1)}$$

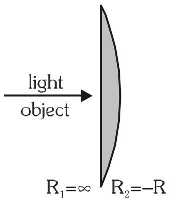
(ii) Focal length of planoconvex lens placed in air



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

$$\Rightarrow \text{Focal length } f = \frac{R}{(\mu - 1)}$$

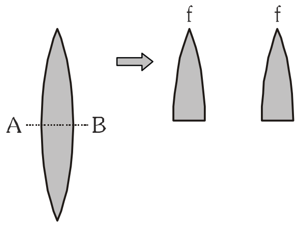
If object is placed towards plane surface



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

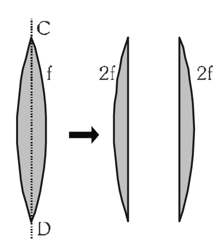
$$\Rightarrow \text{Focal length } f = \frac{R}{(\mu - 1)}$$

(iii) If an equiconvex lens of focal length f is cut into equal parts by a horizontal plane AB then the focal length of each part will be equal to that of initial lens. Because μ, R_1 and R_2 will remain unchanged. Only intensity will be reduced.



$\because$ intensity I $\propto$ (apertures)^2

$\therefore$ intensity through a single part will be reduced

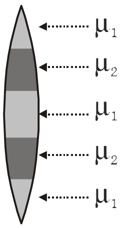


focal length of each part become 2f

(iv) If the same lens is cut into equal parts by a vertical plane CD the focal length of each part will be double of initial value but intensity will remain unchanged.

For equiconvex lens $\frac{1}{f}=\frac{(\mu-1)2}{R}$ For plano convex lens $\frac{1}{f_1}=\frac{\mu-1}{R}$

So $\frac{1}{f}=\frac{2}{f_1}\Rightarrow f_1=2f\Rightarrow$ Focal length of each part = 2 (focal length of original lens)

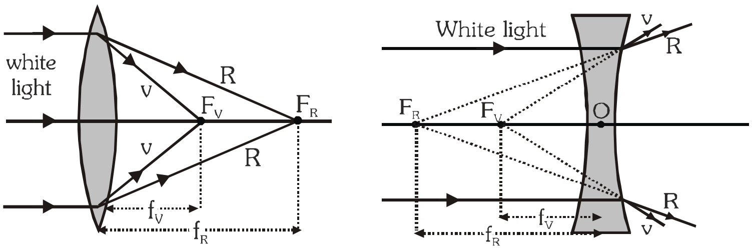


(v) If a lens is made of number of layers of different refractive index for a given wavelength then no. of images is equal to number of refractive index, as

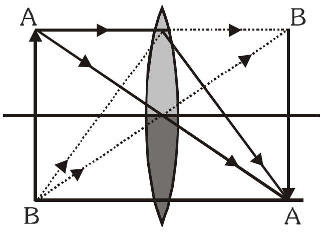
$$\frac{1}{f}\propto(\mu-1)$$

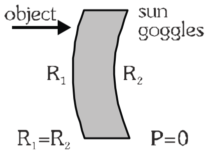
In figure number of images = 2

(vi) Focal length of lens depends on wavelength. $\because \frac{1}{f}\propto(\mu-1)\propto\frac{1}{\lambda}\ [f\propto\lambda]\quad f_R>f_V$



(vii) If half portion of lens is covered by black paper then intensity of image will be reduced but complete image will be formed.





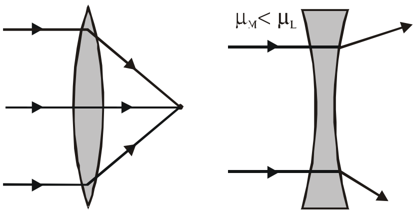
(viii) Sun–goggles :

radius of curvature of two surfaces is equal with centre on the same side

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

$\Rightarrow \frac{1}{f}=0\Rightarrow f=\infty$ and $P=0\ \Rightarrow$ sun goggles have no power

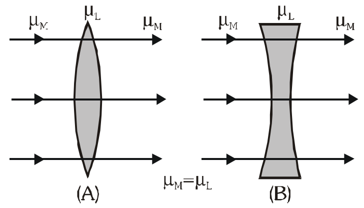
(ix) If refractive index of medium < Refractive index of lens



If $\mu_M < \mu_L$ then f = +ve

Convex lens behave as convex lens. While concave lens behave as concave lens.

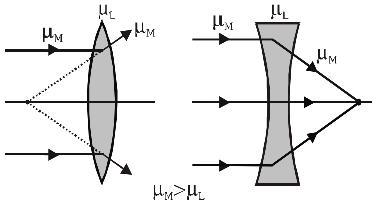
(x) Refractive index of medium = Refractive index of lens ($\mu_M = \mu_L$)



$$\frac{1}{f}=\left(\frac{\mu_L}{\mu_M}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right);\ \frac{1}{f}=0\Rightarrow f=\infty\ \&\ P=0$$

Lens will behave as plane glass plate

(xi) Refractive index of medium > Refractive index of lens



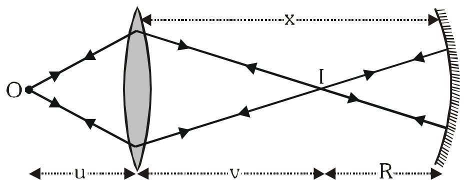
$$\mu_M > \mu_L \Rightarrow \frac{\mu_L}{\mu_M} < 1 \text{ [f will be negative]}$$

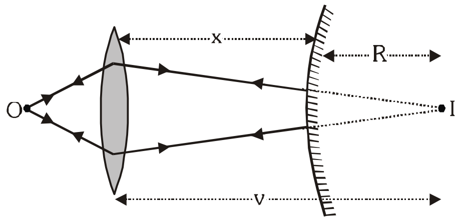
convex lens will behave as concave lens and concave lens will behave as convex lens. If a air bubble is formed in water it behaves as concave lens.

Ex. A point source S is placed at distance of 15 cm from a converging lens of focal length 10 cm. Where should a (i) concave mirror (ii) convex mirror of focal length 12 cm be placed so that real image is formed on object itself.

Sol. u = –15cm, f = +10cm; $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}\Rightarrow\frac{1}{v}-\frac{1}{(-15)}=\frac{1}{10}\Rightarrow v=30$ cm

(i) x = v + 2f ⇒ 30 + 2 × 12 = 54 cm (ii) x = v – 2f = 30 – 2 × 12 = 6 cm





Ex. A convex lens of focal length f is producing real image which is $\frac{1}{n}$ times of the size of the object. Find out position of the object.

Sol. Image is real so $m=\frac{v}{u}=-\frac{1}{n}\Rightarrow v=-\frac{u}{n}$

from lens formula $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}\Rightarrow\frac{1}{-\frac{u}{n}}-\frac{1}{u}=\frac{1}{f}\Rightarrow\frac{-(n+1)}{u}=\frac{1}{f}\Rightarrow u=-f(1+n)$

Ex. (a) If f = +0.5m, what is the power of the lens ?

(b) The radii of curvature of the faces of a double convex lens are 10 cm and 15 cm. Its focal length is 12 cm. What is the refractive index of glass ?

(c) A convex lens has 20 cm focal length in air. What is the focal length in water ? (Refractive index of air–water = 1.33, refractive index for air glass is 1.5)

Sol. (a) $P=\frac{1}{f(m)}=\frac{1}{0.5}=+2D$

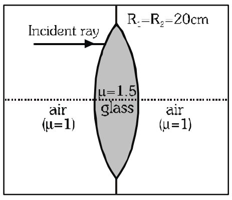
(b) $\frac{1}{f}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)\Rightarrow\frac{1}{12}=(\mu-1)\left(\frac{1}{10}-\frac{1}{-15}\right)\Rightarrow\mu=1.5$

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

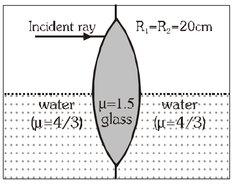
$$\frac{f_w}{f_a}=\frac{(\mu_\ell-1)}{\left({}_w\mu_\ell-1\right)}\Rightarrow f_w=\frac{(1.5-1)}{\left(\frac{1.5}{1.33}-1\right)}\times 20=78.2\text{cm}$$

Ex. Column I (optical system)

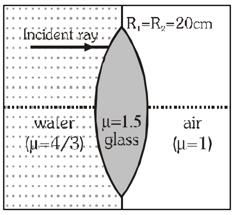
(A)



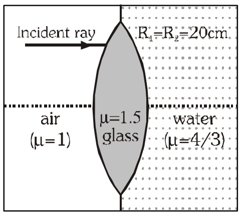
(B)



(C)



(D)



Column II (focal length)

(P) 80 cm (Q) 40 cm (R) 30 cm (S) 20 cm

Sol. Ans. (A) –S (B) –P (C) –R

For (A) : $\frac{1}{f}=(\mu-1)\left(\frac{1}{p_1}+\frac{1}{p_2}\right)=(1.5-1)\left(\frac{1}{20}+\frac{1}{20}\right)=\frac{1}{20}\Rightarrow f=20\text{cm}$

For (B) : $\frac{1}{f}=\left(\frac{1.5}{4/3}-1\right)\left(\frac{1}{20}+\frac{1}{20}\right)=\frac{1}{80}\Rightarrow f=80\text{cm}$

For (C) : $\frac{1.5}{v_1}-\frac{4/3}{\infty}=\left(1.5-\frac{4}{3}\right)\left(\frac{1}{20}\right)$ & $\frac{1}{f}-\frac{1.5}{v_1}=(1-1.5)\left(\frac{1}{-20}\right)\Rightarrow f=30\text{cm}$

For (D) $\frac{1.5}{v_1}-\frac{1}{\infty}=(1.5-1)\left(\frac{1}{20}\right)$ & $\frac{4/3}{f}-\frac{1.5}{v_1}=\left(\frac{4}{3}-1.5\right)\left(-\frac{1}{20}\right)\Rightarrow f=40\text{cm}$

DISPLACEMENT METHOD

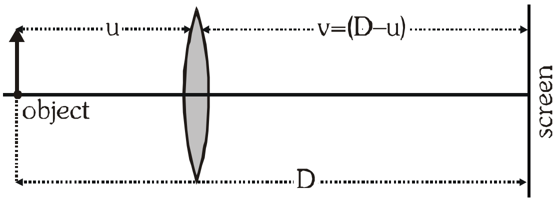
It is used for determination of focal length of convex lens in laboratory.

A thin convex lens of focal length f is placed between an object and a screen fixed at a distance D apart.

If D > 4f there are two position of lens at which a sharp image of the object is formed on the screen

By lens formula $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}\Rightarrow\frac{1}{D-u}-\frac{1}{-u}=\frac{1}{f}$

$\Rightarrow u^2-Du+Df=0\Rightarrow u=\frac{D\pm\sqrt{D(D-4f)}}{2}$



there are three possibilities

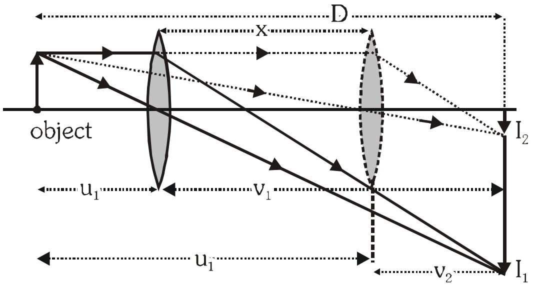
(i) for D < 4f u will be imaginary hence physically no position of lens is possible

(ii) for D = 4f $u=\frac{D}{2}=2f$ so only one position of lens is possible

and since v = D – u = 4f – 2f = u =2f

(iii) for D > 4f $u_1=\frac{D-\sqrt{D(D-4f)}}{2}$ and $u_2=\frac{D+\sqrt{D(D-4f)}}{2}$

So there are two positions of lens for which real image will be formed on the screen.
(for two distances u_1 and u_2 of the object from lens)



If the distance between two positions of lens is x

then $x = u_2 - u_1 = \dfrac{D+\sqrt{D(D-4f)}}{2} - \dfrac{D-\sqrt{D(D-4f)}}{2}$

$= \sqrt{D(D-4f)} \Rightarrow x^2 = D^2 - 4\,Df \Rightarrow f = \dfrac{D^2 - x^2}{4D}$

Distance of image corresponds to two positions of the lens :

$$v_1 = D - u_1 = D - \frac{1}{2}[D - \sqrt{D(D-4f)}] = \frac{1}{2}[D + \sqrt{D(D-4f)}] = u_2 \Rightarrow v_1 = u_2$$

$$v_2 = D - u_2 = D - \frac{1}{2}[D + \sqrt{D(D-4f)}] = \frac{1}{2}[D - \sqrt{D(D-4f)}] = u_1 \Rightarrow v_2 = u_1$$

for two positions of the lens distances of object and image are interchangeable.

Now $x = u_2 - u_1$ and $D = v_1 + u_1 = u_2 + u_1$ $\quad [\because\ v_1 = u_2]$

so $u_1(= v_2) = \dfrac{D-x}{2}$ and $v_1 = \dfrac{D+x}{2} = u_2$; $m_1 = \dfrac{I_1}{O} = \dfrac{v_1}{u_1} = \dfrac{D+x}{D-x}$ and $m_2 = \dfrac{I_2}{O} = \dfrac{v_2}{u_2} = \dfrac{D-x}{D+x}$

Now $m_1 \times m_2 = \dfrac{D+x}{D-x} \times \dfrac{D-x}{D+x} \Rightarrow \dfrac{I_1 I_2}{O^2} = 1 \Rightarrow O = \sqrt{I_1 I_2}$

Ex. A convex lens is placed between an object and a screen which are at a fixed distance apart for one position of the lens. The magnification of the image obtained on the screen is m_1. When the lens is moved by a distance d the magnification of the image obtained on the same screen is m_2, Find the focal length of the lens.

Sol. If D is the distance between the object and the screen, d the separation of the two position of lens throwing two images on the screen then

$m_1 = \dfrac{(D+d)}{(D-d)}$ and $m_2 = \dfrac{(D-d)}{(D+d)}$ $\therefore\ m_1 - m_2 = \dfrac{4Dd}{D^2 - d^2}$ but $\dfrac{D^2 - d^2}{4D} = f$ so $m_1 - m_2 = \dfrac{d}{f}$ $\Rightarrow f = \dfrac{d}{m_1 - m_2}$

Ex. In a displacement method using lens, we obtain two images for separation of the lens d. One image is magnified as much as the other is diminished. If m is the magnifications of one image, find the focal length of the lens.

