Chapter-9: Ray optics and Optical instruments

Optics: It is the branch of physics which deals with the study of nature, production and propagation of light. It is divided into two groups-(i) ray optics and (ii) wave optics

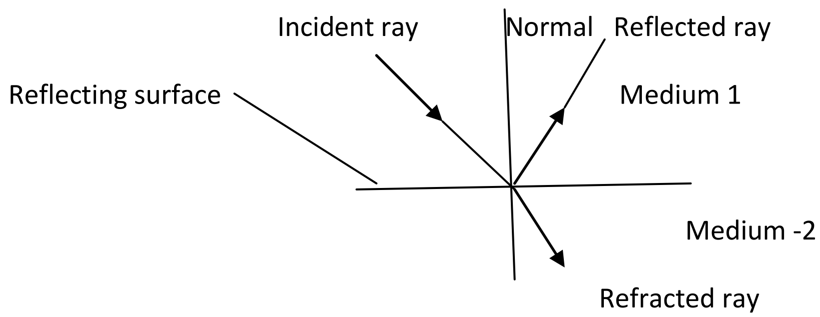
Ray or geometrical optics: It concerns itself with the particle nature of light. It is based on

a) Rectilinear propagation of light and
b) Laws of reflection and refraction of light

Wave or physical nature of light: It concerns itself with wave nature of light and is based on phenomena like (i) Interference, (ii) Diffraction and (iii) Polarisation of light

We have studied that light is an electromagnetic wave.

Behaviour of light at the interface of two media: Reflection and refraction of light



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

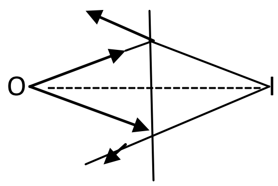
a) A part of incident light is turned back to the first medium. This is called reflection of light.
b) A part of incident light is transmitted into the second medium along a changed direction. This called refraction of light.
c) The remaining third part of light energy is absorbed by the second medium. This is called absorption of light.

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

a) The angle of incidence $\angle i$ = angle of reflection $\angle r$
b) The incident ray, the reflected ray and the normal at the point of incidence lie in the same plane.

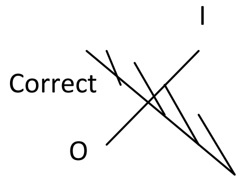
If the object is real, the image formed by a plane mirror is

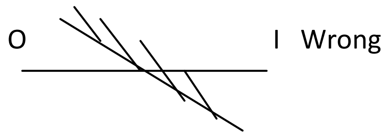
a) Virtual
b) Erect
c) Of same size and
d) At the same distance from the mirror



Important points in reflection from a plane mirror:

a) To find the location of image of an object from an inclined plane mirror, we have to see the perpendicular distance of the object from the mirror.





b) Suppose a mirror is rotated by angle θ (say anticlockwise), keeping the incident ray fixed, then the reflected ray rotates by 2θ along the same sense (anticlockwise).
Suppose the incident ray makes an angle i, after rotating the mirror by angle θ CCW, the reflected ray angle i - 2θ from the Y-axis.

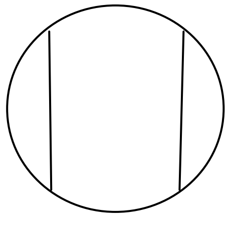
c) The minimum length of plane mirror to see one's full height (H) in it is H/2.
d) A man is standing exactly mid way between a wall and a mirror and he wants to see the full height of the wall (behind him) in a plane mirror in front of him. The minimum length of mirror in this case is H/3.
e) Focal length as well as the radius of curvature of a plane mirror is infinity.
f) Power of a plane mirror is zero.
g) When two plane mirrors are kept facing to each other at an angle θ and an object is placed between them, then
    i. Number of images, $n = \left(\frac{360}{\theta} - 1\right)$, if $\frac{360^0}{\theta}$ is even.
    ii. Number of images, $n = \frac{360^0}{\theta}$, if 360/θ is odd.

    Or, number of images formed is $n = \frac{360}{\theta} - 1$ if θ is a sub multiple of 180^0. If θ is not sub multiple of 180, then number of images formed is the integers next higher to it.

    Example-Let θ = 72^0, then 360/72 = 5 (odd), so number of images is 5. If θ = 90^0, the number of images formed is 3.

h) A man approaches a vertical plane at a speed of 2 m/s; at what rate does he approach his image? [Ans. 4m/s] or a plane mirror is approaching you at a speed of 10 m/s, at what speed will your image approach you.

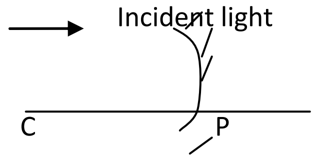
Spherical Mirrors: A hollow glass of sphere cut by a plane and if either side of this spherical surface is silvered, we get spherical mirror.



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

It is of two types-

- Concave mirror: A spherical mirror in which outer bulged surface is silvered polished and the reflection of light takes place from the inner hollow surface.
- Convex mirror: A spherical mirror in which inner hollow surface is silvered and the reflection of light takes place from the outer bulged surface.



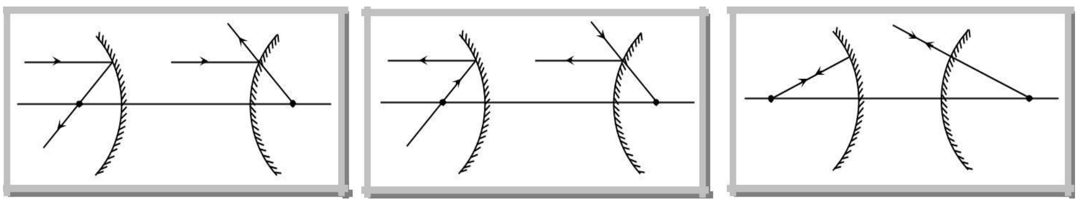
A

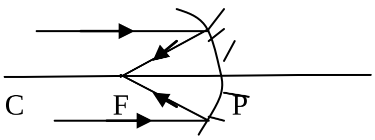
Some definitions related to spherical mirrors:

a) Pole (P): Mid point of the mirror
b) Centre of curvature (C): Centre of the sphere of which the mirror is a part. (Concave mirror)
c) Radius of curvature (R): Distance between pole and centre of curvature (PC).
d) Aperture: AB is the aperture of the mirror.

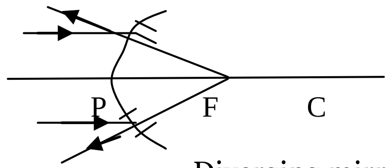
Rules of image formation and sign convention:

Rule (i) Rule (ii) Rule (iii)





Converging mirror



Diverging mirror

Principal Focus in case of concave mirror:

A narrow beam of rays parallel and near to the parallel axis, is reflected from a concave mirror so the all rays converge to a point F on the principal axis. F is called the principal focus of the mirror and it is a real focus, since light actually passes through it.

Concave mirrors are also known as converging mirrors because of their action on a parallel beam of light.

Concave mirrors are used in (i) Car head lights, railway engine, torch lights, (ii) Search lights and (iii) Telescope

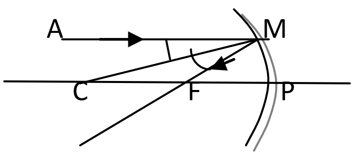
Principal Focus in case of concave mirror: A narrow beam of rays parallel and near to the parallel axis, falling on a convex mirror, is reflected to form a divergent beam which appears to come from a point F behind the mirror. A convex mirror thus has a virtual principal focus. It is also called a diverging mirror.

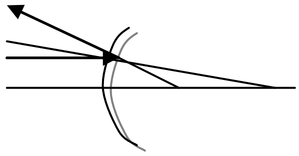
The distance FP is called the focal length of a mirror. In case of concave mirror, f is negative and in case of convex mirror, f is positive. Here $f = \frac{R}{2}$, where R is the radius of curvature.

Paraxial rays: Rays which are close to the principal axis and make small angles with it. That is, they are nearly parallel to the axis, are called paraxial rays. We will focus only mirrors of small aperture for paraxial rays, however, it will be made larger for clarity.

Concave Mirror Convex Mirror

Relation between f and R:





Here, CM is the normal to the mirror at M because radius of a spherical surface is the perpendicular to the surface. From the first law of reflection,

$\angle$i = $\angle$r, so, $\angle$AMC = $\angle$CMF, but $\angle$AMC = $\angle$MCF (alternate angles)

Therefore, $\angle$CMF = $\angle$MCF,

Therefore, $\triangle$FCM is thus isosceles with FC = FM, the rays are paraxial so M is very close to P.