Sol. From above question $f = \dfrac{d}{m_1 - m_2}$ here if m_1 is taken as m, $m_2 = \dfrac{1}{m}$, so f becomes $\dfrac{md}{(m^2 - 1)}$

Ex. In the displacement method the distance between the object and the screen is 70 cm and the focal length of the lens is 16 cm, find the separations of the magnified and diminished image position of the lens.

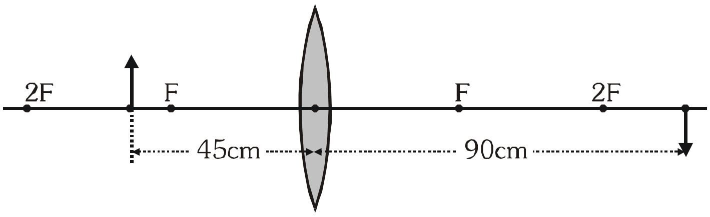
Sol. $d = \sqrt{D^2 - 4fd} = \sqrt{(70)^2 - 4 \times 16 \times 70} = \sqrt{420} = 20.5\text{cm}$

Ex. An object 25 cm high is placed in front of a convex lens of focal length 30 cm. If the height of image formed is 50 cm, find the distance between the object and the image (real and virtual) ?

Sol. As object is in front of the lens, it is real and as $h_1 = 25$ cm, $f = 30$ cm, $h_2 = -50$ cm ;

$$m = \frac{h_2}{h_1} = \frac{-50}{25} = -2$$

$$m = \frac{f}{f+u} \Rightarrow -2 = \frac{30}{30+u} \Rightarrow u = -45 \text{ cm} \Rightarrow m = \frac{v}{u} \Rightarrow -2 = \frac{v}{-45} \Rightarrow v = 90 \text{ cm}$$



As in this situation object and image are on opposite sides of lens, the distance between object and image $d_1 = u + v = 45 + 90 = 135$ cm. If the image is erect (i.e., virtual)

$$m = \frac{f}{f+u} \Rightarrow 2 = \frac{30}{30+u} \Rightarrow u = -15 \text{ cm} \Rightarrow m = -\frac{v}{u} \Rightarrow 2 = \frac{-v}{-15} \Rightarrow v = 30 \text{ cm}$$

As in the situation both image and object are in front of the lens, the distance between object and image

$d_2 = v - u = 30 - 15 = 15$ cm.

COMBINATION OF LENSES AND MIRRORS

When several lenses or mirrors are used, the image formation is considered one after another in steps, The image formed by the lens facing the object serves as an object for the next lens or mirror, the image formed by the second lens acts as an object for the third, and so on, The total magnification in such situations will be given by

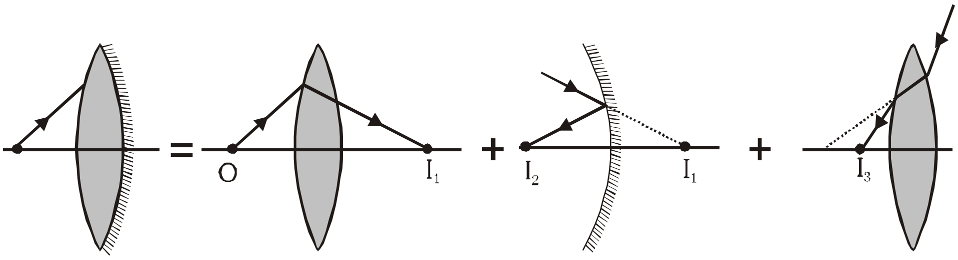
$$m = \frac{I}{O} = \frac{I_1}{O} \times \frac{I_2}{I_1} \times \dots \Rightarrow m = m_1 \times m_2 \times \dots$$

Power of Lens [in air] $P_L = \frac{1}{f_L}$ Converging lens $P_L = +ve$ Diverging lens $P_L = -ve$

Power For mirror $P_L = -\frac{1}{f_m}$ Convex mirror $P_M = -ve$ Concave mirror $P_M = +ve$

SILVERING OF LENS

Calculate equivalent focal length of a equiconvex lens silvered at one side.

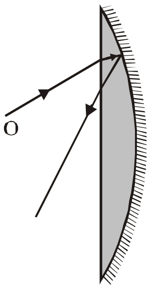


$$P = P_L + P_M + P_L = 2P_L + P_M$$

$$\frac{1}{F} = \frac{1}{f_\ell} + \frac{1}{f_m} + \frac{1}{f_\ell} = \frac{2}{f_\ell} + \frac{1}{f_m} = \frac{2(\mu-1)\times 2}{R} + \frac{2}{R} = \frac{4\mu - 4 + 2}{R} \Rightarrow F = \frac{R}{4\mu - 2}$$

Ex. Calculate equivalent focal length of plano convex lens for following case :–
(i) When curved surface is silvered. (ii) When plane surface is silvered.

Sol. (i)

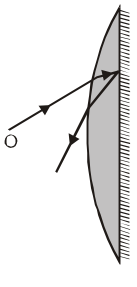


$$P = 2P_L + P_M$$

$$\Rightarrow \frac{1}{F} = \frac{2}{f_\ell} + \frac{1}{f_m} \Rightarrow \frac{1}{F} = \frac{2(\mu-1)}{R} + \frac{2}{R}$$

$$\Rightarrow \frac{1}{F} = \frac{2\mu}{R} \Rightarrow F = \frac{R}{2\mu}$$

(ii)



$$P = 2P_L + P_M$$

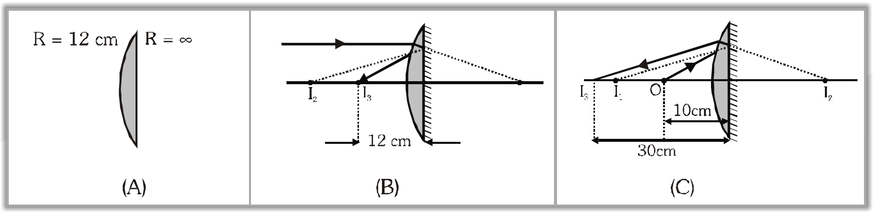
$$\Rightarrow \frac{1}{F} = \frac{2}{f_L} + \frac{1}{f_m} \Rightarrow \frac{1}{F} = \frac{2(\mu-1)}{R} + \frac{1}{\infty}$$

$$\Rightarrow F = \frac{R}{2(\mu-1)}$$

Ex. The radius of curvature of the convex face of a plano–convex lens is 12 cm and its refractive index is 1.5. (a) Find the focal length of this lens. The plane surface of the lens is now silvered. (b) At what distance from the lens will parallel rays incident on the convex face converge ? (c) Sketch the ray diagram to locate the image, when a point object is placed on the axis 20 cm from the lens. (d) Calculate the image distance when the object is placed as in (c).

Sol. (a) As for a lens, by lens–maker's formula $\frac{1}{f} = (\mu - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$ Here $\mu = 1.5$; $R_1 = 12$ cm and $R_2 = \infty$

So $\frac{1}{f} = (1.5 - 1)\left[\frac{1}{12} - \frac{1}{\infty}\right]$ i.e. f = 24 cm i.e., the lens as convergent with focal length 24 cm.



(A) (B) (C)

(b) As light after passing through the lens will be incident on the mirror which will reflect it back through the lens again, so $P = P_L + P_M + P_L = 2P_L + P_M$ But $P_L = \frac{1}{f_L} = \frac{1}{0.24}$ and $P_M = -\frac{1}{\infty} = 0$ $\left[\text{as } f_M = \frac{R}{2} = \infty\right]$

So $P = 2 \times \frac{1}{0.24} + 0 = \frac{1}{0.12}$ D. The system is equivalent to a concave mirror of focal length F,

$P = -\frac{1}{F}$

i.e., $F = -\frac{1}{P} = -0.12$ m $= -12$ cm i.e., the rays will behave as a concave mirror of focal length 12 cm.

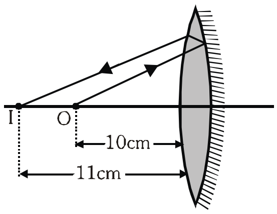
So as for parallel incident rays u = – ∞, from mirror formula $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ we have $\frac{1}{v} + \frac{1}{-\infty} = \frac{1}{-12}$

$\Rightarrow$ v = – 12 cm i.e., parallel incident rays will focus will at a distance of 12 cm in front of the lens as shown in Figure (c) and (d) When object is at 20 cm in front of the given silvered lens which behaves as a concave mirror of focal length 12 cm, from mirror formula $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ we have $\frac{1}{v} + \frac{1}{-20} = \frac{1}{-12}$

$\Rightarrow$ v= – 30 cm i.e., the silvered lens will form image at a distance of 30 cm in front of it as shown in fig. (C)

Ex. A pin is placed 10 cm in front of a convex lens of focal length 20 cm, made of material having refractive index 1.5. The surface of the lens farther away from the pin is silvered and has a radius of curvature 22 cm. Determine the position of the final image. Is the image real or virtual ?

Sol. As radius of curvature of silvered surface is 22 cm, so



$f_M = \frac{R}{2} = \frac{-22}{2} = -11$ cm $= -0.11$ m and hence,

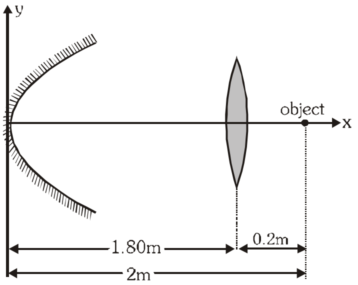
$P_M = -\frac{1}{f_M} = -\frac{1}{-0.11} = \frac{1}{0.11}$ D

Further as the focal length of lens is 20 cm, i.e., 0.20 m its power will be given by :

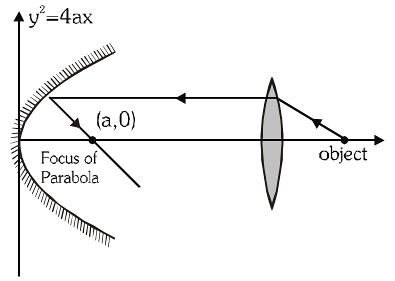
$P_L = \frac{1}{f_L} = \frac{1}{0.20}$ D. Now as in image formation, light after passing through the lens will be reflected back by the curved mirror through the lens again $P = P_L + P_M + P_L = 2P_L + P_M$ i.e. $P = \frac{2}{0.20} + \frac{1}{0.11} = \frac{210}{11}$ D.

So the focal length of equivalent mirror $F = -\frac{1}{P} = -\frac{11}{210}\text{m} = -\frac{110}{21}\text{cm}$ i.e., the silvered lens behave as a concave mirror of focal length (110/21) cm. So for object at a distance 10 cm in front of it, $\frac{1}{v} + \frac{1}{-10} = -\frac{21}{110}$ i.e., $v = -11$cm i.e., image will be 11 cm in front of the silvered lens and will be real as shown in Figure.

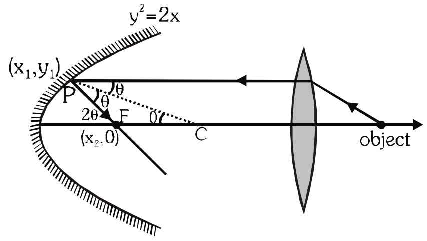
Ex. A point object is kept at a distance of 2m from a parabolic reflecting surface $y^2 = 2x$. An equiconvex lens is kept at a distance of 1.80 m from the parabolic surface. The focal length of the lens is 20 cm. Find the position from origin of the image in cm, after reflection from the surface.



Sol.



OR



Comparing with $y^2 = 4ax \Rightarrow a = 0.5$

$\Rightarrow$ final position of image = 0.5 m = 50 cm

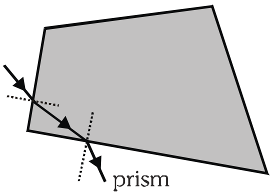
PC is a normal so $\tan(\pi - \theta) = \frac{-1}{(dy/dx)_{x_1,y_1}} = -y_1$

But $\tan 2\theta = \frac{y_1 - 0}{x_2 - x_1}$ & $\tan 2\theta = \frac{2\tan\theta}{1 - \tan^2\theta}$

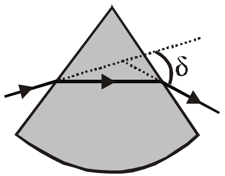
$\Rightarrow \frac{y_1}{x_2 - x_1} = \frac{2(y_1)}{1 - y_1^2}\, x_2 = \frac{1}{2}\text{m}$

PRISM

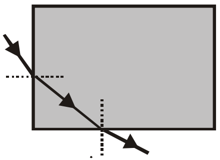
A prism is a homogeneous, transparent medium (such as glass) enclosed by two plane surfaces inclined at an angle. These surfaces are called the 'refracting surfaces' and the angle between them is called the 'refracting angle' or the 'angle of prism'. The section cut by a plane perpendicular to the refracting surfaces is called the 'principal section' of the prism.



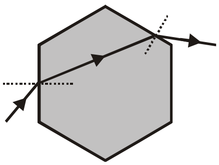
prism



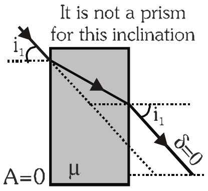
prism

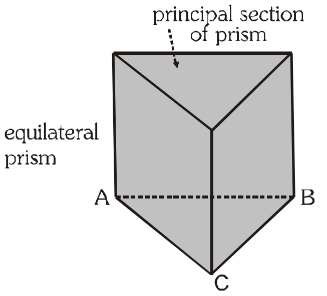


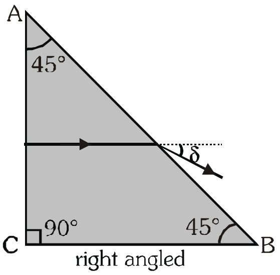
prism



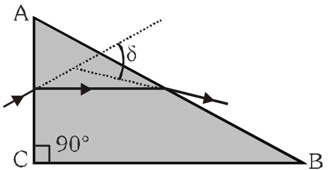
prism







right angled
isosceles prism



right angled prism

DEVIATION

PQ = incident ray

QR = Refracted ray

RS = emergent ray

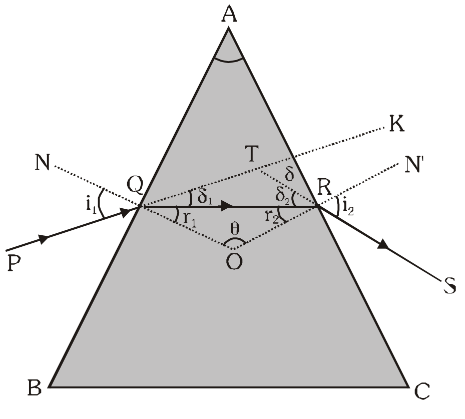
A = Prism angle

i_1 = incident angle on face AB

i_2 = emergent angle on face AC

r_1 = refracted angle on face AB

r_2 = incident angle on face AC



Angle of deviation on face AB. $\delta_1 = i_1 - r_1$

Angle of deviation on face AC $\delta_2 = i_2 - r_2$

Total angle of deviation

$\delta = \delta_1 + \delta_2 \Rightarrow \delta = (i_1 - r_1) + (i_2 - r_2) = i_1 + i_2 - (r_1 + r_2)$ .....(i)

In ΔQOR $r_1 + r_2 + \theta = 180°$ ...(ii)

In AQOR $A + \theta = 180°$ ...(iii)

from (ii) and (iii) $r_1 + r_2 = A$ ...(iv)

from (i) and (iv) Total angle of deviation $\delta = i_1 + i_2 - A$

from Snell's law at surface AB $\mu_1 \sin i_1 = \mu_2 \sin r_1$

and at surface AC $\mu_2 \sin r_2 = \mu_1 \sin i_2$

CONDITION OF MINIMUM DEVIATION

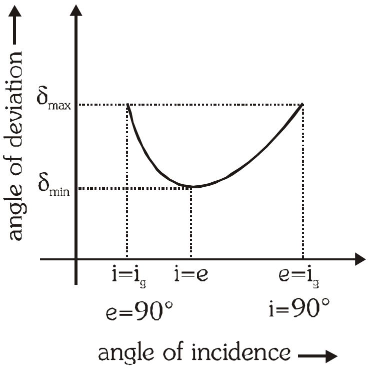
For minimum deviation

In this condition $i_1 = i_2 = i \Rightarrow r_1 = r_2 = r$ and since $r_1 + r_2 = A \therefore r + r = A \Rightarrow 2r = A \Rightarrow r = \frac{A}{2}$

Minimum deviation $\delta_{min} = 2i - A;\ i = \frac{A+\delta_{min}}{2},\ r = \frac{A}{2}$

if prism is placed in air $\mu_1 = 1;\ 1 \times \sin i = \mu \sin r$

$$\sin\left[\frac{A+\delta_{min}}{2}\right] = \mu \sin\frac{A}{2} \Rightarrow \mu = \frac{\sin\left[\frac{A+\delta_{min}}{2}\right]}{\sin\frac{A}{2}}$$



if angle of prism is small $A < 10°$ then $\sin\theta \approx \theta$

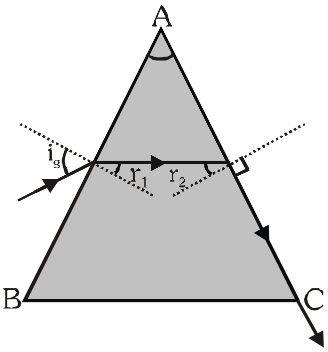
$$\mu = \frac{\frac{A+\delta_{min}}{2}}{\frac{A}{2}} = \frac{A+\delta_{min}}{A} \Rightarrow A + \delta_{min} = \mu A \Rightarrow \delta_{min} = (\mu-1)A$$

CONDITION FOR MAXIMUM DEVIATION/GRAZING EMERGENCE

- **Angle of incidence (i_g)for grazing emergence**

For i_g, $e = 90°$

Applying Snell's law at face AC



$\mu \sin r_2 = 1 \times 1 \Rightarrow \sin r_2 = \frac{1}{\mu};\ r_2 = \sin^{-1}\left(\frac{1}{\mu}\right) = \theta_c$

$r_1 + r_2 = A \Rightarrow r_1 = A - \theta_c$

Again, Applying Snell's law at face AB

$1 \times \sin i_g = \mu \sin r_1;\ 1 \times \sin i_g = \mu\sin(A - \theta_c)$

$\sin i_g = \mu[\sin A\cos\theta_c - \cos A\sin\theta_c]$

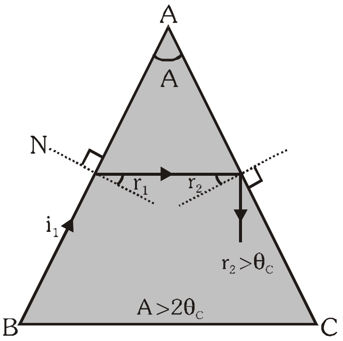
$$i_g = \sin^{-1}\left[\sqrt{\mu^2-1}\sin A - \cos A\right] \qquad \left[\left(\text{as } \sin\theta_c = \frac{1}{\mu},\ \cos\theta_c = \frac{\sqrt{\mu^2-1}}{\mu}\right)\right]$$

If i increases beyond i_g, r_1 increases thus r_2 decreases and becomes less than θ_c and ray emerges.

Thus $\quad i \geq i_g \Rightarrow$ ray emerges, otherwise TIR. $\delta_{max} = i_g + 90° - A$

NO EMERGENCE CONDITION

Let maximum incident angle on the face AB $i_{max} = 90°$



$1 \times \sin 90° = \mu \sin r_1;\ \sin r_1 = \frac{1}{\mu} = \sin\theta_C;\ r_1 = \theta_C$ ...(i)

if TIR occur at face AC then $\quad r_2 > \theta_C$ ...(ii)

$r_1 + r_2 = A$ ...(iii)

from (i) and (ii) $r_1 + r_2 > \theta_C + \theta_C \Rightarrow r_1 + r_2 > 2\theta_C$ ...(iv)

from (iii) and (iv) $A > 2\theta_C \Rightarrow \frac{A}{2} > \theta_C \Rightarrow \sin\frac{A}{2} > \sin\theta_C \Rightarrow \sin\frac{A}{2} > \frac{1}{\mu} \Rightarrow \frac{1}{\sin\frac{A}{2}} < \mu$

Ex. A ray of light passes through an equilateral prism such that angle of incidence is equal of emergence and the later is equal to 3/4th of the angle of prism. Calculate the angle of deviation. Refractive index of prism is 1.5.

Sol. $A = 60°, \mu = 1.5$; $\quad i_1 = i_2 = \frac{3}{4}A = 45°, \quad \delta = ?$

$\because A + \delta = i_1 + i_2 \quad \therefore 60° + \delta = 45° + 45° \Rightarrow \delta = 90° - 60° = 30°$

Ex. A prism of refractive index 1.53 is placed in water of refractive index 1.33. If the angle of prism is 60°, calculate the angle of minimum deviation in water. (sin 35.1° = 0.575)

Sol. Here, ${}^a\mu_g = 1.33$, ${}^a\mu_w = 1.53$, $A = 60°$, $\delta_m = ?$ ${}^w\mu_g = \frac{{}^a\mu_g}{{}^a\mu_w} = \frac{1.53}{1.33} = 1.15 \because {}^w\mu_g = \frac{\sin\frac{A+\delta_m}{2}}{\sin\frac{A}{2}}$

$$\therefore \frac{\sin(A+\delta_m)}{2} = {}^w\mu_g \times \sin\frac{A}{2} = 1.15\sin\frac{60°}{2} = 0.575 \Rightarrow \frac{A+\delta_m}{2} = \sin^{-1}(0.575) = 35.1°$$

$\therefore \delta_m = 35.1 \times 2 - 60 = 10.2°$

KEY POINTS

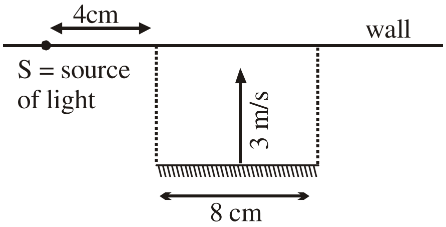
- Angle of prism or refracting angle of prism means the angle between the faces on which light is incident and from which it emerges.
- If the faces of a prism on which light is incident and from which it emerges are parallel then the angle of prism will be zero and as incident ray will emerge parallel to itself, deviation will also be zero, i.e., the prism will act as a transparent plate.
- If μ of the material of the prism is equal to that of surroundings, no refraction at its faces will take place and light will pass through it undeviated, i.e., δ = 0.

EXERCISE (S)

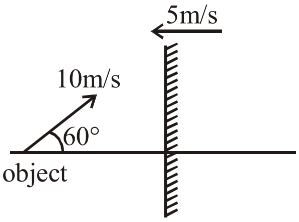
Plane mirror :

1. A fluorescent lamp of length 1 m is placed horizontally at a depth of 1.2 m below a ceiling. A plane mirror of length 0.6 m is placed below the lamp parallel to and symmetric to the lamp at a distance 2.4m from it. The length of the reflected patch of length on the ceiling ______ . **GO0001**

2. A plane mirror of length 8 cm is moving with speed 3 m/s towards a wall in situation as shown in figure. Size of spot formed on the wall is 32/x cm. Find the value of x. **GO0002**

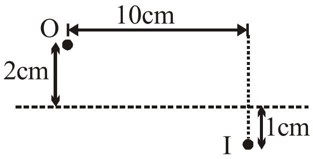


3. The angle between the velocity vector of object and image is $\frac{\pi}{\alpha}$. Velocity are shown in the figure. Then the value of α is. **GO0003**



Spherical mirror :

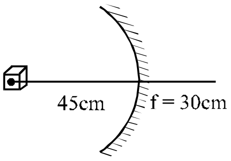
4. The principal axis of a spherical mirror is shown by dotted line. O is the point object whose real image is I. Find the distance of the pole and centre of curvature of the mirror from object measured along principal axis by drawing ray diagram. **GO0004**



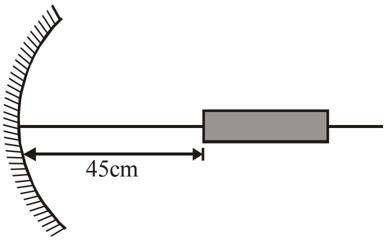
5. An experimentalist devises a method for finding the radius of curvature of a convex mirror. He uses a plane mirror strip between the object and the convex mirror and adjusts it till the two virtual images formed by reflection at both the mirrors coincide without parallax. In his observations, the object distance from the convex mirror is 0.5 m while it is 0.30 m in front of the plane mirror. Find the radius of curvature (in cm) of the convex mirror. **GO0005**

6. A thin rod of length d/3 is placed along the principal axis of a concave mirror of focal length = d such that its image, which is real and elongated, just touches the rod. Find the length of the image? **GO0006**

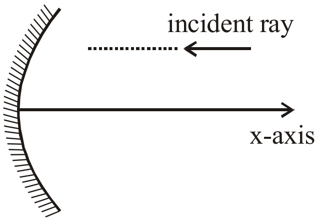
7. A cube of side length 1mm is placed on the axis of a concave mirror at a distance of 45 cm from the pole as shown in the figure. One edge of the cube is parallel to the axis. The focal length of the mirror is 30 cm. Find approximate volume of the image. **GO0007**



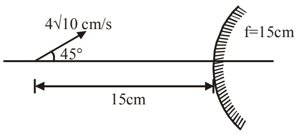
8. An object of length 30 cm is placed on principal axis of a concave mirror of focal length 30 cm. Its one end at a distance of 45 cm as shown. If length of image is 10x (in cm) find the value of x. **GO0008**



9. A parabolic reflecting surface given by $x = \frac{y^2}{2}$, is placed at oirign, as shown. An incidnet ray moving along y = 1 is incident on it. The ray gets reflected by the surface twice. The deviation suffered by the ray is $\frac{\pi}{n}$ radians. Find n. **GO0010**

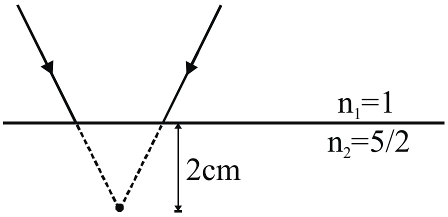


10. In the figure shown , the speed cm/s of image with respect to mirror is : **GO0011**



Refraction on plane surface :

11. In the given figure rays incident on an interface would converge 2 cm below the interface if they continued to move in straight lines without bending. But due to refraction, the rays will bend and meet somewhere else. Find the distance of meeting point of refracted rays below the interface (in cm). (Assuming the rays to be making small angles with the normal to the interface) **GO0012**



12. A point object is placed 33 cm from a convex mirror of curvature radius = 40 cm. A glass plate of thickness 6 cm and index 2.0 is placed between the object and mirror, close to the mirror. Find the distance of final image from the object? **GO0013**

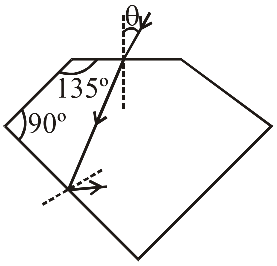
13. An opaque cylindrical tank with an open top has a diameter of 3.00 m and is completely filled with water. When the setting sun reaches an angle of 37° above the horizon, sunlight ceases to illuminate any part of the bottom of the tank. How deep is tank in meter? **GO0014**

14. A cylindrical bucket of depth 60 cm is partly filled with a liquid of refractive index 1.5 and with oil (on top of liquid) of refractive index 2. It appears that the volume of air, volume of liquid and volume of oil are equal, to an observer who views from top of the bucket. The apparent depth of the bucket as seen by the observer is given as α cm. Fill $\left(\frac{\alpha}{5}\right)$ in OMR sheet. **GO0015**

Total internal reflection :

15. A room contains air in which the speed of sound is 340 m/s. The walls of the room are made of concrete, in which the speed of sound is 1700 m/s. (a) Find the critical angle for total internal reflection of sound at the concrete–air boundary. (b) In which medium must the sound be traveling to undergo total internal reflection? (Assume sound waves follow snell's law) **GO0016**

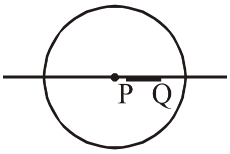
16. A ray of light enters a diamond (n = 2) from air and is being internally reflected near the bottom as shown in the figure. Find maximum value of angle θ possible ? **GO0017**



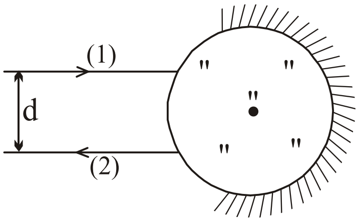
Refraction at curved surface :

17. A small object of length 1 mm lies along the principal axis of a spherical glass of radius R = 10 cm and refractive index is 3/2. The object is seen from air along the principal axis from left. The distance of object from the centre is 5 cm. Find the size of the image. Is real, inverted ?