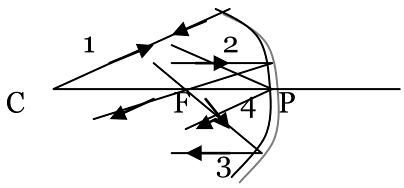
Therefore, FM = FP $\Rightarrow$ FP = FC or $2FP = CP \Rightarrow f = \frac{R}{2}$ ■

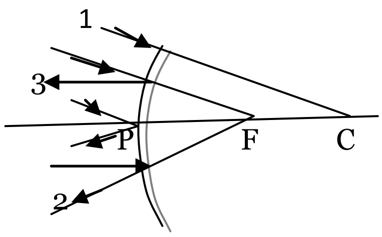
Images formed by spherical mirrors:

In general, position of images and its nature (i. e. whether it is real or virtual, erect or inverted, magnified or diminished) depend on the distance of object from the mirror.

Information about the image can be obtained either by drawing a ray diagram or by calculation using formulae.

Ray diagram: We will consider the small objects and mirrors of small aperture so that all rays are paraxial. To construct the image of a point object, two of the followings four rays are drawn passing through object. To construct the image of an extended object, , the image of two end points are drawn. The image of a point objects lying on principal axis is formed on the principal axis itself. The four rays are as under:





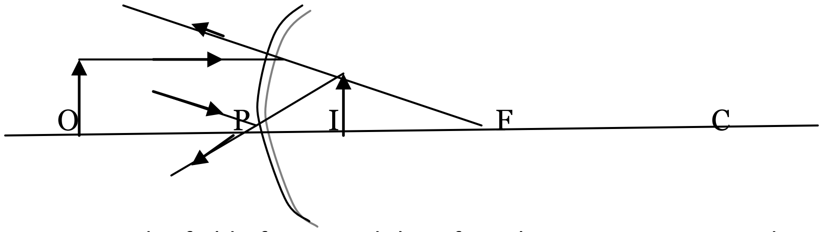
Ray 1: A ray through the centre of curvature which strikes the mirror normally and is reflected back along the same path.

Ray 2: A ray parallel to principal axis after reflection either actually passes the principal focus or appears to diverge from it.

Ray 3: A ray passing through the principal focus F or appears to converge at F, is reflected parallel to principal axis.

Ray 4: A ray striking at pole P is reflected symmetrically back in the opposite side.

Note: Images formed by convex mirror is always virtual, erect and diminished, no matter where the object is.



Convex mirrors give a wider field of view and therefore these mirrors are used in

a) Rear view mirrors in cars or scooters

Note:

1. Convex mirrors are preferred because there is only a small movement of image for a large movement of the object.
2. The image formed by concave mirror is always real and inverted except in one case when the object is placed between F and P and in this case, the image is virtual and erect and on the same side of object.

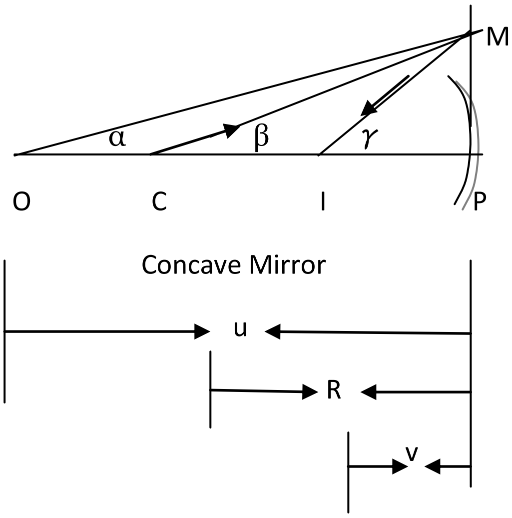
The mirror formula:

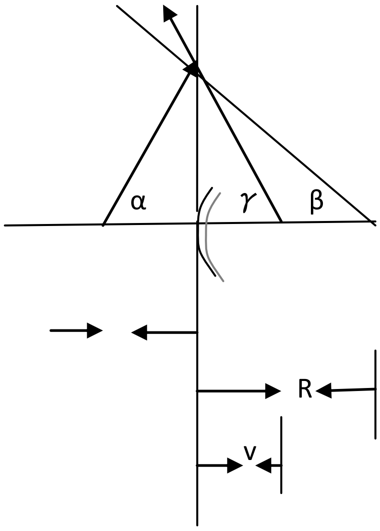
The mirror formula is a mathematical relationship between object distance u, the image distance v and the focal length f of a spherical mirror. The relation is

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

This formula is applicable to all concave and convex mirrors whether the image formed is real or virtual.

Derivation of Mirror formula using a point Object:-





Derivation for Concave Mirror equation:

Fig. 1 gives a real point image of O and fig. 2 gives virtual point image of O. Let α, β, γ be the angles as shown.

As the rays are paraxial, so these angles are small. We can take,

$$\alpha = \tan\alpha = \frac{MP}{OP}, \beta = \tan\beta = \frac{MP}{CP} \; and \; \gamma = \tan\gamma = \frac{MP}{IP}$$

Concave Mirror Formula:

In ΔCMO, $\beta = \alpha + \theta \Rightarrow \theta = \beta - \alpha - - - - (1)$

In ΔCMI, $\gamma = \beta + \theta \Rightarrow \theta = \gamma - \beta - - - - (2)$

From equation (1) and (2) above,

$$\beta - \alpha = \gamma - \beta \Rightarrow 2\beta = \alpha + \gamma \Rightarrow 2\frac{MP}{CP} = \frac{MP}{OP} + \frac{MP}{IP} \Rightarrow \frac{2}{R} = \frac{1}{u} + \frac{1}{v} - - - (3)$$

Since , R =2f, so, from equation (3),

If now, we substitute the values with sign as CP = -R, OP = -u, IP = -v, then we get,

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

This equation (4) is the mirror equation for Concave mirror as well for convex mirror.

In fig.2 also, CP = +R, OP = -u, IP = +v, we get the same result as in equation (4) for convex mirror.

Try yourself to find convex mirror equation.

Note: Out of u, v and f, values of two will be known to us and we will be asked to find the third. In such types of problems, two cases are possible.

Case-1: When sign of all three is known to us from the given information. Under this condition, substitute all three with sign, then answer.

Case 2: When sign of third unknown quantity is not known to us. Under such condition, substitute known quantity with sign. Sign with numerical value will automatically come in the answer.

Derivation of Concave Mirror formula in case of extended object:

As shown in the fig. 3:

Δ ABC and Δ A'B'C are similar triangles. So,

$$\frac{A'B'}{AB} = \frac{B'C}{BC} = \frac{CP - B'P}{BP - CP} = \frac{-R + v}{-u + R} - - - - (1)$$

Similarly, △ APB and A'PB' are similar triangle. So,

$$\frac{A'B'}{AB} = \frac{PB'}{PB} = \frac{-v}{-u} - - - - - - (2)$$

From equation (1) and (2),

$$\frac{-R + v}{-u + R} = \frac{-v}{-u} \Rightarrow uR - uv = uv - vR \Rightarrow 2uv = (u + v)R \Rightarrow \frac{2}{R} = \frac{1}{v} + \frac{1}{u} \Rightarrow \frac{1}{f} = \frac{1}{v} + \frac{1}{u} \qquad \blacksquare$$

Here, R = 2 f, this equation (3) is the mirror formula for extended object.

Magnification (m) : In mirror, it is also called linear or transverse (in case of extended object)or lateral magnification (in case of point object): It is defined as the ratio of height of object to the height of image. As in fig. 3,

$$m = \frac{AB}{A'B'} = \frac{BP}{B'P} \Rightarrow \frac{+h_1}{-h_2} = \frac{-u}{-v} \Rightarrow \frac{h_2}{h_1} = -\frac{v}{u}$$

Linear magnification in terms of v and f:

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

So, $m = -v\left(\frac{v-f}{vf}\right) = \frac{f-v}{f}$, hence, magnification

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

Important points:

a) If $|m| > 1$, the image is magnified, b) If $|m| < 1$, the image is diminished, c) If $|m| = 1$, the image is of same size as that of object, d) If m is positive or (v is +ve) , the image is virtual and erect, e) If m is negative or v is –ve, the image is real and inverted.