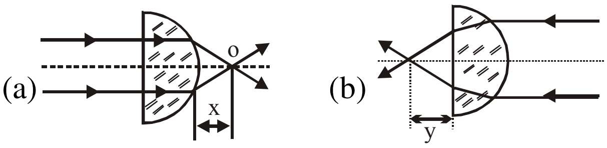
GO0019



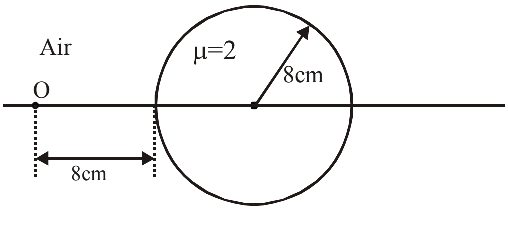
18. A transparent sphere of radius R = 2.0 m has a mirrored surface on its right half as shown in figure. A light ray travelling in air is incident on the left side of the sphere. The incident light ray(1) & exiting light ray (2) are parallel & separated by distance d = 2.0 m. Then find the refractive index of the material. (take : sin15°= 0.25) **GO0020**



19. A narrow beam of light passing through the hemisphere of material with refractive index n, intersects at point O. Where does the beam converge (i.e. y in cm) if beam were to travel in the opposite direction as shown in figure (b)? The value of x is given to be 10 cm. Radius of the hemisphere is also 10 cm :- **GO0021**



20. On the axis of a transparent sphere of refractive index (n=2) & radius 8 cm, an object is kept at the distance 8 cm from the surface of the sphere. Find the minimum distance of the image after all possible refraction from the surface of the sphere in cm. **GO0022**

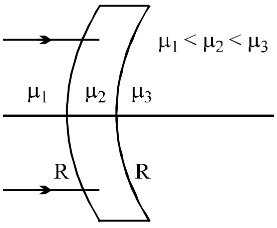


Lens :

21. A meniscus lens is made of a material of refractive index μ_2. Both its surfaces have radii of curvature R. It has two different media of refractive indices μ_1 and μ_3 respectively, on its two sides (see figure). Calculate its focal length for $\mu_1 < \mu_2 < \mu_3$, when light is incident on it as shown.

[IIT-JEE 2003]

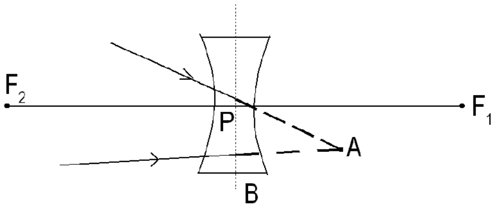
GO0023



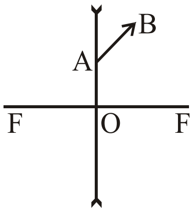
22. A converging beam of rays is incident on a diverging lens. Having passed through the lens the rays intersect at a point 15 cm from the lens. If the lens is removed, the point where the rays meet will move 5cm closer to the mounting that holds. Find the focal length (in cm) of the lens without sign.

GO0024

23. The rays of a converging beam meet at a point A. A diverging lens is placed in their path in the plane B. Plot the position of the point where the rays meet after passing through the lens. The position of the principal foci FF is known. **GO0025**



24. Figure shows ray AB that has passed through a divergent lens. Construct the path of the ray up to the lens if the position of its foci F is known.



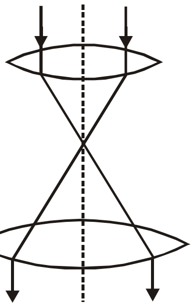
GO0026

25. A plano convex lens (μ = 1.5) has a maximum thickness of 1 mm. If diameter of its aperture is 4 cm. Find (i) Radius of curvature of curved surface; (ii) its focal length in air. **GO0027**

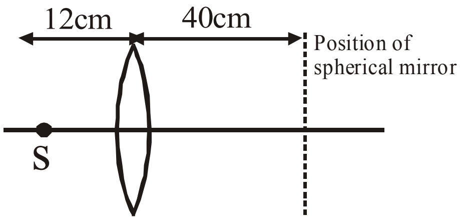
26. A point source of light is kept at a distance of 150 cm from a converging lens, on its optical axis. The focal length of the lens is 100 cm and its diameter is 3 cm. A screen is placed on the other side of the lens, perpendicular to the axis of lens, at a distance 200 cm from it. Then find the area of the illuminated part of the screen? (Assume all rays incident on lens as paraxial) **GO0028**

27. There are two thin symmetrical lenses, one is converging, with refractive index $n_1 = 1.70$, and the other is diverging with refractive index $n_2 = 1.50$. Both lenses have the same curvature radius of their surface equal to R = 10 cm. The lenses are put close together and submerged into water. The focal length of lens system is found to be $\frac{100}{x}$cm in water. What is the value of x. (R.I. of water = 4/3) **GO0029**

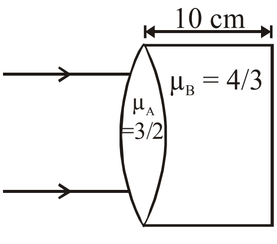
28. Consider a 'beam expander' which consists of two converging lenses of focal lengths 40 cm and 100cm having a common optical axis. A laser beam of diameter 2 mm is incident on the 40 cm focal length lens. Then what is the diameter (in mm) of the final beam (see figure)?
GO0030



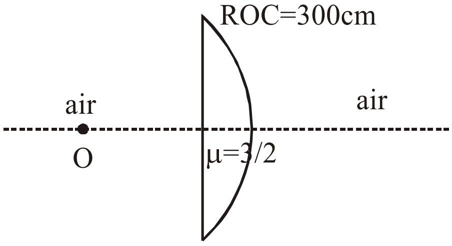
29. A converging lens and a spherical mirror are placed with their principal axis coinciding. Their separation equals 40 cm. A point source S is placed on the principal axis at a distance of 12 cm from the lens as shown in the figure. It is found that the final beam comes out parallel to the principal axis. Focal length of the lens equals 15 cm. Find the focal length of the mirror.
GO0031



30. A parallel paraxial beam of light is incident on the arrangement as shown $\mu_A = 3/2$, $\mu_B = 4/3$, the two spherical surfaces are very close and each has radius of curvature 10 cm. Find the point where the rays are focussed. (w.r.t. point of entry) **GO0032**

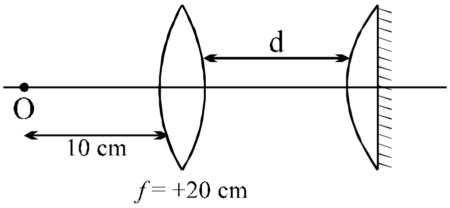


31. Plane surface of a thin planoconvex lens reflects 50% of light, while the curved surface is completely transparent, if final image of 'O' after refraction through thin lens coincides with the image formed due to partial reflection from plane surface. If distance between O and lens is x (in m) then find the value of x/4. **GO0033**

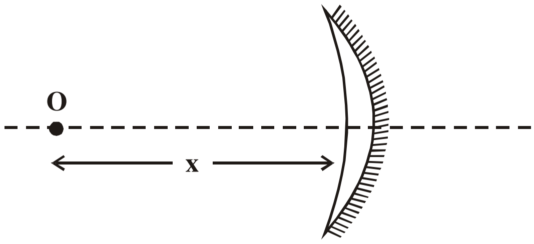


32. A lens is placed at origin, with x-axis as its principal axis. A ray of light is incident on it from the –ve side of x-axis along the line $y = \frac{x}{400} + 0.1$, where x, y are in cm. Focal length of lens is 30 cm. Find the equation of the ray after passing through the lens. **GO0034**

33. A convex lens of focal length 20 cm and another plano convex lens of focal length 40 cm are placed co-axially (see fig.). The plano convex lens is silvered on plane surface. What should be the 5d (in m) so that final image of the object 'O' is formed on O itself. **GO0035**



34. Radii of curvature of a concavo-convex lens (refractive index = 1.5) are 40 cm and 20 cm as shown. The convex side is silvered. The distance x (in cm) on the principal axis where an object is placed so that its image is created on the object itself, is given as 4β. Find the value of β.
GO0036

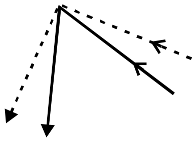


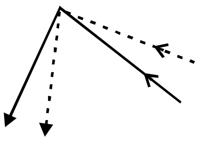
EXERCISE (O)

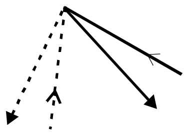
SINGLE CORRECT TYPE QUESTIONS

Plane mirror :

1. Each of these diagrams is supposed to show two different rays being reflected from the same point on the same mirror. Which option is correct :-

(I)


(II)


(III)


(A) Only I (B) Only II (C) Only III (D) All **GO0055**

2. If two mirrors are kept at 60° to each other, then the number of images formed by them is :- **[AIEEE- 2002]**

(A) 5 (B) 6 (C) 7 (D) 8 **GO0056**

3. A point object approaches a plane mirror with a speed of 10 ms^{-1}, while the image recedes away from the mirror with a speed of 6 ms^{-1} (as seen by stationary observer). The direction and magnitude of the velocity of mirror is :-

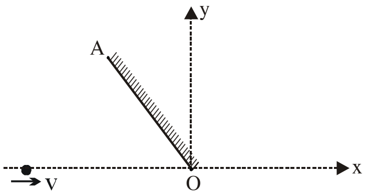
(A) towards the object, 8 ms^{-1} (B) towards the image, 6 ms^{-1}

(C) away from the object, 8 ms^{-1} (D) away from the object, 2 ms^{-1} **GO0058**

4. A boy of TOA3 batch is 1.8m tall and can see his image in a plane mirror fixed on a wall. His eyes are 1.6m from the floor level. The minimum length of the mirror to see his full image is :-

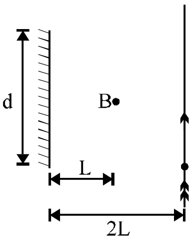
(A) 0.9 m (B) 0.85 m (C) 0.8 m (D) Can't be determined **GO0059**

5. A plane mirror OA of length 2 m is kept along the line y = –x as shown in the figure. An insect having velocity of $4\hat{i}$ cm/s is moving along the x-axis from far away. The time span for which the insect can see its image will be :-



(A) 50 sec (B) 25 sec (C) $25\sqrt{2}$ sec (D) $50\sqrt{2}$ sec **GO0060**

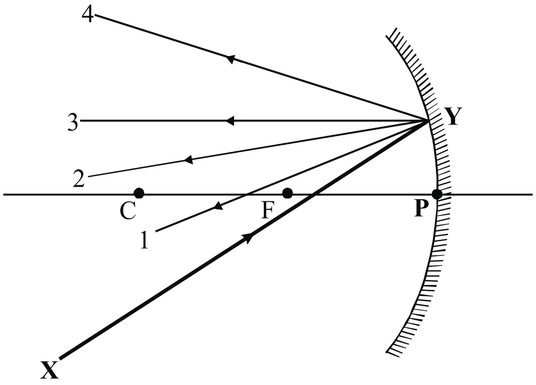
6. A point source of light *B* is placed at a distance *L* in front of the centre of a mirror of width *d* hung vertically on a wall. A man walks in front of the mirror along a line parallel to the mirror at a distance 2*L* from it as shown. The greatest distance over which he can see the image of the light source in the mirror is :- **[IIT-JEE '2000 (Scr)]**



(A) d/2 (B) d (C) 2d (D) 3d **GO0061**

Spherical mirror :

7. Figure shows a small concave mirror with *CP* as its principal axis. A ray *XY* is incident on the mirror. Which of the four rays can be the reflected ray.



(A) 1 (B) 2 (C) 3 (D) 4 **GO0062**

8. The distance of an object from a spherical mirror is equal to the focal length of the mirror. Then the image:

(A) must be at infinity (B) may be at infinity

(C) may be at the focus (D) none **GO0063**

9. An object is placed in front of a spherical mirror whose 2 times magnified image is formed on screen. Then choose **CORRECT** option :-

(A) Mirror is concave m = +2 (B) Mirror is concave m = –2

(C) Mirror is convex m = +2 (D) Mirror is convex m = –2 **GO0064**

10. The table below lists object and image positions for four objects placed in front of mirrors, using Cartesian sign convention with pole of the mirror as origin and direction of incident rays as positive. In the following cases, the case in which images is formed by a convex spherical mirror, is :-

	Object position	**Image position**
(A)	– 25.0 cm	– 16.7 cm
(B)	– 5.0 cm	10.0 cm
(C)	– 20.0 cm	5.71 cm
(D)	– 40.0 cm	80.0 cm

GO0065

11. A particle approaches from very large distance towards concave mirror along the principal axis. By the time the particle reaches the mirror the distance between the particle and its image

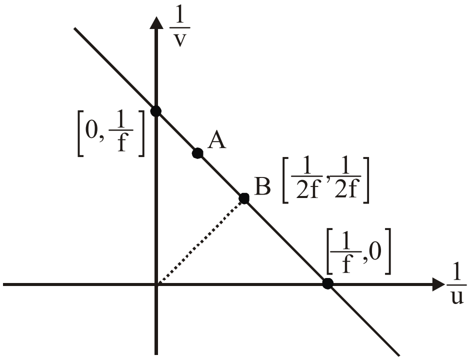
(A) first decreases then increases

(B) first increases then decreases

(C) first increases then decreases and then again increases

(D) first decreases then increases and then again decreases **GO0066**

12. Figure shows $\frac{1}{v}$ vs $\frac{1}{u}$ curve for convex mirror. Nature of image at point A is :-



(A) Real, erect, magnified

(B) virtual, inverted, magnified

(C) virtual, inverted, diminished

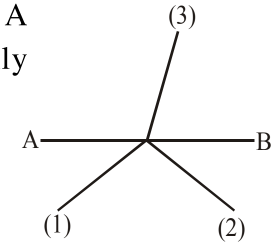
(D) virtual, erect, diminished **GO0067**

13. A boy of height 1 m stands in front of a convex mirror. His distance from the mirror is equal to its focal length. The height of his image is :- (Assume paraxial ray approximation holds)

(A) 0.25 m (B) 0.33 m (C) 0.5 m (D) 0.67 m **GO0068**

Refraction at plane surface :

14. AB is a boundary separating two media of different refractive indices. A ray is incident on the boundary is partially reflected and partially transmitted. Choose the **CORRECT** statement.



(A) 3 is incident ray and 1 is refracted ray

(B) 2 is incident ray and 1 is partially reflected ray

(C) 1 is incident ray and 3 is refracted ray

(D) 3 is incident ray and 2 is partially reflected ray **GO0069**

15. **Statement-1:** You see a geostationary satellite above the horizon. You desire to communicate with the satellite by sending a beam of laser light. You should aim your laser slightly higher than the line of sight of the satellite.

Statement-2: Light bends away from the normal while moving from denser to rarer medium.

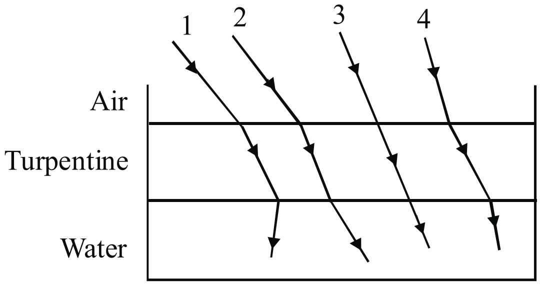
(A) Statement-1 is true, statement-2 is true and statement-2 is correct explanation for statement-1.

(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the correct explanation for statement-1.

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true. **GO0070**

16. The optical density of turpentine is higher than that of water while its mass density is lower. Figure shows a layer of turpentine floating over water in a container. For which one of the four rays incident on turpentine in figure, the path shown is **CORRECT** ?



(A) 1 (B) 2 (C) 3 (D) 4 **GO0071**

17. When a ray of light of frequency 6×10^{14} Hz travels from water of refractive index 4/3 to the glass of refractive index 8/5, its :-

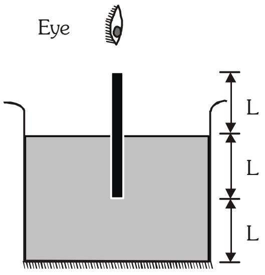
(A) frequency decreases to 5/6 of its initial value

(B) speed decreases to 5/6 of its initial value

(C) wavelength decreases to 6/5 of its initial value

(D) speed increases to 6/5 of its initial value **GO0072**

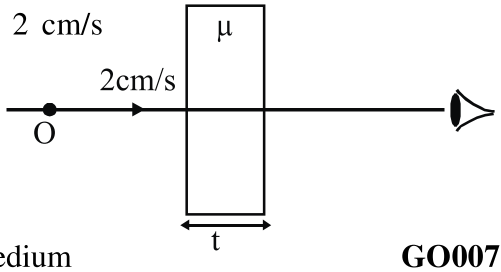
18. What is the length of the image of the rod in mirror, according to the observer in air? (refractive index of the liquid is μ)



(A) $\mu L + L$ (B) $L + \frac{L}{\mu}$ (C) $L\mu + \frac{L}{\mu}$ (D) None of these

GO0074

19. A glass slab of width '*t*', refractive index 'μ' is placed as shown in the figure. If the point object, moves with a speed 2 cm/s towards the slab the speed observered will be



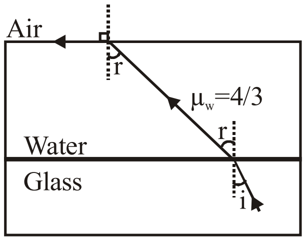
(A) 2 cm/s

(B) less than 2 cm/s

(C) greater than 2 cm/s

(D) dependent on the refractive index of surrounding medium **GO0075**

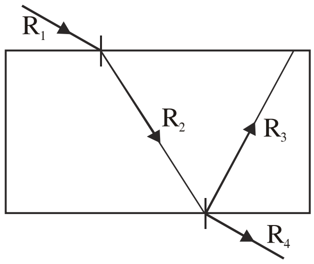
20. A ray of light is incident at the glass–water interface at an angle i, it emerges finally parallel to the surface of water, then the value of μ_g would be :– **[IIT-JEE 2003]**



(A) (4/3) sin i (B) 1/sin i (C) 4/3 (D) 1 **GO0076**

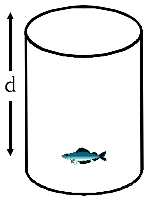
Total internal reflection :

21. A ray R_1 is incident on the plane surface of the glass slab (kept in air) of refractive index √2 at an angle of incidence equal to the critical angle for this air glass system. The refracted ray R_2 undergoes partial reflection and refraction at the other surface. The angle between reflected ray R_3 and the refracted ray R_4 at that surface is :



(A) 45° (B) 135° (C) 105° (D) 75° **GO0078**

22. A fish floats in liquid with its eye at the centre of an opaque walled full tank of liquid of circular cross section. When the fish look upwards, it can see a fish-eye view of the surrounding scene i.e. it is able to view the entire space above the liquid surface. The diameter of the tank is 30 cm, and the critical angle for liquid is 37°. At what maximum depth below the surface of the liquid, d, must the fish be floating? $\left(\sin 37° = \frac{3}{5}\right)$



(A) 16 cm (B) 20 cm (C) 11.25 cm (D) 25 cm **GO0079**

23. **Statement-1**: When light falls on a sphere made of diamond total internal reflection takes place which makes it shine more than a similar sphere made of common glass.

Statement-2: Refractive index for diamond is more than refractive index of cheap glass.

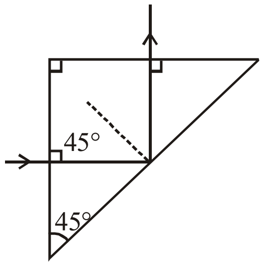
(A) Statement-1 is true, statement-2 is true and statement-2 is correct explanation for statement-1.

(B) Statement-1 is true, statement-2 is true and statement-2 is NOT the correct explanation for statement-1.

(C) Statement-1 is true, statement-2 is false.

(D) Statement-1 is false, statement-2 is true. **GO0080**

24. A light ray is incident perpendicular to one face of a 90° prism and is totally internally reflected at the glass-air interface. If the angle of reflection is 45°, we conclude that the refractive index n : **[AIEEE-2004]**



(A) $n < \frac{1}{\sqrt{2}}$ (B) $n > \sqrt{2}$ (C) $n > \frac{1}{\sqrt{2}}$ (D) $n < \sqrt{2}$ **GO0081**

Prism :

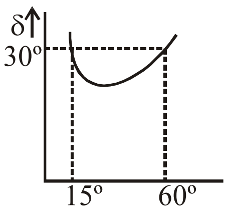
25. A ray of light is incident at 60° on a prism of refracting angle 30°. The emerging ray is at an angle 30° with the incident ray. The value of refractive index of the prism is :-

(A) $\frac{\sqrt{3}}{4}$ (B) $\frac{\sqrt{3}}{2}$ (C) $\sqrt{3}$ (D) $\frac{2}{\sqrt{3}}$ **GO0082**

26. The refracting angle of the prism is 60° and minimum deviation of 30°, then the angle of incidence is:-

(A) 30° (B) 45° (C) 25° (D) 60° **GO0083**

27. Figure shows graph of deviation δ versus angle of incidence for a light ray striking a prism. Angle of prism is :-



(A) 30° (B) 45° (C) 60° (D) 75° **GO0084**

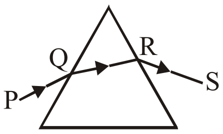
28. There is a prism with refractive index equal to $\sqrt{2}$ and the refracting angle equal to 30°. One of the refracting surface of the prism is polished. A beam of monochromatic light will retrace its path if its angle of incidence over the first refracting surface of the prism is :-

(A) 0° (B) 30° (C) 45° (D) 60° **GO0085**

29. The refractive index for the material of a 60° prism is 1.50. Then the angle of incidence for minimum deviation is nearly. ($\sin 42° \approx \frac{2}{3}$ and $\sin 49° \approx \frac{3}{4}$)

(A) 30° (B) 49° (C) 38° (D) 28° **GO0086**

30. A ray of light is incident on an equilateral glass prism placed on a horizontal table. For minimum deviation which of the following is true ?



(A) PQ is horizontal

(B) QR is horizontal

(C) RS is horizontal

(D) Either PQ or RS is horizontal **GO0087**

31. An isosceles glass prism having refractive index μ has one of its faces coated with silver. A ray of light is incident normally on the other face (which is equal to the silvered face). The ray of light is reflected twice on the same sized faces and then emerges through the base of the prism perpendicularly. The angles of prism are :-

(A) 40°, 70°, 70° (B) 50°, 65°, 65° (C) 36°, 72°, 72° (D) data insufficient

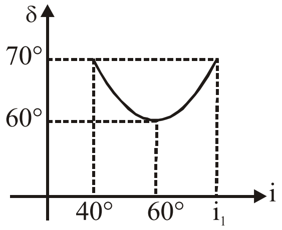
GO0088

32. A given ray of light suffers minimum deviation in an equilateral prism P. If refractive index increases slightly then the ray will now suffer :-

(A) greater deviation (B) no deviation

(C) same deviation as before (D) Lesser deviation **GO0089**

33. The curve of angle of incidence versus angle of deviation shown has been plotted for prism. The value of refractive index of the prism used is :



(A) $\sqrt{3}$ (B) $\sqrt{2}$ (C) $\frac{\sqrt{3}}{\sqrt{2}}$ (D) $\frac{2}{\sqrt{3}}$ **GO0090**

34. A beam of monochromatic light is incident at i = 50° on one face of an equilateral prism, the angle of emergence is 40°, then the angle of minimum deviation is :

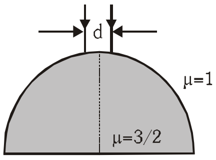
(A) 30° (B) < 30° (C) ≤ 30° (D) ≥ 30° **GO0091**

35. The angle of a prism is 6° and its refractive index for green light is 1.5. If a green ray passes through it, the deviation will be :-

(A) 30° (B) 15° (C) 9° (D) 3° **GO0092**

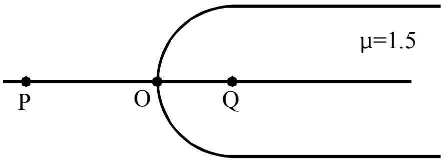
Refraction at curved surface :

36. A beam of diameter 'd' is incident on a glass hemisphere as shown. If the radius of curvature of the hemisphere is very large in comparison to d, then the diameter of the beam at the base of the hemisphere will be :-



(A) $\frac{3}{4}$d (B) d (C) $\frac{d}{3}$ (D) $\frac{2}{3}d$ **GO0093**

37. One end of a glass rod of refractive index n = 1.5 is a spherical surface of radius of curvature R. The centre of the spherical surface lies inside the glass. A point object placed in air on the axis of the rod at the point P has its real image inside glass at the point Q (see fig.). A line joining the points P and Q cuts the surface at O such that OP = 2OQ. The distance PO is :-



(A) 8 R (B) 7 R (C) 2 R (D) None of these

GO0094

38. An air bubble is inside water. The refractive index of water is 4/3. At what distance from the air bubble should a point object be placed so as to form a real image at the same distance from the bubble:

(A) 2R (B) 3R

(C) 4R (D) The air bubble cannot form a real image

GO0095

39. A point object is placed at the centre of a glass sphere of radius 6 cm and refractive index 1.5. The distance of the virtual image from the surface of the sphere is :- **[IIT-JEE 2004 (Scr)]**

(A) 2 cm (B) 4 cm (C) 6 cm (D) 12 cm **GO0096**

Lens :

40. A concave lens of glass, refractive index 1.5, has both surfaces of same radius of curvature R. On immersion in a medium of refractive index 1.75, it will behave as a :-

(A) convergent lens of focal length 3.5R (B) convergent lens of focal length 3.0 R.

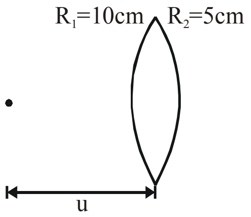
(C) divergent lens of focal length 3.5 R (D) divergent lens of focal length 3.0 R

GO0097

41. A convergent (biconvex) lens is placed inside a jar filled with a liquid. The lens has focal length 20cm, when in air and its material has a refractive index of 1.5. If the liquid has a refractive index of 1.6, the focal length of the lens while in the jar, is :-

(A) –110 cm (B) –130 cm (C) –160 cm (D) –180 cm **GO0098**

42. A thin convex lens is made of a material of refractive index 1.6. An object is kept at a distance of u from the lens on the principal axis as shown in the figure. The radius of curvature of the surfaces are 10 cm and 5cm. Now, the lens is reversed such that the face having radius of curvature 5cm lies close to the object. The difference in image position as obtained for both the cases is equal to :-



(A) 0.4 u (B) 0.6 u (C) 0.8 u (D) 0 **GO0099**

43. A point object is placed on the principal axis of a converging lens and its image (I_1) is formed on its principal axis. If the lens is rotated by an small angle θ about its optical centre such that its principal axis also rotates by the same amount then the image (I_2) of the same object is formed at point P. Choose the correct option.

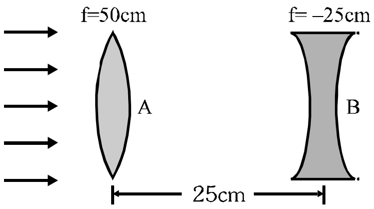
(A) Point P lies on the new principal axis.

(B) Point P lies on the old principal axis.

(C) Point P is anywhere between the two principal axes

(D) None of these **GO0101**

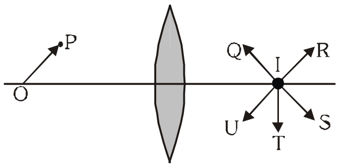
44. The two lenses shown are illuminated by a beam of parallel light from the left. Lens B is then moved slowly toward lens A. The beam emerging from lens B is :



(A) Initially parallel and then diverging (B) Always diverging

(C) Initially converging and finally parallel (D) Always parallel **GO0102**

45. A point object O moves from the principal axis of a converging lens in a direction OP. I the image of O, will move initially in the direction :

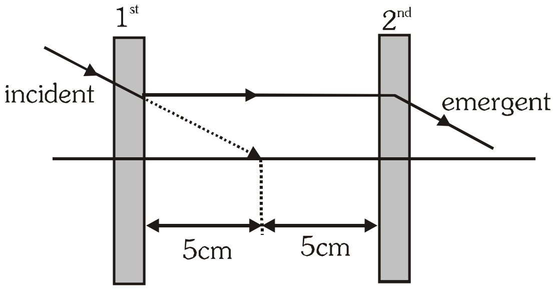


(A) IQ (B) IR (C) IS (D) IU **GO0103**

46. When the object is at distances u_1 and u_2 the images formed by the same lens are real and virtual respectively and of the same size. Then focal length of the lens is :

(A) $\frac{1}{2}\sqrt{u_1u_2}$ (B) $\frac{u_1+u_2}{2}$ (C) $\sqrt{u_1u_2}$ (D) $\sqrt{(u_1+u_2)}$ **GO0104**

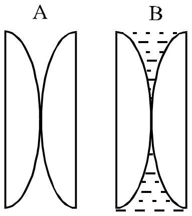
47. Look at the ray diagram shown, what will be the focal length of the 1st and the 2nd lens, if the incident light ray passes without any deviation ?