For concave Mirror:

Ser. No.	Position of Object	Details of Image
1	At ∞	At F, real, inverted, $|m| \ll 1$
2	Between C and ∞	Between F and C, real, inverted, $|m| < 1$
3	At C	At C, real, inverted, $|m| = 1$
4	Between F and C	Between C and ∞, real, inverted, $|m| > 1$
5	At F	At infinity, real, inverted, $|m| \gg 1$
6	Between F and P	Behind the mirror, virtual, erect, $|m| > 1$

For Convex Mirror:

Ser. No.	Position of Object	Details of Image
1	At ∞	At F, virtual, erect, $|m| \ll 1$
2	In front of mirror	Between P and CF, virtual, erect, $|m| < 1$

Graph between 1/v versus 1/u:

Case 1: When the image is real i.e. the object lies between f and infinity. In such a situation, u, v and f are negative.

Hence the mirror formula $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ becomes $\frac{1}{v} = -\frac{1}{u} + \frac{1}{f}$, Comparing equation (1) with y =-mx +c, we get slope m = -1 and intercept c = 1/f. The graph is in fig. 1.

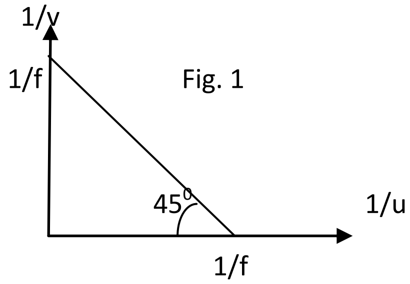


Fig. 1

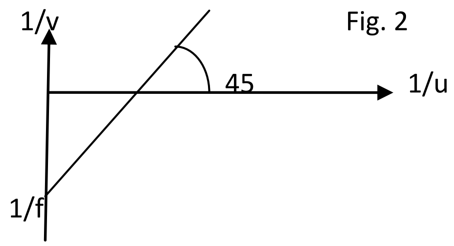


Fig. 2

Case 2: When image is virtual i.e. object lies between p and f, then u and f are negative and v is positive (in concave mirror), then, $\frac{1}{v}=\frac{1}{u}-\frac{1}{f}$, comparing it with y = mx +c, m =1, c = -1/f. The graph is shown in the fig. 2.

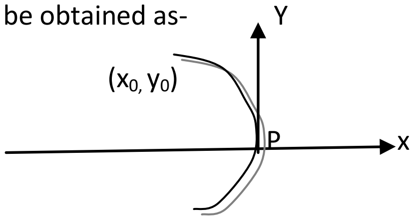
Important formulae:

1. Two laws of reflection
   a) ∠i = ∠r
   b) Incident ray, reflected ray and normal lie on the same plane
2. Reflection from plane surface (or from plane mirror)
   a) If object is real, its image from a plane mirror is virtual, erect, same size and at same perpendicular distance from the mirror.
   b) F = ∞, P = 0
3. Reflection from spherical surface (concave or convex mirror)
   a) $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$
   b) $m=-\frac{v}{u}$
   c) $f=\frac{R}{2}$
   d) $P\ (dioptre)=\frac{-1}{f\ (metre)}$
   e) Image speed $=(m^2)\ Object\ speed$
      They travel in the opposite directions.

Notes:

A. Methods of finding co-ordinates of image of a point object if the co-ordinates of objects are known:

Suppose the co-ordinate of object is (x_0, y_0) with respect to co-ordinate axes. So co-ordinates of image (x_i, y_i) can be obtained as-



Using mirror formula $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}, \frac{1}{x_i}+\frac{1}{x_o}=\frac{1}{f}$ or $x_i=\frac{fx_0}{x_0-f}$

Similarly, using magnification formula $m=\frac{y_i}{y_o}=-\frac{v}{u}=-\frac{x_i}{x_0}$ or $y_i=\frac{fy_0}{f-x_0}$

Q. 1. The coordinate of object and image for convex mirror is given as (10 cm, 5 cm) and (8 cm, 4 cm).Find-

a) Its focal length [Ans. +40 cm]
b) Its magnification {Ans. + 0.8]

B. If an object is placed with its length along the principal axis, then so called longitudinal magnification becomes
$m_L=\frac{I}{0}=-\frac{(v_2-v_1)}{(u_2-u_1)}=-\frac{dv}{du}$ (for small objects)
Differentiating u and v separately with its own respect (taking as variables) and keeping f constant in mirror formula, we get (1/v + 1/u = 1/f)

$$-\frac{dv}{v^2}-\frac{du}{u^2}=0 \Rightarrow \frac{dv}{du}=-\frac{v^2}{u^2}$$

So, $m_L = \frac{v^2}{u^2} = m^2$

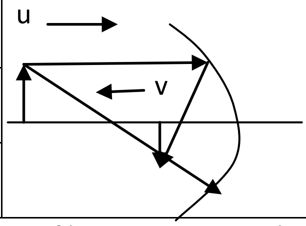
For an extended object: If an object is placed transversely on principal axis and

If we differentiate mirror formula with time, keeping f constant, we get

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

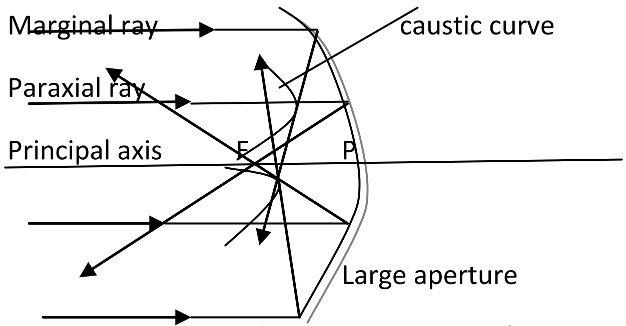
Here du/dt is the rate by which u is changing, or it is the object speed if mirror is stationary. So, at known value of v and u, if object speed is given, we can find the image speed from the formula in equation (1).

Object and Image movement:

O moved from infinity towards focus	Rate of decrease of u =-du/dt	Rate of increase of v = dv/dt, dv/dt < (-du/dt)	Further v< u when O lies between ∞ and C
When O at C, image is also at C	dv/dt = - du/dt		Speed of image = speed of object
When object lies between C and F	dv/dt>du/dt		v > u
When O comes inside F			Image becomes virtual

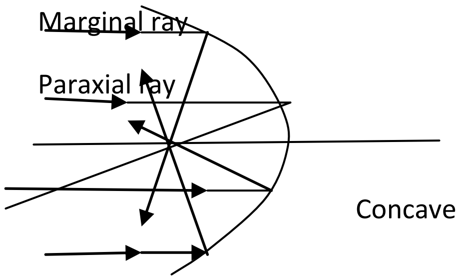
Spherical Aberration: The inability of a spherical mirror of large aperture to bring all rays of wide beam of light falling on it to focus at a single point is called spherical aberration.

Only the paraxial rays are focussed at principal focus. The marginal rays meet the principal axis at a point closure to the pole than the principal focus. The different rays are reflected on to surface known as Caustic curve. This results in blurred image of the object.



Spherical aberration can be reduced by following methods: a) By using spherical mirrors of small aperture, b) By using stoppers so as to cut off the marginal rays, c) By using parabolic mirrors

Parabolic mirrors:



Concave parabolic mirror

Uses of Parabolic mirrors:

a) A concave parabolic mirror can focus a wide parallel beam to a single point. This property is used by dish antenna to collect and bring to focus microwave signals from satellite.
b) Parabolic mirrors are used as a reflectors in search lights, car head lights etc.
c) They are used in astronomical telescopes of large aperture for overcoming spherical aberration.

Laws of refraction

When light passes from one medium (say air) to another medium (say glass), part of it is reflected back into the first medium and the rest passes into the second medium. When it passes into the second medium, its direction of travel is changed. It either bends towards the normal or away from the normal. This phenomenon is known as refraction.

There are two types of refractions:

1. For two particular media, the ratio of sine of the angle of incidence to the sine of angle of refraction is constant. That is,

$$\frac{\sin i}{\sin r} = Constant = 1\mu_2 = \frac{\mu_2}{\mu_1} - - - - (1)$$

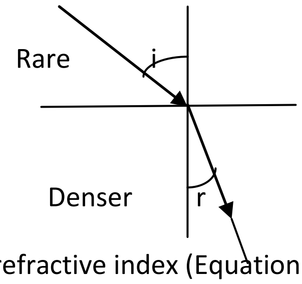
   Equation (1) is known as Snell's law.
2. The incident ray, the normal and the refracted ray all lie in the same plane.