(A) –5 cm and +10 cm (B) +5cm and +10cm

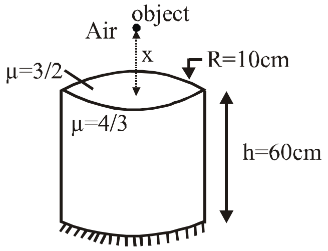
(C) –5cm and +5cm (D) +5cm and – 5cm **GO0105**

48. Figure A shows two identical plano-convex lenses in contact as shown. The combination has focal length 24 cm. Figure B shows the same with a liquid introduced between them. If refractive index of glass of the lenses is 1.50 and that of the liquid is 1.60, the focal length of the system in figure B will be :-



(A) –120 cm (B) 120 cm (C) –24 cm (D) 24 cm **GO0106**

49. In the arrangement shown given that a biconvex lens of radius of curvature equal to 10 cm and concave mirror has focal length equal to 20cm. Then find the distance 'x' such that the final image formed by the system coincides with the object.



(A) 15 cm (B) 22.5 cm (C) 20 cm (D) 17.5 cm **GO0107**

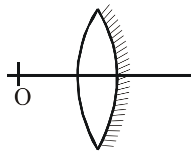
50. A convex lens of focal length 30 cm forms an image of height 2 cm for an object situated at infinity. If a convcave lens of focal length 20 cm is placed coaxially at a distance of 26 cm in front of convex lens then size image would be :- **[IIT-JEE 2003 (Scr)]**

(A) 2.5 cm (B) 5.0 (C) 1.25 (D) None **GO0108**

51. A plano-convex lens of refractive index 1.5 and radius of curvature 30 cm is silvered at the curved surface. Now, this lens has been used to form the image of an object. At what distance from this lens, an object be placed in order to have a real image of the size of the object? **[AIEEE-2004]**

(A) 20 cm (B) 30 cm (C) 60 cm (D) 80 cm **GO0109**

52. An equiconvex lens of refractive index μ and radius of curvature R has its one surface silvered. A point source O is placed before the silvered lens so that its image is coincident with it, the distance of the object from the lens is :-

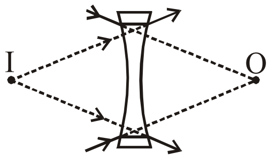


(A) $\frac{R}{(\mu-1)}$ (B) $\frac{2R}{(\mu-1)}$ (C) $\frac{R}{(2\mu-1)}$ (D) $\frac{2R}{(2\mu-1)}$ **GO0110**

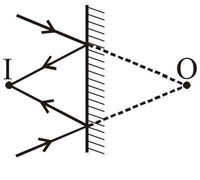
MULTIPLE CORRECT TYPE QUESTIONS

Spherical mirror :

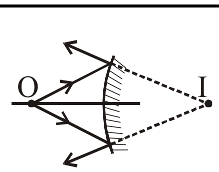
53. The nature of object and image given with each of the optical condition is shown. Choose the **correct** option(s) :-

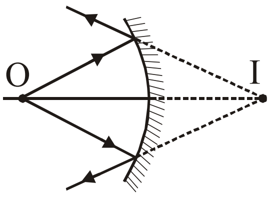
(A) Virtual image 

Virtual object

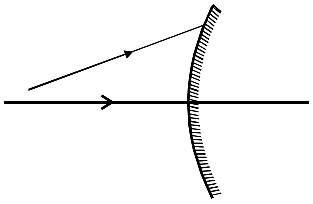
(B) Virtual image 

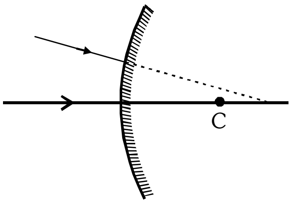
Real object

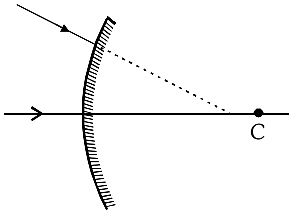
(C) Real object  Virtual image

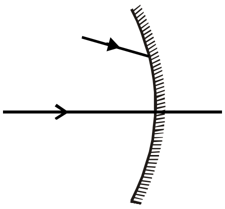
(D) Real object  Virtual image **GO0121**

54. In which of the following diagrams the image formed is virtual and inverted ?

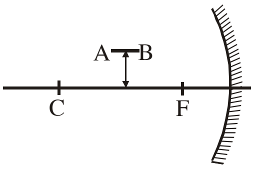
(A) 

(B) 

(C) 

(D)  **GO0122**

55. An object AB is placed parallel and close to the optical axis between focus F and centre of curvature C of a converging mirror of focal length f as shown in figure.

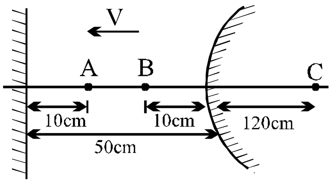


(A) Image of A will be closer than that of B from the mirror.
(B) Image of AB will be parallel to the optical axis.
(C) Length of image is equal to AB.
(D) Length of image is more than AB. **GO0123**

56. Mark the **CORRECT** statement :-
(A) Virtual image of virtual object can be formed by a single optical element
(B) Virtual image of virtual object formed by a single optical element can be inverted
(C) Virtual image of real object can be formed by a single optical element
(D) Virtual image of real object formed by a single optical element can be inverted **GO0124**

57. A concave mirror forms an image of the sun at a distance of 12 cm from it.
(A) the radius of curvature of this mirror is 6 cm.
(B) to use it as a shaving mirror, it can be held at a distance of 8-10 cm from the face
(C) if an object is kept at a distance of 24 cm from it, the image formed will be of the same size as the object
(D) all the above alternatives are correct. **GO0125**

58. In the figure shown consider the first reflection at the plane mirror and second at the convex mirror. AB is object.



(A) the second image is real , inverted of 1/5 th magnification w.r.t AB

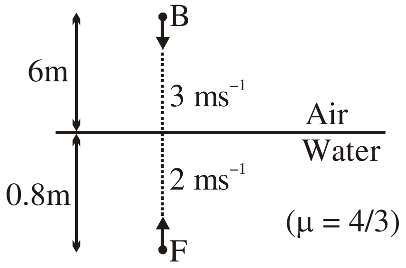
(B) the second image is virtual and erect with magnification1/5 w.r.t AB

(C) the second image moves towards the convex mirror

(D) the second image moves away from the convex mirror. **GO0126**

Refraction at plane surface :

59. A fish, F in the pond, is at a depth of 0.8 m from water surface and is moving vertically upwards with velocity 2 $\mathrm{ms^{-1}}$. At the same instant, a bird B is at a height of 6 m from water surface and is moving downwards with velocity 3 $\mathrm{ms^{-1}}$. At this instant both are on the same vertical lines as shown in the figure. Which of the following statement(s) is(are) correct?



(A) Height of B, observed by F (from itself) is equal to 8.00 m.

(B) Depth of F, observed by B (from itself) is equal to 6.60 m.

(C) Velocity of B, observed by F (relative to itself) is equal to 5.00 $\mathrm{ms^{-1}}$.

(D) Velocity of F, observed by B (relative to itself) if equal to 4.50 $\mathrm{ms^{-1}}$. **GO0127**

Total internal reflection :

60. In the figure (a) light is incident at an angle θ which is slightly greater than the critical angle. Now, keeping the incident fixed a slab of refractive index n_3 is placed on surface AB in fig. (b). Which of the following statements are correct:

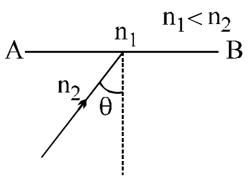


Fig. (a)

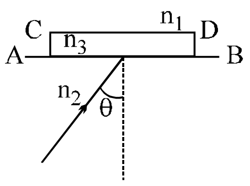


Fig. (b)

(A) total internal reflection occurs at AB for $n_3 < n_1$

(B) total internal reflection occurs at AB for $n_3 > n_1$

(C) the ray will return back to the same medium for all values of n_3

(D) total internal reflection occurs at CD for $n_3 < n_1$ **GO0128**

61. For the refraction of light through a prism

(A) For every angle of deviation there are two angles of incidence.

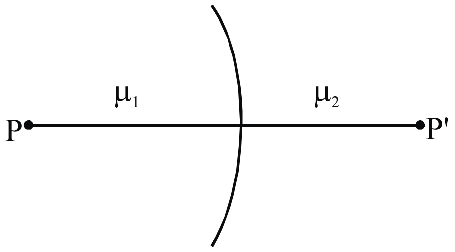
(B) The light travelling inside an equilateral prism is necessarily parallel to the base when prism is set for minimum deviation.

(C) There are two angles of incidence for maximum deviation.

(D) Angle of minimum deviation will increase if refractive index of prism is increased keeping the outside medium unchanged if $\mu_P > \mu_S$. **GO0129**

Refraction at curved surface :

62. Two refracting media are separated by a spherical interface as shown in the figure. *PP*' is the principal axis, μ_1 and μ_2 are the refractive indices of medium of incidence and medium of refraction respectively, then



(A) if $\mu_2 > \mu_1$, then there cannot be a real image of real object.

(B) if $\mu_2 > \mu_1$, then there cannot be a real image of virtual object.

(C) if $\mu_1 > \mu_2$, then there cannot be a virtual image of virtual object.

(D) if $\mu_1 > \mu_2$, then there cannot be a real image of real object. **GO0130**

Lens :

63. Optical axis of a thin equi-convex lens is the X-axis. The co-ordinate of a point object and its image are (–20 cm, 1 cm) and (25 cm, –2 cm) respectively

(A) the lens is located at x = 5 cm

(B) the lens is located at x = –5 cm

(C) the focal length of the lens is 10 cm

(D) the focal length of the lens is 15 cm **GO0131**

64. The principal axis of an optical device is along y = –1, image of a small body placed at (–30,3) is formed at a point (60, –3). Then the optical device is

(A) A convex lens of focal length 20 cm

(B) A concave mirror of focal length 60 cm

(C) A concave lens of focal length 20 cm

(D) A convex mirror of focal length 60 cm **GO0132**

65. In displacement method, the distance between object and screen is 96 cm. The ratio of length of two images formed by a convex lens placed between them is 4.84 :-

(A) Ratio of the length of object to the length of shorter image is 11/5.

(B) Distance between the two positions of the lens is 36 cm.

(C) Focal length of the lens is 20.625 cm.

(D) Distance of the lens from the shorter image is 30 cm. **GO0133**

66. A lens is formed by a material having refecting index $\frac{3}{2}$ & radii of curvature 20cm & 10 cm. Then choose the correct option(s) :-

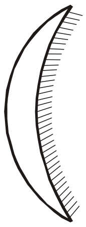
(A) If lens is concavo-convex & light is falling on the surface having radius of curvature 20 cm, then focal length is 40 cm

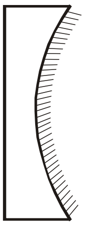
(B) If lens is concavo-convex & light is falling on the surface having radius of curvature 10 cm, then focal length is –40 cm

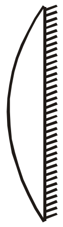
(C) If lens is convexo-concave & light is falling on the surface having radius of curvature 20 cm, then focal length is 40 cm

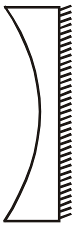
(D) If lens is convexo-concave & light is falling on the surface having radius of curvature 10 cm, then focal length is –40 cm **GO0134**

67. Which of the following silvered lenses kept in air may form real image of a real object.

(A) 

(B) 

(C) 

(D)  **GO0135**

68. A man wanted to get a picture of a Zebra. He photographed a white donkey after fitting a glass with black streaks onto the objective of his camera.

(A) the image will look like a white donkey on the photograph.

(B) the image will look like a Zebra on the photograph.

(C) the image will be more intense compared to the case in which no such glass is used.

(D) the image will be less intense compared to the case in which no such glass is used.

GO0136

COMPREHENSION TYPE QUESTIONS

Paragraph for Question No. 69 to 71

A real object is placed perpendicular to the principal axis of a concave mirror at a position (1) such that the image formed is real with a magnification 2. The object is now shifted to another position (2) at a distance 15 cm from the position (1) and a real image is obtained with a magnification 8. Shifting the position of object from (2) to a third position (3) gives an image with magnification 1/2.

69. Position of the image when the object is at position (3) is :-

(A) between centre of curvature and ∞ (B) between focus and centre of curvature

(C) at focus (D) between pole and focus **GO0137**

70. Focal length of the mirror is :-

(A) – 60 cm (B) –40 cm (C) –30 cm (D) –25 cm **GO0137**

71. Distance of position (1) of the object from pole and that of position (2) of object from pole are , respectively :-

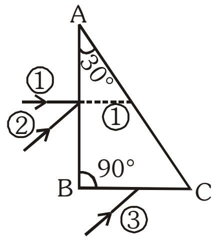
(A) 60 cm, 75 cm (B) 75 cm, 60 cm (C) 60 cm, 45 cm (D) 45 cm, 30 cm

GO0137

Paragraph for Question No. 72 to 74

ABC is a right-angled prism kept in air. A ray (1) is incident on the face AB along the normal. Refractive index of the material of prism is the minimum value that will be required so that ray (1) undergoes total internal reflection at the face AC.

Another ray (2) is incident on the face AB such that it emerges from face AC along the normal to AC. A third ray (3) falls on the face BC and emerges from face AC such that its angle of emergence is the same as that of incidence. Assuming light (1), (2) and (3) to have the same frequency, answer the following questions.



72. Refractive index of the material of prism is :-

(A) $\sqrt{2}$ (B) 2 (C) 1.5 (D) 2.2 **GO0138**

73. Angle of incidence of ray (2) is :-

(A) 0° (B) 45° (C) 60° (D) 90° **GO0138**

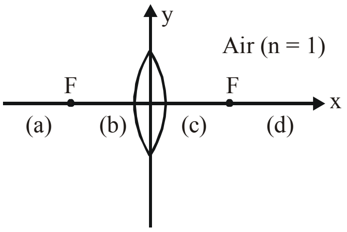
74. Deviation suffered by ray (3) is :-

(A) 60° (B) 30° (C) 90° (D) 120° **GO0138**

Paragraph for Question no. 75 and 76

This question concerns a symmetrical lens shown, along with its two focal points. It is made of plastic with (n = 1.2), and has a focal length f. Four different regions are shown :

Here (a) $-\infty < x < -f$; (b) $-f < x < 0$; (c) $0 < x < f$; (d) $f < x < \infty$



75. If an object is placed somewhere in region (a), in which region does the image appear ?

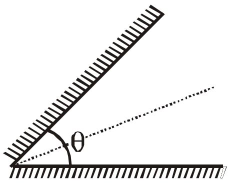
(A) (a) (B) (b) (C) (c) (D) (d) **GO0139**

76. If incident rays are converging then in which region does the image appear ?

(A) (a) (B) (b) (C) (c) (D) (d) **GO0139**

MATRIX MATCH TYPE QUESTIONS

77. Angle between two mirrors 'θ' and location of object is given in column I and some possible number of images are given in column II.