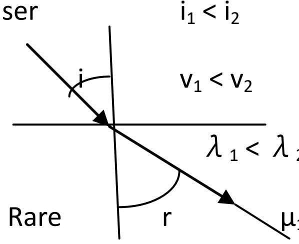
$i_1 > i_2$

$v_1 > v_2$

$\lambda_1 > \lambda_2$

$\mu_2 > \mu_1$





$i_1 < i_2$

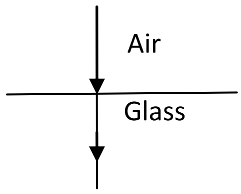
$v_1 < v_2$

$\lambda_1 < \lambda_2$

$\mu_1 > \mu_2$

The constant ratio is called the refractive index (Equation 1 above) for light passing from the first to the second medium (or refractive index of medium 2 with respect to medium 1). It is denoted by $1\mu_2$.

No refraction: A ray of light travelling along the normal passes undeflected (i =r).



Note 2:

a) For two media,

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

b) If medium 1 is vacuum (say air), we refer $1\mu_2$ as μ_2 or simply μ. (($\mu_{air} = 1$).
c) If $\mu_2 > \mu_1$, $i > r$, if a ray of light passes from rare to denser medium, it bends towards normal and vice-versa. Again,

$${}_1\mu_2 = \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{\mu_2}{\mu_1}$$

Here, v_1 is the speed of light in medium 1 and v_2 is the speed of light in medium 2. Correspondingly, λ_1 *and* λ_2 are wave lengths in medium 1 and medium 2 respectively.

d) If $\mu_2 > \mu_1$ then $v_1 > v_2$ and $\lambda_1 > \lambda_2$, i. e. in a rare medium, speed and wavelength of light is more.
e) In general, speed of light in any medium is less than its speed in vacuum.

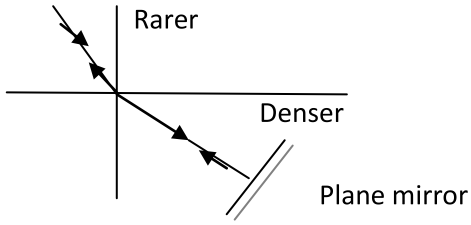
So, Definition of refractive index (μ) is as

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

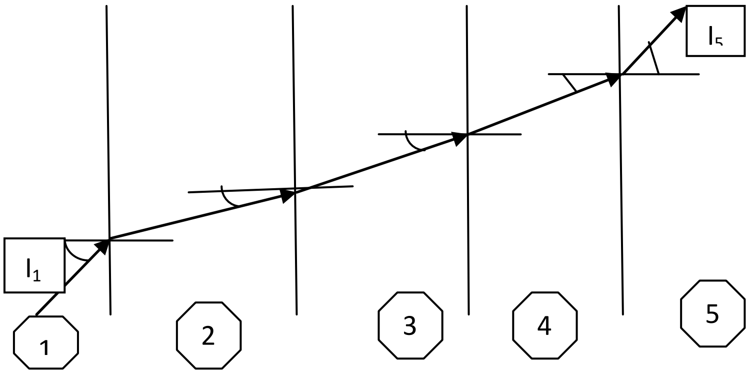
f) As ray of light moves from medium 1 to medium 2, its wave length changes but its frequency remains constant.

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

${}_1\mu_2 = \frac{\mu_2}{\mu_1}$ and ${}_2\mu_1 = \frac{\mu_1}{\mu_2}$ so, ${}_1\mu_2 = \frac{1}{{}_2\mu_1}$



h) Experiments show that if the boundaries of the media are parallel, the emergent ray CD although laterally displaced, is parallel to the incident ray AB if $\mu_1 = \mu_5$ or $\mu_1 \sin i_1 = \mu_5 \sin i_5$. So, $i_1 = i_5\ if\ \mu_1 = \mu_5$



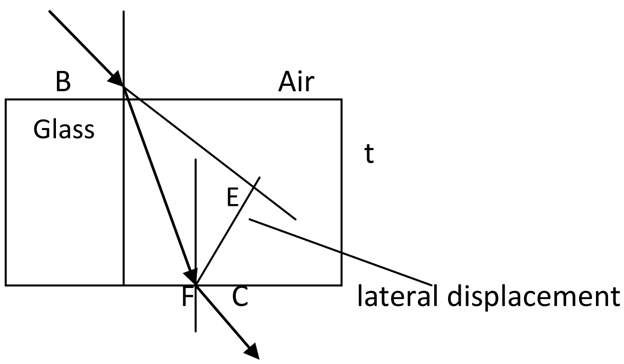
If any of the boundaries is not parallel, we cannot use this law directly by jumping the intervening media.

Cause of Refraction: Refraction (bending of light) occurs due to change in speed of light as it passes from one medium to other. Larger the change in speed of light as it passes from one medium to another, the more is the bending due to refraction.

Refraction of light due to (i) Plane Surface, (ii) Curved spherical surface, (iii) Thin lenses

And (iv) Prism

Expression for lateral displacement:



Lateral displacement

d=CE=BC sin (i-r)

Hence,

$$d = BC\sin(i-r) = \frac{BF}{\cos r}\sin(i-r) = t\frac{\sin(i-r)}{\cos r}$$

From Snell's law, $\sin r = \frac{\sin i}{\mu}$

Finally, we get, $d = t\sin i\left[1 - \frac{\cos i}{(\mu^2 - sin^2 i)^{\frac{1}{2}}}\right] ----(1)$

Hence, d →maximum value when i→90^0, so $d_{max} = t\sin 90^0 = t$

S0, the displacement of emergent ray cannot exceed the thickness of the glass slab.

From equation (1), the lateral shift produced by a glass slab increases with

a) Increase in the thickness of the glass slab
b) Increase in the value of angle of incidence
c) Increase in the value of refractive index of the slab.

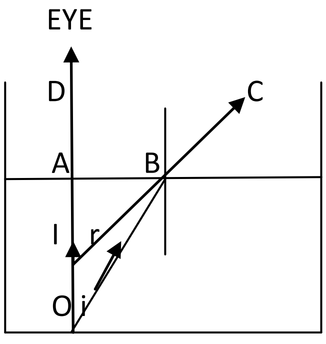
Practical application of refraction:

Why the apparent depth of an object placed in a denser medium less than the real depth?

It is due to refraction.

Let a point object O placed at the bottom of a beaker filled with water. The rays OA and OB starting from O are refracted along AD and BC respectively. These rays appear to diverge from point I. So I is the virtual image of O. Clearly the apparent depth AI is smaller than real depth AO. That is why a water tank appears shallower or an object placed at the bottom appears to be raised.

From Snell's law, $w^{\mu}{}_a = \frac{\sin i}{\sin r} = \frac{\frac{AB}{BO}}{\frac{AB}{BI}} = \frac{BI}{BO}$



As the size of pupil is small, the ray BC will enter the eye only if B is close to A. Then BI = AI and BO = AO, therefore,

$$w^{\mu}{}_a = \frac{AI}{AO} \Rightarrow a^{\mu}{}_w = \frac{AO}{AI}$$

That is, $Apparent\ depth = \frac{Real\ depth}{refractive\ index}$

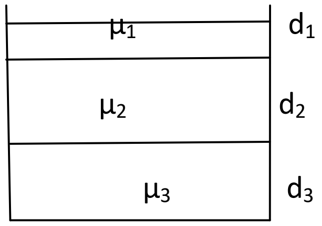
Normal shift: The height through which an object appears to be raised in a denser medium is called normal shift. Normal shift = Real depth – Apparent depth, or

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

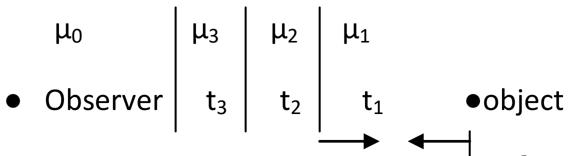
So, the higher is the value of μ, the greater the normal shift.

Refraction through composite slabs or through a number of parallel media as seen from μ_0

Three immiscible liquids of refractive indices μ_1, μ_2 and μ_3 ($\mu_3 > \mu_2 > \mu_1$) are filled in a vessel. Their depths are d_1, d_2 and d_3 respectively. The apparent depth (for normal incidence) when seen from top of first liquid will be



$d_{app} = \frac{d_1}{\mu_1} + \frac{d_2}{\mu_2} + \frac{d_3}{\mu_3}$ when top of first liquid is air.



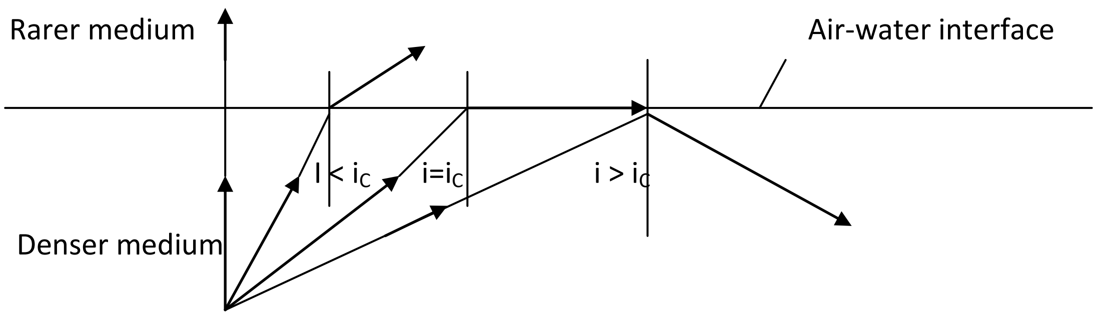
$$Apparent\ depth\ D_{app} = \sum \frac{d}{\mu_{rel}} = \frac{t_1}{\frac{\mu_1}{\mu_0}} + \frac{t_2}{\frac{\mu_2}{\mu_0}} + \frac{t_3}{\frac{\mu_3}{\mu_0}} + - - -$$

$$Apparent\ shift\ s = t_1\left(1 - \frac{1}{\mu_{1rel}}\right) + t_2\left(1 - \frac{1}{\mu_{2rel}}\right) + t_3\left(1 - \frac{1}{\mu_{3rel}}\right) + - - - -$$

Total Internal Reflection (TIR): If a light passes from an optically denser medium to rarer medium, then at the interface, the light is partly reflected back into the denser medium and partly refracted to the rarer medium. This reflection is called internal reflection.

Critical angle (i_C): The incidence angle in denser medium at which the refracted ray makes 90^0 angles along the surface of separation is called critical angle.

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



Necessary condition for total internal reflection:

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

Relation between critical angle and refractive index:

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

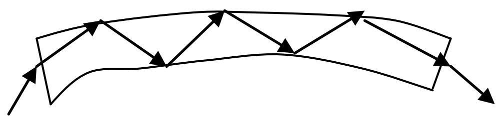
Here, i = i_C and r = 90^0, $\mu_a = 1$ and $\mu_2 = \mu$ (say), so, $\mu \sin i_C = \sin 90^0 \Rightarrow \mu = \frac{1}{\sin i_C}$

Critical angles of some transparent media:

Substance	Refractive index	Critical angle (^{0})
Water	1.33	48.75
Crown glass	1.52	41.14
Flint glass	1.65	32.31
Diamond	2.42	24.41

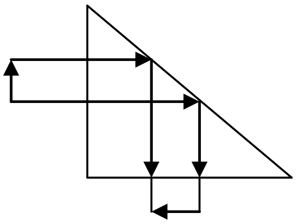
Applications to total internal reflection:

1. **Sparkling of diamond or brilliance of diamond**: The brilliance of diamond is due to TIR of light. The diamond is cut suitably so that light entering the diamond from any face falls at an angle greater than its critical angle (24.4^0).Therefore; it suffers multiple TIR at various faces and remains within the diamond, failing to come out. Hence the diamond sparkles.
2. **Mirage**: It is an optical illusion which occurs in deserts on hot summer days. The object such as a tree appears to be inverted as if the tree is on a bank of pond.
3. **Optical fibres**: It consists of several thousands of very long fine quality fibres of glass or quartz. The diameter of each fibre of the order 10^{-4} cm and refractive index of the material being the order of 1.5. The fibres are coated with thin layer of material of lower refractive index (1.48 nearly). This coating is cladding. Light incident on one end of the fibre at a small angle enters the fibre and strikes the cladding interface at an angle of incidence greater than critical angle and is reflected back into the core. Light thus travels inside the optical fibre in zig-zag path and finally comes out of the fibre at the other end and there is no loss of light through the sides of fibre.
   The only condition is that angle of incidence must be greater than critical angle of the fibre material w.r.t. to its coating.

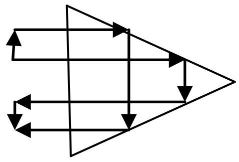


4. Totally reflecting glass prisms: These are right angled isosceles prism (45^0-90^0-45^0) which turns the light through 90^0 or 180^0. They are based on phenomenon of total

internal reflection of light. In totally reflecting glass prism, angle of incidence made 45^0 which is greater than the critical angle of glass air interface (42^0) of glass material (μ = 1.5), hence, light suffers total internal reflection.



Deviate a ray through 90^0



Deviate a ray through 180^0

Application of optical fibres:

1. It is used in medical and optical examination of even the inaccessible parts of human body (in endoscopy).
2. It is used in transmission and reception of electrical signals by converting them first into light signals.
3. It is used in telephones and other transmitting cables. Each fibre can carry up to 2000 telephone message with almost no loss of intensity.

Refraction of light from a curved (spherical) surface:

There are 16 cases as

a) Refraction through a curved surface when
   i. When the surface is convex or concave
   ii. When the light passes from rarer to denser medium
   iii. the object lies in rarer/denser medium
   iv. When the image formed is real or virtual

So, there are 2 x 2 x2 x 2 = 16 cases.

Assumptions:

1. Object taken as point object
2. For paraxial rays, sin or tan of angle equals to angle itself.

New Cartesian Sign convention:

1. All distances taken along incident light is positive and opposite to it is negative.
2. Height above principal axis is positive and below principal axis is negative.
3. All distances are measured from principal axis.

The formula of refraction through curved convex surface:

a) Object is placed in rarer medium, light passes from rarer to denser medium and image formed is real (in medium 2) or is virtual(formed in medium 1), the formula is given as $\frac{\mu_2}{v}-\frac{\mu_1}{u}=\frac{\mu_2-\mu_1}{R}$

b) Object is placed in denser medium, light passes from denser to rarer medium and the image formed is real (formed in rarer medium) or virtual (formed in denser medium), the formula is given as $\frac{\mu_1}{v}-\frac{\mu_2}{u}=\frac{\mu_1-\mu_2}{R}$

(Just replaced μ_1 by μ_2 and μ_2 by μ_1), So

i. When the light passes from rarer to denser medium, object lies in rarer medium, whether the surface is convex or concave and the image is real or virtual, the formula is given as

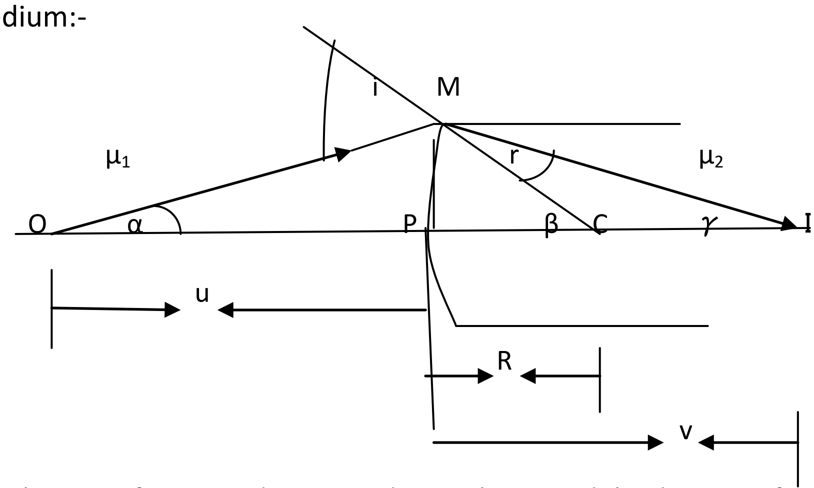
$$\frac{\mu_2}{v}-\frac{\mu_1}{u}=\frac{\mu_2-\mu_1}{R}$$

ii. When the light passes from dense to rarer medium, object lies in denser medium, whether the surface is convex or concave and the image is real or virtual, the formula is given as

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

(Note: All formulae must be derived with sign convention)

Derive the refraction formula through a curved convex (spherical) surface when a light ray passes from rarer to denser medium:-



Here, i = α + β and β = r + γ

Considering two transparent media having refractive indices μ_1 and μ_2 as shown and the distance of object O from M is u, image distance is v and radius of curvature R.