	Column–I		**Column–II**
(A)	$\theta = 30°$ and object is on bisector	(P)	9
(B)	$\theta = 36°$ and object is on bisector	(Q)	11
(C)	$\theta = 22.5°$ and object is on bisector	(R)	8
(D)	$\theta = 50°$ and object is on bisector	(S)	15

GO0140

78. An object O is kept perpendicular to the principal axis of a spherical mirror. In column I, coordinate of, object, u with sign in cm, type of mirror and its focal length in cm is given

	Column I		**Column II**
(A)	$u = -18$, concave mirror, 12	(P)	Image is real
(B)	$u = -12$, concave mirror, 18	(Q)	Image is virtual
(C)	$u = -8$, convex mirror, 10	(R)	Image diminished
(D)	$u = -10$, convex mirror, 8	(S)	Image is enlarged
		(T)	Image is inverted

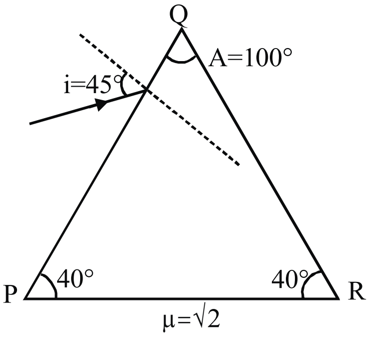
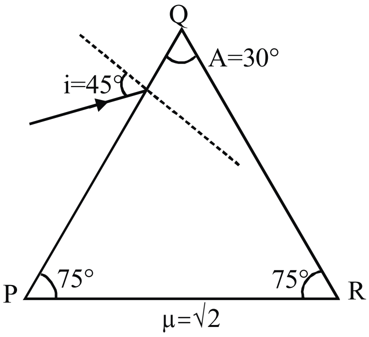
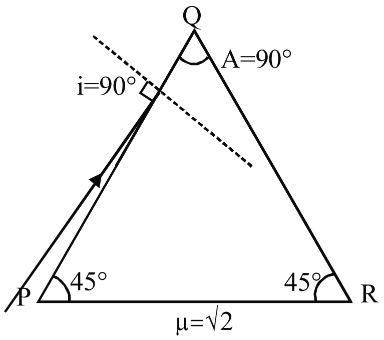
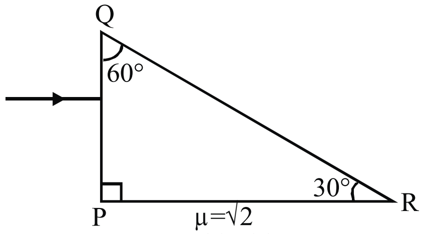
GO0141

79.

	Column-I		**Column-II**
(A)	An object is placed at a distance equal to focal length from pole before convex mirror	(P)	Maginification is (∞)
(B)	An object is placed at focus before a concave mirror	(Q)	Magnification is (0.5)
(C)	An object is placed at the centre of curvature before a concave mirror.	(R)	Magnification is (1/3)
(D)	An object is placed at a distance equal to radius of curvature before a convex mirror.	(S)	Magnification is (–1)

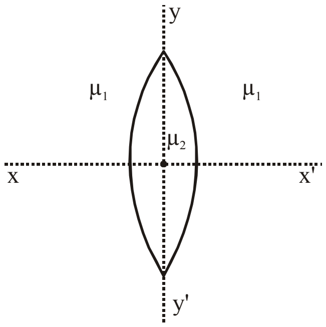
GO0142

80. Light is incident at surface PQ of prism as shown in column-I then match the column-I with column-II (surrounding medium is air in all cases)

Column-I	**Column-II**
(A) 	(P) Total internal reflection takes place at surface QR.
(B) 	(Q) Light emerges normally from the surface QR
(C)  Grazing incidence	(R) Light emerges parallel to surface QR
(D)  Normal incidence	(S) The light ray emerges from face PR perpendicularly
	(T) When light ray passes through the prism it is parallel to the base PR.

GO0143

81. An equi-convex lens of refractive index μ_2 and focal length f(in air) is kept in medium of refractive index μ_1.



	Column A		Column B
(P)	If lens is cut in two equal parts by a plane yy'. ($\mu_1 = 1$)	(1)	Lens will act as a glass slab
(Q)	If lens is cut in two equal parts by a plane xx' . ($\mu_1 = 1$)	(2)	Lens will be converging and focal length will change.
(R)	If $\mu_1 = \mu_2$.	(3)	Lens will be converging and focal length will remain same
(S)	If $\mu_1 > \mu_2$.	(4)	Lens will be diverging and focal length will change.

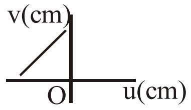
Codes :

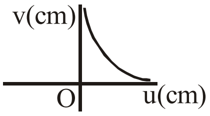
	P	Q	R	S
(A)	2	4	1	3
(B)	2	3	1	4
(C)	3	4	2	1
(D)	1	2	3	4

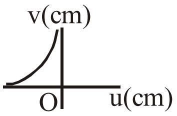
GO0144

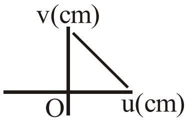
EXERCISE - (JM)

1. A student measures the focal length of a convex lens by putting an object pin at a distance 'u' from the lens and measuring the distance 'v' of the image pin. The graph between 'u' and 'v' plotted by the student should look like :- **[AIEEE - 2008]**

(1) 

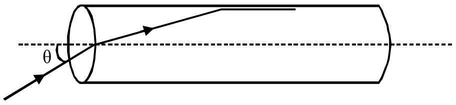
(2) 

(3) 

(4) 

GO0228

2. A transparent solid cyclindrical rod has a refractive index of $\frac{2}{\sqrt{3}}$. It is surrounded by air. A light ray is incident at the mid-point of one end of the rod as shown in the figure. **[AIEEE - 2009]**



The incident angle θ for which the light ray grazes along the wall of the rod is :-

(1) $\sin^{-1}\left(\frac{2}{\sqrt{3}}\right)$ (2) $\sin^{-1}\left(\frac{1}{\sqrt{3}}\right)$ (3) $\sin^{-1}\left(\frac{1}{2}\right)$ (4) $\sin^{-1}\left(\frac{\sqrt{3}}{2}\right)$

GO0229

3. A car is fitted with a convex side-view mirror of focal length 20 cm. A second car 2.8 m behind the first car is overtaking the first car at a relative speed of 15 m/s. The speed of the image of the second car as seen in the mirror of the first one is:- **[AIEEE- 2011]**

(1) 10 m/s (2) 15 m/s (3) $\frac{1}{10}$ m/s (4) $\frac{1}{15}$ m/s **GO0184**

4. A beaker contains water up to a height h_1 and kerosene of height h_2 above watger so that the total height of (water + kerosene) is $(h_1 + h_2)$. Refractive index of water is μ_1 and that of kerosene is μ_2. The apparent shift in the position of the bottom of the beaker when viewed from above is :- **[AIEEE- 2011]**

(1) $\left(1-\frac{1}{\mu_1}\right)h_2+\left(1-\frac{1}{\mu_2}\right)h_1$ (2) $\left(1+\frac{1}{\mu_1}\right)h_1-\left(1+\frac{1}{\mu_2}\right)h_2$

(3) $\left(1-\frac{1}{\mu_1}\right)h_1+\left(1-\frac{1}{\mu_2}\right)h_2$ (4) $\left(1+\frac{1}{\mu_1}\right)h_2-\left(1+\frac{1}{\mu_2}\right)h_1$ **GO0186**

5. An object 2.4 m in front of a lens forms a sharp image on a film 12 cm behind the lens. A glass plate 1 cm thick, of refractive index 1.50 is interposed between lens and film with its plane faces parallel to film. At what distance (from lens) should object be shifted to be in sharp focus on film ?

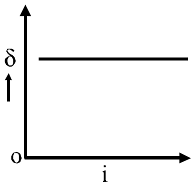
[AIEEE- 2012]

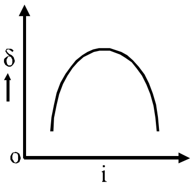
(1) 5.6 m (2) 7.2 m (3) 2.4 m (4) 3.2 m **GO0187**

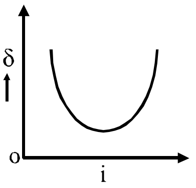
6. Diameter of a plano-convex lens is 6cm and thickness at the centre is 3 mm. If speed of light in material of lens is 2×10^8 m/s, the focal length of the lens is : **[JEE-Main- 2013]**

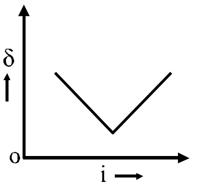
(1) 15 cm (2) 20 cm (3) 30 cm (4) 10 cm **GO0188**

7. The graph between angle of deviation (δ) and angle of incidence (i) for a triangular prism is represented by :- **[JEE-Main- 2013]**

(1)


(2)


(3)


(4)


GO0189

8. A thin convex lens made from crown glass $\left(\mu = \frac{3}{2}\right)$ has focal length f. When it is measured in two different liquids having refractive indices $\frac{4}{3}$ and $\frac{5}{3}$, it has the focal length f_1 and f_2 respectively. The correct relation between the focal lengths is : **[JEE-Main- 2014]**

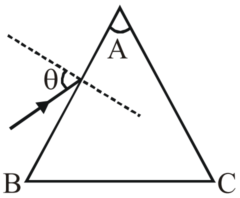
(1) $f_2 > f$ and f_1 becomes negative

(2) f_1 and f_2 both become negative

(3) $f_1 = f_2 < f$

(4) $f_1 > f$ and f_2 become negative **GO0190**

9. Monochromatic light is incident on a glass prism of angle A. If the refractive index of the material of the prism is μ, a ray, incident at an angle θ, on the face AB would get transmitted through the face AC of the prism provided : **[JEE-Main- 2015]**



(1) $\theta > \cos^{-1}\left[\mu \sin\left(A + \sin^{-1}\left(\frac{1}{\mu}\right)\right)\right]$ (2) $\theta < \cos^{-1}\left[\mu \sin\left(A + \sin^{-1}\left(\frac{1}{\mu}\right)\right)\right]$

(3) $\theta > \sin^{-1}\left[\mu \sin\left(A - \sin^{-1}\left(\frac{1}{\mu}\right)\right)\right]$ (4) $\theta < \sin^{-1}\left[\mu \sin\left(A - \sin^{-1}\left(\frac{1}{\mu}\right)\right)\right]$ **GO0192**

10. In an experiment for determination of refractive index of glass of a prism by i – δ, plot, it was found that a ray incident at angle 35°, suffers a deviation of 40° and that it emerges at angle 79°. In that case which of the following is closest to the maximum possible value of the refractive index? **[JEE-Main- 2016]**

(1) 1.8 (2) 1.5 (3) 1.6 (4) 1.7 **GO0194**

11. A diverging lens with magnitude of focal length 25 cm is placed at a distance of 15 cm from a converging lens of magnitude of focal length 20 cm. A beam of parallel light falls on the diverging lens. The final image formed is : **[JEE-Main- 2017]**

(1) real and at a distance of 40 cm from the divergent lens
(2) real and at a distance of 6 cm from the convergent lens
(3) real and at a distance of 40 cm from convergent lens
(4) virtual and at a distance of 40 cm from convergent lens. **GO0195**

12. Two plane mirrors arc inclined to each other such that a ray of light incident on the first mirror (M_1) and parallel to the second mirror (M_2) is finally reflected from the second mirror (M_2) parallel to the first mirror (M_1). The angle between the two mirrors will be :**[JEE Main-2019_Jan]**

(1) 90° (2) 45° (3) 75° (4) 60° **GO0230**

13. A convex lens is put 10 cm from a light source and it makes a sharp image on a screen, kept 10 cm from the lens. Now a glass block (refractive index 1.5) of 1.5 cm thickness is placed in contact with the light source. To get the sharp image again, the screen is shifted by a distance d. Then d is :

(1) 0.55 cm away from the lens **[JEE Main-2019_Jan]**
(2) 1.1 cm away from the lens
(3) 0.55 cm towards the lens
(4) 0 **GO0231**

14. A plano convex lens of refractive index μ_1 and focal length f_1 is kept in contact with another plano concave lens of refractive index μ_2 and focal length f_2. If the radius of curvature of their spherical faces is R each and $f_1 = 2f_2$, then μ_1 and μ_2 are related as : **[JEE Main-2019_Jan]**

(1) $\mu_1 + \mu_2 = 3$ (2) $2\mu_1 - \mu_2 = 1$ (3) $2\mu_2 - \mu_1 = 1$ (4) $3\mu_2 - 2\mu_1 = 1$ **GO0232**

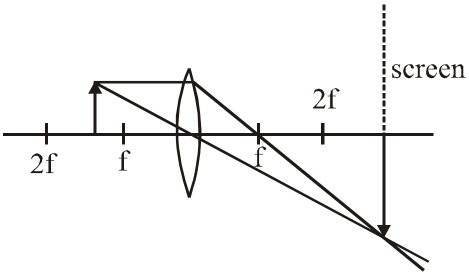
15. A monochromatic light is incident at a certain angle on an equilateral triangular prism and suffers minimum deviation. If the refractive index of the material of the prism is $\sqrt{3}$, then the angle of incidence is :- **[JEE Main-2019_Jan]**

(1) 30° (2) 45° (3) 90° (4) 60° **GO0233**

16. An object is at a distacen of 20 m from a convex lens of focal length 0.3 m. The lens forms an image of the object. If the object moves away from the lens at a speed of 5 m/s, the speed and direction of the image will be : **[JEE Main-2019_Jan]**

(1) 0.92×10^{-3} m/s away from the lens
(2) 2.26×10^{-3} m/s away from the lens
(3) 1.16×10^{-3} m/s towards the lens
(4) 3.22×10^{-3} m/s towards the lens **GO0234**