Let PC be the normal, applying Snell's law, $\mu_1 \sin i = \mu_2 \sin r$

For paraxial rays, $\sin i = i$ *and* $\sin r = r$, therefore, $\frac{\mu_2}{\mu_1}=\frac{i}{r}-----(1)$

Also, $\tan\alpha=\alpha=\frac{MP}{-u}$, $\tan\beta=\beta=\frac{MP}{R}$ and $\tan\gamma=\gamma=\frac{MP}{v}$ [for paraxial rays, tan α = α, tan β = β and tan γ = γ], hence,

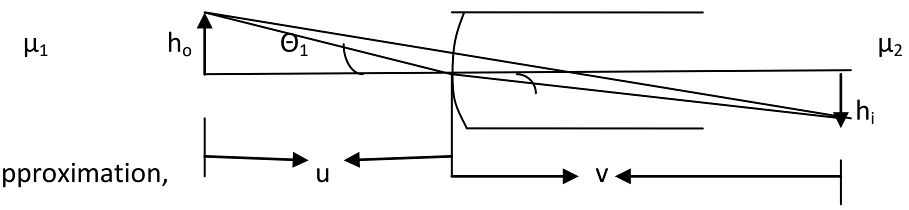
$$\frac{\mu_2}{\mu_1}=\frac{\alpha+\beta}{\beta-\gamma}=\frac{\frac{MP}{-u}+\frac{MP}{R}}{\frac{MP}{R}-\frac{MP}{v}}=\frac{\frac{1}{R}-\frac{1}{u}}{\frac{1}{R}-\frac{1}{v}}\Rightarrow\frac{\mu_2}{R}-\frac{\mu_2}{v}=\frac{\mu_1}{R}-\frac{\mu_1}{u}\Rightarrow\frac{\mu_2}{v}-\frac{\mu_1}{u}=\frac{\mu_2-\mu_1}{R}$$

So, when a light travels from rarer medium to denser medium, the following formula takes place as,

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

Derive the formula of lateral magnification through a curved surface:

We take the curved surface as convex. The figure is shown below-



With the paraxial approximation,

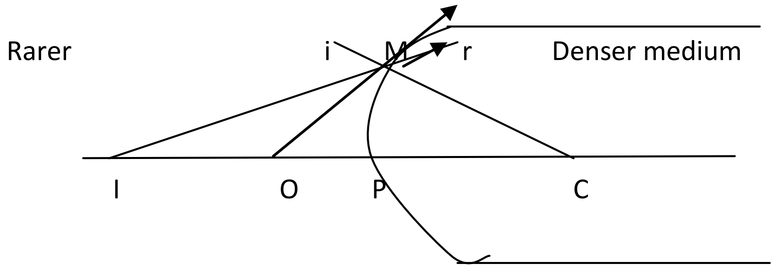
$\sin\theta_1 = \theta_1 = \tan\theta_1 = \frac{h_o}{-u}$ and $\sin\theta_2 = \theta_2 = \tan\theta_2 = \frac{-h_i}{v}$

Applying Snell's law, $\mu_1 \sin\theta_1 = \mu_2 \sin\theta_2$

So, Magnification, $m = \frac{h_i}{h_o} = \left(\frac{\mu_1}{\mu_2}\right)\left(\frac{v}{u}\right)$

Note: Curved refracting surface for convex lens means bulging portion is on rarer side.

Ray diagram and derivation of formula for refraction through a curved (convex) spherical surface when image formed is **virtual** and the light ray travels from rarer to denser medium:

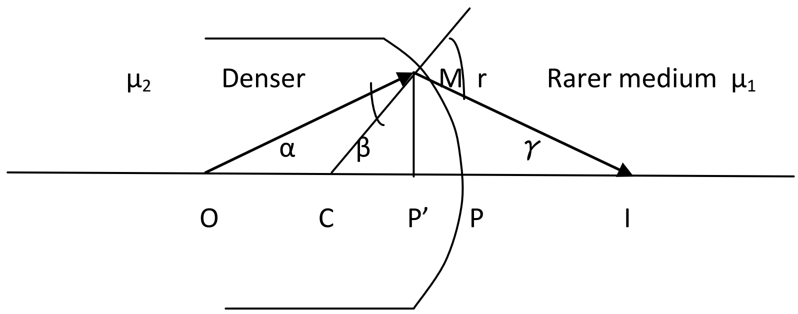


Here, r = β + γ

i = α + β

Derivation of formula for refraction through a curved (convex) surface when light travels from denser to rarer medium and image formed is **real:**

Let the object lies in denser medium of refractive index μ_2 and if image formed is real, it will be in rarer medium of refractive index μ_1.

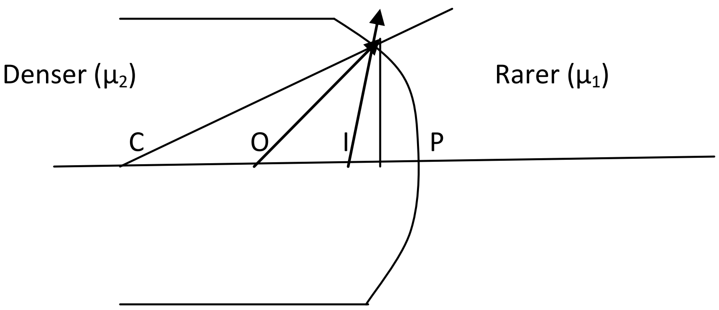


OCPI

Here, β = i + α

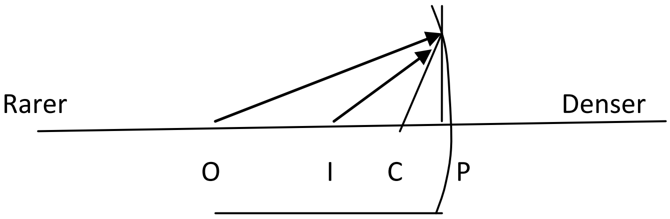
r = β + γ

Derivation of formula for refraction through curved (convex) spherical surface when image is **virtual** and light ray travels from denser to rarer medium:



COIP

Refraction through Concave spherical surface: Derivation of formula for refraction through curved (concave) spherical surface when image is virtual and light ray travels from rarer to denser medium:



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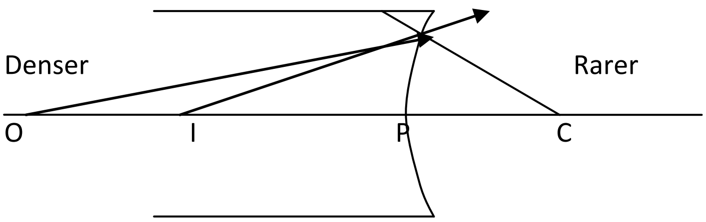
Derivation of formula for refraction through curved (concave) spherical surface when image is virtual and light ray travels from denser to rarer medium:



OIPC

Lenses: A lens is a piece of a refracting medium by two surfaces, at least one of which is a curved surface.

Type of lenses:

1. Convex or converging lenses and
2. Concave or diverging lenses

Convex lenses: It is thicker at the centre that at the edges. It converges a parallel beam of light on refraction through it. It has a real focus.

Types of convex or converging lenses:

a) Double convex lens-In which both surfaces are convex.
b) Planoconvex lens-In which one side is convex and other is plane
c) Concavoconvex lens- In which one side is convex and other is concave.

Types of concave or diverging lens:

a) Double concave or biconcave lens-In this case, both sides are concave.
b) Planoconcave lens- In this, one side is plane and other is concave
c) Convexoconcave lens-In which one side is concave and other is convex.

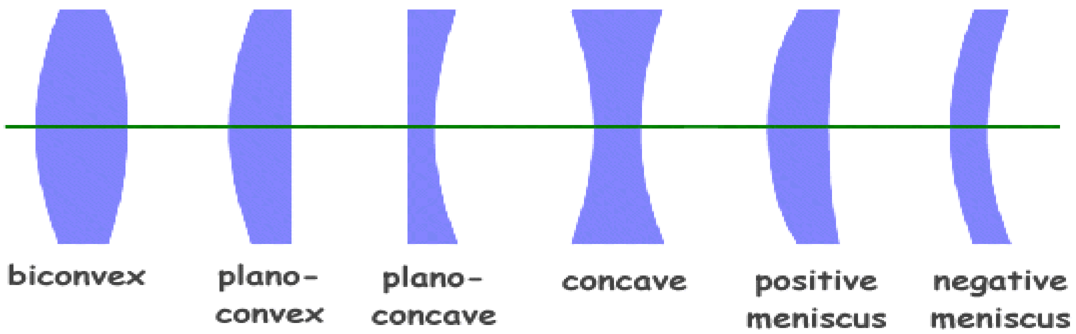
New Cartesian Sign Convention:

1. All distances measured from the optical centre of the lens.
2. The distances measured in the same direction as incident light travels, are taken positive and the distances measured in the direction opposite to the direction of incident light, are taken negative.
3. Height measured upward and perpendicular to the principal axis is taken positive and height measured downward and perpendicular to the principal axis is taken negative.

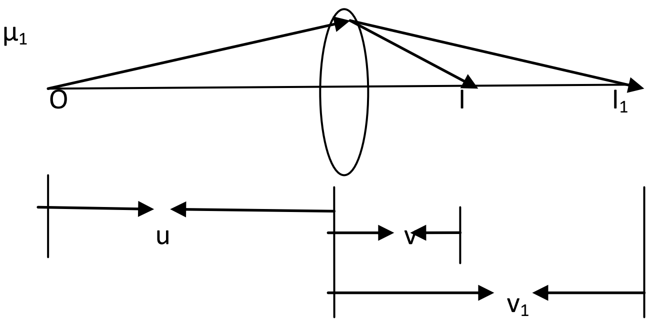
[Note: Principal axis is the imaginary axis passing through the optical centre and centre of curvature of spherical lenses.]

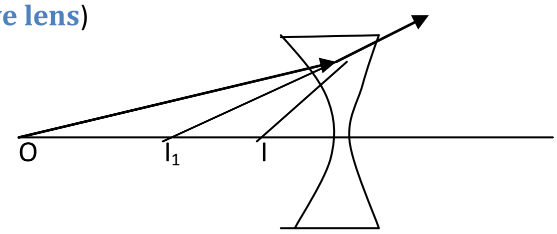
Assumptions used in the study of refraction at a spherical surface:

1. The object taken as a point object placed on the principal axis.
2. The aperture of the spherical refracting surface is small.
3. The incident and refracted rays make small angles with the principal axis so that sine or tangents of these angles may be taken equal to angles themselves.



Derive the Lens Maker Formula: (Convex and Concave lens)





Let v_1 be the image formed by refracting surface of radius R_1. This image acts as an object for the second refracting surface of radius R_2.

Applying curved surface refraction formula through convex surface

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

When refraction takes place from rarer to denser medium, we get

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

When refraction takes place from denser to rarer medium, we get

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

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

$$\mu_1\left(\frac{1}{v} - \frac{1}{u}\right) = (\mu_2 - \mu_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \Rightarrow \frac{1}{v} - \frac{1}{u} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) ----(3)$$

This expression (3) is valid for paraxial rays and when lens is thin and lens thickness is much less than R_1 and R_2. The focal length f of a thin lens is the image distance that corresponds to an object at infinity. So, putting u = ∞ and v = f, we get from equation (3) as

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

This equation (4) is a lens maker formula.

If the refractive index of the material is μ and the lens is placed in air, then $\mu_2 = 1$ and $\mu_1 = 1$ and hence lens maker formula becomes

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

Combining equation (3) and (4), we get,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} ----(5)$$

This equation (5) is the thin lens formula.

Note: Focal length of mirror depends upon the radius of curvature while focal length of lens depends upon μ_1, μ_2, R_1 and R_2.

1. Thus, if a lens and a mirror are immersed in a liquid, the focal length of lens would change while that of the mirror will remain unchanged.
2. If refractive index of the material of the lens is less than that in a medium, then lens changes its behaviour, i. e. a converging lens behaves as diverging lens and diverging lens behaves as a converging lens.
3. An air bubble in water seems as a convex lens but behaves as a concave lens.

Displacement method to determine the focal length of a convex lens:

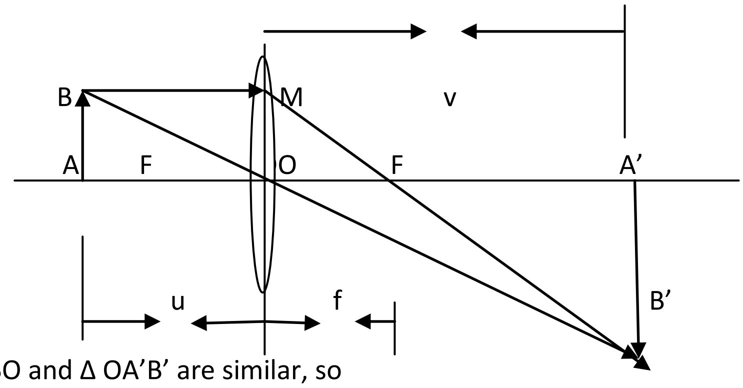
If the distance d between an object and screen is greater than 4 times the focal length of a convex lens, then there are two positions of the lens between the object and the screen at which a sharp image of object is formed on the screen. This method is called displacement method and is used in laboratory to determine the focal length of convex lens.

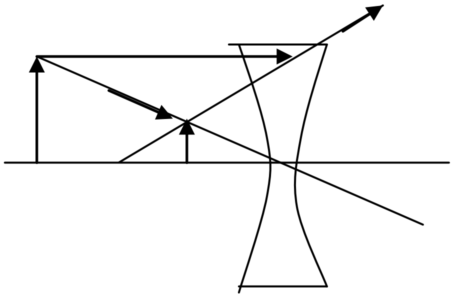
$f = \frac{D^2 - d^2}{4D}$, where D is the distance between object and screen, d = separation between images

Thin Lens formula:

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

Derive the formula made in equation (1) above for both convex and concave lenses-





$\triangle$ ABO and Δ OA'B' are similar, so

$$\frac{A'B'}{AB} = \frac{OA'}{OA} = \frac{v}{-u} - - - - - - (1)$$

$\triangle$ OMF and $\triangle$ FA'B' are similar, so

$$\frac{A'B'}{OM} = \frac{FA'}{OF} \Rightarrow \frac{A'B'}{AB} = \frac{v-f}{f} - - - - (2)$$

From equation (1) and (2), $\frac{v}{-u} = \frac{v-f}{f}$

Or, $vf = -uv + uf \Rightarrow (u-v)f = uv \Rightarrow \frac{1}{v} - \frac{1}{u} = \frac{1}{f}$, or $\boxed{\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \quad \blacksquare}$

This formula is valid for both convex and concave lens as well as for real and virtual images.

Linear magnification (m) (or transverse or lateral) for thin lenses (concave and convex):

$$m = \frac{size\ of\ image}{size\ of\ object}$$

In the figure-1 above, let AB = h_1 and A'B' = h_2, hence, $m = \frac{h_2}{h_1} = \frac{I}{O}$

$\triangle$ ABO and Δ OA'B' are similar, so, $\frac{A'B'}{AB} = \frac{OA'}{OA} = \frac{v}{-u} = m = \frac{-h_2}{h_1}$

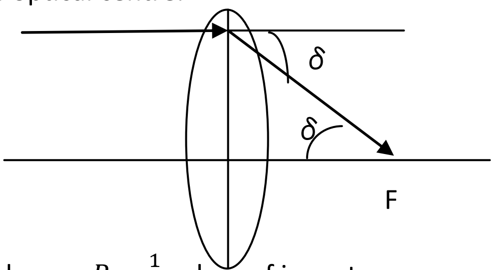
Hence, magnification, $m = \frac{I}{O} = \frac{v}{u} = \frac{f}{f+u} = \frac{f-v}{f}$

Power of a lens:

The power of a lens is the measure of degree of convergence or divergence of the light rays falling on it.

So, the smaller the focal length, the more is the ability to bend light rays and the greater is its power.

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



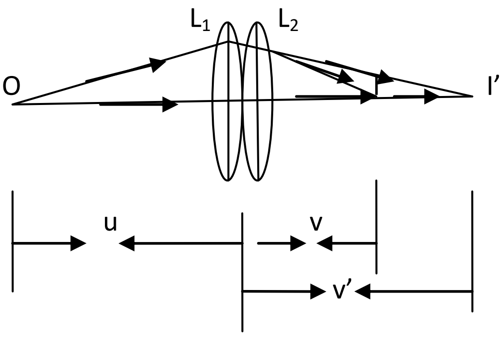
$\mathrm{P} = \tan\delta = \frac{h}{f}$, Here, h = unit distance = 1 m, hence, $P = \frac{1}{f}$ where, f in metre

The Unit of Power of a lens: Dioptre (D), so, one dioptre is the power of a lens whose principal focus is 1 m. If power of a lens is given as + 2 D, it means it is a convex lens and its focal length is 50 cm. If power of a lens is – 2.5 D, it means it a concave lens and its focal length is -40 cm.

When lenses are used in combination, the total magnification is $m = m_1 \; x \; m_2 \; x \; m_3 \; x \; - - -$

Combination of Lenses: Focal length and power of two or more lenses in contact:

Derive an expression of effective focal length of two thin lenses placed in contact co-axially with each other.