17. Formation of real image using a biconvex lens is shown below. If the whole set up is immersed in water without disturbing the object and the screen position, what will one observe on the screen ? **[JEE Main-2019_Jan]**



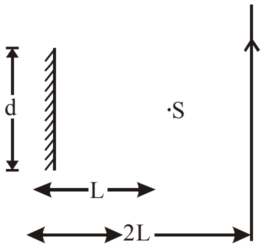
(1) Image disappears (2) No change (3) Erect real image (4) Magnified image

GO0235

18. A plano-convex lens (focal length f_2, refractive index μ_2, radius of curvature R) fits exactly into a plano-concave lens (focal length f_1, refractive index μ_1, radius of curvature R). Their plane surfaces are parallel to each other. Then, the focal length of the combination will be : **[JEE Main-2019_Jan]**

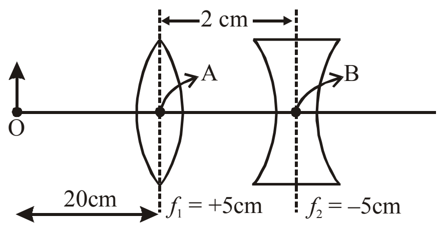
(1) $f_1 - f_2$ (2) $f_1 + f_2$ (3) $\frac{R}{\mu_2 - \mu_1}$ (4) $\frac{2f_1f_2}{f_1 + f_2}$ **GO0236**

19. A point source of light, S is placed at a distance L in front of the centre of plane mirror of width d which is hanging vertically on a wall. A man walks in front of the mirror along a line parallel to the mirror, at a distance 2L as shown below. The distance over which the man can see the image of the light source in the mirror is : **[JEE Main-2019_Jan]**



(1) 3d (2) $\frac{d}{2}$ (3) d (4) 2d **GO0237**

20. What is the position and nature of image formed by lens combination shown in figure? (f_1, f_2 are focal lengths) **[JEE Main-2019_Jan]**



(1) 70 cm from point B at left; virtual (2) 40 cm from point B at right; real

(3) $\frac{20}{3}$ cm from point B at right , real (4) 70 cm from point B at right, real **GO0238**

21. A convex lens (of focal length 20 cm) and a concave mirror, having their principal axes along the same lines, are kept 80 cm apart from each other. The concave mirror is to the right of the convex lens. When an object is kept at a distance of 30 cm to the left of the convex lens, its image remains at the same position even if the concave mirror is removed. The maximum distance of the object for which this concave mirror, by itself would produce a virtual image would be :-

[JEE Main-2019_April]

(1) 20 cm (2) 10 cm (3) 25 cm (4) 30 cm **GO0239**

22. An upright object is placed at a distance of 40 cm in front of a convergent lens of focal length 20 cm. A convergent mirror of focal length 10 cm is placed at a distance of 60 cm on the other side of the lens. The position and size of the final image will be : **[JEE Main-2019_April]**

(1) 40 cm from the convergent mirror, same size as the object

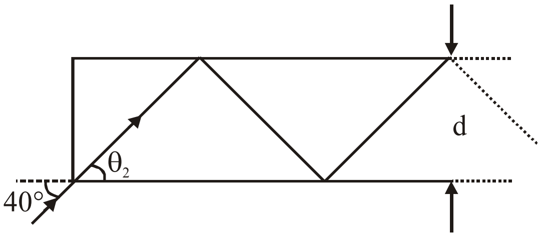
(2) 20 cm from the convergent mirror, same size as the object

(3) 20 cm from the convergent mirror, twice the size of the object

(4) 40 cm from the convergent lens, twice the size of the object **GO0240**

23. In figure, the optical fiber is ℓ = 2m long and has a diameter of d = 20 μm. If a ray of light is incident on one end of the fiber at angle θ_1 = 40°, the number of reflection it makes before emerging from the other end is close to: (refractive index of fibre is 1.31 and sin 40° = 0.64)

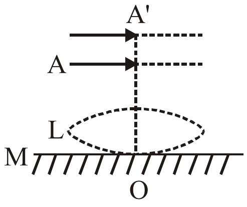
[JEE Main-2019_April]



(1) 55000 (2) 57000 (3) 66000 (4) 45000 **GO0241**

24. A thin convex lens L (refractive index = 1.5) is placed on a plane mirror M. When a pin is placed at A, such that OA = 18 cm, its real inverted image is formed at A itself, as shown in figure. When a liquid of refractive index μ_1 is put between the lens and the mirror, The pin has to be moved to A', such that OA' = 27 cm, to get its inverted real image at A' itself. The value of μ_1 will be :-

[JEE Main-2019_April]



(1) $\sqrt{2}$ (2) $\frac{4}{3}$ (3) $\sqrt{3}$ (4) $\frac{3}{2}$ **GO0242**

25. A convex lens of focal length 20 cm produces images of the same magnification 2 when an object is kept at two distances x_1 and x_2 ($x_1 > x_2$) from the lens. The ratio of x_1 and x_2 is :-

[JEE Main-2019_April]

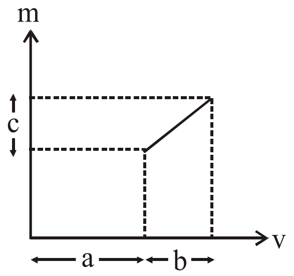
(1) 5 : 3 (2) 2 : 1 (3) 4 : 3 (4) 3 : 1 **GO0243**

26. A concave mirror for face viewing has focal length of 0.4 m. The distance at which you hold the mirror from your face in order to see your image upright with a magnification of 5 is :

[JEE Main-2019_April]

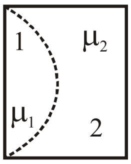
(1) 1.60 m (2) 0.24 m (3) 0.16 m (4) 0.32 m **GO0244**

27. The graph shows how the magnification m produced by a thin lens varies with image distance v. What is the focal length of the lens used ? **[JEE Main-2019_April]**



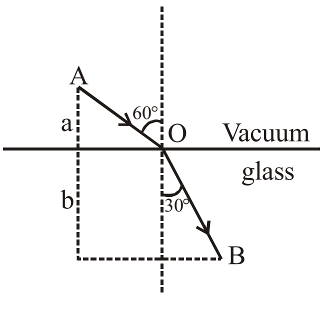
(1) $\frac{b^2c}{a}$ (2) $\frac{b^2}{ac}$ (3) $\frac{a}{c}$ (4) $\frac{b}{c}$ **GO0245**

28. One plano-convex and one plano-concave lens of same radius of curvature 'R' but of different materials are joined side by side as shown in the figure. If the refractive index of the material of 1 is μ_1 and that of 2 is μ_2, then the focal length of the combination is : **[JEE Main-2019_April]**



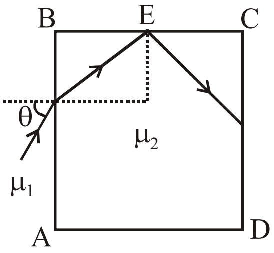
(1) $\frac{R}{2-(\mu_1-\mu_2)}$ (2) $\frac{2R}{\mu_1-\mu_2}$ (3) $\frac{R}{2(\mu_1-\mu_2)}$ (4) $\frac{R}{\mu_1-\mu_2}$ **GO0246**

29. A ray of light AO in vacuum is incident on a glass slab at angle 60° and refracted at angle 30° along OB as shown in the figure. The optical path length of light ray from A to B is :**[JEE Main-2019_April]**



(1) 2a + 2b (2) $2a+\frac{2b}{3}$ (3) $\frac{2\sqrt{3}}{a}+2b$ (4) $2a+\frac{2b}{\sqrt{3}}$ **GO0247**

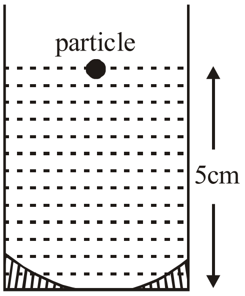
30. A transparent cube of side d, made of a material of refractive index μ_2, is immersed in a liquid of refractive index $\mu_1(\mu_1 < \mu_2)$. A ray is incident on the face AB at an angle θ(shown in the figure). Total internal reflection takes place at point E on the face BC. The θ must satisfy : **[JEE Main-2019_April]**



(1) $\theta < \sin^{-1}\frac{\mu_1}{\mu_2}$ (2) $\theta < \sin^{-1}\sqrt{\frac{\mu_2^2}{\mu_1^2}-1}$ (3) $\theta > \sin^{-1}\frac{\mu_1}{\mu_2}$ (4) $\theta > \sin^{-1}\sqrt{\frac{\mu_2^2}{\mu_1^2}-1}$

GO0248

31. A concave mirror has radius of curvature of 40 cm. It is at the bottom of a glass that has water filled up to 5 cm (see figure). If a small particle is floating on the surface of water, its image as seen, from directly above the glass, is at a distance d from the surface of water. The value of d is close to : (Refractive index of water = 1.33) **[JEE Main-2019_April]**



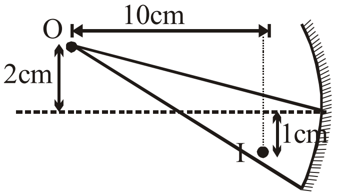
(1) 8.8 cm (2) 11.7 cm (3) 6.7 cm (4) 13.4 cm **GO0249**

ANSWER KEY

EXERCISE (S)

1. Ans. 3m **2. Ans.** 2 **3. Ans.** 2

4. Ans. 20 cm from object, 20/3 cm from object



5. Ans. 25

6. Ans. d/2 **7. Ans.** 16 mm^3 **8. Ans.** 4 **9. Ans.** 1

10. Ans. 5 **11. Ans.** 5 **12. Ans.** 42 cm **13. Ans.** 4

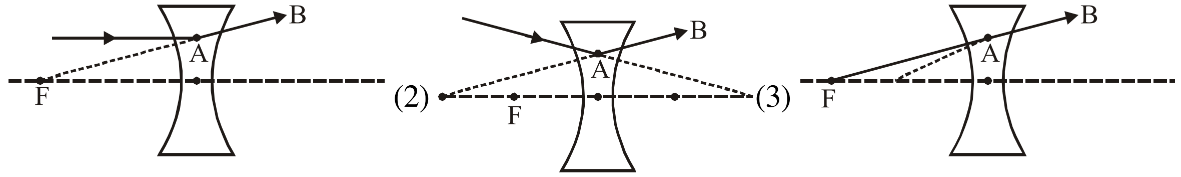
14. Ans. 8 **15. Ans.** (a) $\sin^{-1}\left(\frac{1}{5}\right)$ (b) air

16. Ans. $\theta < \sin^{-1}(2\sin 15°)$ **17. Ans.** $\left(\frac{8}{3}\text{mm}\right)$ **18. Ans.** 2 **19. Ans.** 5cm

20. Ans. 8 **21. Ans.** $f = v = \frac{\mu_3 R}{\mu_3 - \mu_1}$ **22. Ans.** 30

23. Ans. Real, below principal axis, anywhere b/w P & ∞

24. Ans. (1)



25. Ans. (i) 0.2 m, (ii) 0.4 m **26. Ans.** (π/4) cm^2 **27. Ans.** 3 **28. Ans.** 5

29. Ans. (–20 cm) **30. Ans.** 17.5 cm **31. Ans.** 3

32. Ans. $y = -\frac{x}{1200} + 0.1$ **33. Ans.** 1 **34. Ans.** 4

EXERCISE (O)

1. Ans. (A) 2. Ans. (A) 3. Ans. (C) 4. Ans. (A) 5. Ans. (D) 6. Ans. (D)
7. Ans. (D) 8. Ans. (B) 9. Ans. (B) 10. Ans. (C) 11. Ans. (D) 12. Ans. (C)
13. Ans. (C) 14. Ans. (C) 15. Ans. (D) 16. Ans. (B) 17. Ans. (B) 18. Ans. (B)
19. Ans. (A) 20. Ans. (B) 21. Ans. (C) 22. Ans. (B) 23. Ans. (D) 24. Ans. (B)
25. Ans. (C) 26. Ans. (B) 27. Ans. (B) 28. Ans. (C) 29. Ans. (B) 30. Ans. (B)
31. Ans. (C) 32. Ans. (A) 33. Ans. (A) 34. Ans. (B) 35. Ans. (D) 36. Ans. (D)

37. Ans. (A) **38. Ans. (D)** **39. Ans. (C)** **40. Ans. (A)** **41. Ans. (C)** **42. Ans. (D)**
43. Ans. (B) **44. Ans. (A)** **45. Ans. (C)** **46. Ans. (B)** **47. Ans. (C)** **48. Ans. (A)**
49. Ans. (B) **50. Ans. (A)** **51. Ans. (A)** **52. Ans. (C)** **53. Ans. (A,C,D)**
54. Ans. (B, C) **55. Ans. (A,D)** **56. Ans. (A,B,C)** **57. Ans. (B,C)** **58. Ans. (B,C)**
59. Ans. (B,D) **60. Ans. (A,C)** **61. Ans. (B,C,D)** **62. Ans. (A,C)** **63. Ans. (B,C)**
64. Ans. (A,B) **65. Ans. (A,B,C,D)** **66. Ans. (A,D)** **67. Ans. (A, C)**
68. Ans. (A, D) **69. Ans. (B)** **70. Ans. (B)** **71. Ans. (C)** **72. Ans. (B)** **73. Ans. (D)**
74. Ans. (D) **75. Ans. (D)** **76. Ans. (C)**
77. Ans. (A) → (Q), (B) → (P), (C) → (S), (D) → (R)
78. Ans. (A)→(P,S,T);(B)→(Q,S);(C)→(Q, R) (D)→(Q, R)
79. Ans. (A)-Q; (B)-P; (C)-S; (D)-R **80. Ans. (A)-P; (B)-Q; (C)-RT; (D)-PT**
81. Ans. (B)

EXERCISE - (JM)

1. Ans. (3) **2. Ans. (2)** **3. Ans. (4)** **4. Ans. (3)** **5. Ans. (1)** **6. Ans. (3)**
7. Ans. (3) **8. Ans. (4)** **9. Ans. (3)** **10. Ans. (2)** **11. Ans. (3)** **12. Ans. (4)**
13. Ans. (1) **14. Ans. (2)** **15. Ans. (4)** **16. Ans. (3)** **17. Ans. (1)** **18. Ans. (3)**
19. Ans. (1) **20. Ans. (4)** **21. Ans. (2)** **22. Ans. (2)** **23. Ans. (2)** **24. Ans. (2)**
25. Ans. (4) **26. Ans. (4)** **27. Ans. (4)** **28. Ans. (4)** **29. Ans. (1)** **30. Ans. (2)**
31. Ans. (1)

Important Notes

Important Notes