Let OC_1 is u and in the absence of second

Lens L_2, real image formed by lens L_1 is I' at

distance v'.

Using thin lens formula,

$$\frac{1}{f_1} = \frac{1}{v'} - \frac{1}{u} - - - - - - (1)$$

The image I' acts as a virtual object for the second lens L_2 which finally forms its real image at I of O at distance v. Thus,

$$\frac{1}{f_2} = \frac{1}{v} - \frac{1}{v'} - - - - - - (2)$$

Adding equation (1) and (2), the equivalent focal length of the combination is

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f_1}+\frac{1}{f_2}----(3)$$

If we assume the combined lens act as a single lens of focal length F and makes image at distance v of an object O placed at a distance u, then

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

Comparing equation (3) and (4), we get

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

Similarly, if more than two lenses in contact, the equivalent focal length is

$$\frac{1}{f}=\sum_{i=1}^{i=n}\frac{1}{f_i}$$

Here f_1, f_2 etc. are substituted with sign.

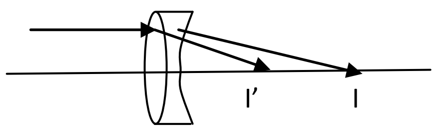
For n thin lenses in contact, the equivalent power is given by

$$P=P_1+P_2+P_3\pm----$$

If one of the lenses is concave then combined focal length is

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

Here f_2 is negative for concave lens.

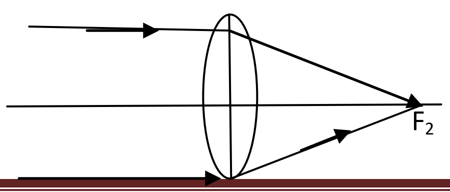


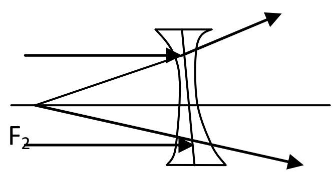
If f_1 = f_2, then f = ∞ and combined lens behave as plane mirror.

If $f_1>f_2$, the combined lens behaves as concave lens and if $f_1<f_2$, the combined lens behave as a convex lens.

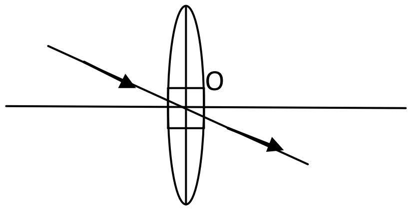
Images formed by thin lenses: To construct the image of a small object perpendicular to the axis of a lens, two of the following three rays are drawn from the top of the object.

1. A ray parallel to the principal axis passes through the principal focus (in case of convex lens) or appears to diverge from it.

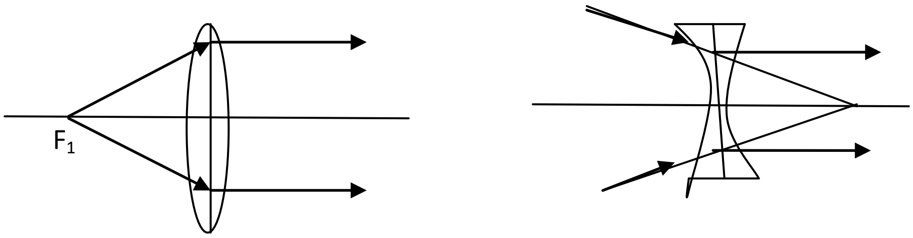




2. A ray through the optical centre passes undeviated because middle of a lens acts like a thin parallel sided slab.



3. A ray passing through the first focus F_1 becomes parallel to the principal axis after refraction.



Construct the ray diagram to show the nature of the images as for convex lens:

Object Position	Image Position	Size of image.	Nature of image
At infinity	At focus	Very small (Diminished)	Real & inverted
Between 2F and ∞	Between 2F & F	small	Real & inverted
At 2F	At 2F	Equal as object	Real & inverted
Between 2 F & F	Between 2F & ∞	Large	Real & inverted
At F	At infinity	Very large	Real & inverted
Between F and Optical centre	Beyond first focus	Large	Virtual & erect

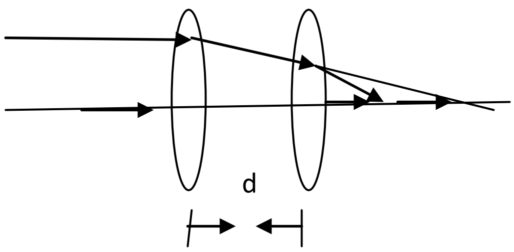
Construct the ray diagram to show the nature of the images as for concave lens:

Object position	Image Position	Size of image	Nature of image
At any position on principal axis	Between F and Optical centre	Smaller	Virtual and Erect

Combined focal length of two convex lenses when separated by distance d:

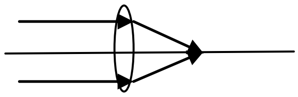
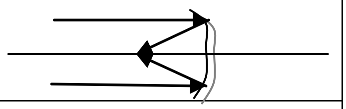
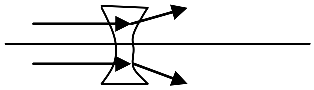
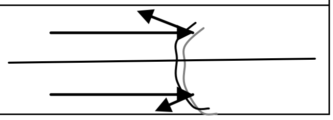
$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$

And combined power is given by $P = P_1 + P_2 - dP_1P_2$



Comparison of focal length, power and ray diagram of lens and mirror:

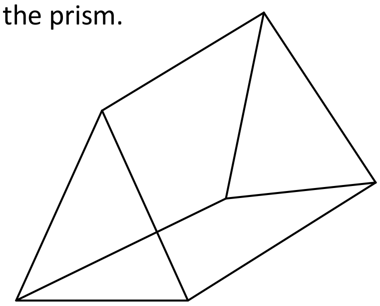
The shorter the focal length of a lens or mirror, the more it converges or diverges, i. e. the bending of light is more for shorter focal length.

Nature of lens/Mirror	Focal length (f)	Power	Converging /diverging	Ray diagram
Convex lens	Positive	$P = \frac{1}{f}$ (Positive)	Converging	
Concave mirror	Negative	$P = -\frac{1}{f}$ (Positive)	Converging	
Concave lens	Negative	$P = \frac{1}{f}$ (Negative)	Diverging	
Convex mirror	Positive	$P = -\frac{1}{f}$ (Negative)	Diverging	

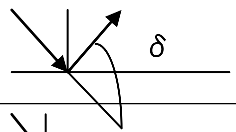
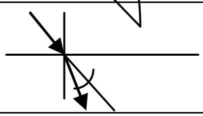
Refraction of Light through a Prism:

A prism a wedge shaped portion of a transparent refracting medium bounded by two plane faces inclined to each other at certain angle.

Here, two plane faces are ABED and ACFD and these two faces are inclined to each other, called refracting faces of the prism.



Deviation (δ):

Mirror/Lenses/ Prism	Deviation angle	Ray diagram
Reflection	$\delta = 180 - 2i = 180 - 2r$	
Refraction	$\delta = i - r$	
Prism	$\delta = i_1 + i_2 - A$ If i and A are small, deviation $\delta = (\mu - 1)A$	

The angle of deviation is the angle between incident ray and emergent ray.

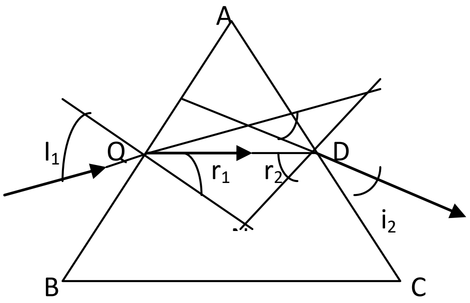


Fig. 1: Refraction through a prism

From the quadrilateral triangle AQFD, $\angle A + \angle F = 180^0$

In $\triangle$QFD, $\angle F + r_1 + r_2 = 180^0$, so , $\angle A = r_1+r_2$ -------- (1)

Now, deviation $\delta = \delta_1 + \delta_2$ ------- (2)

And, $\delta_1 = i_1 - r_1$ and $\delta_2 = i_2 - r_2$ hence from equation (2), $\delta = (i_1 + i_2)-(r_1 + r_2) = (i_1+i_2) - A$ [from eqn. 1]

Therefore, $\delta = i_1 + i_2 - A$------- (3)

Factors on which angle of deviation depend:

1. The angle of incidence
2. The angle of prism or refracted angle
3. The material of prism and
4. The wavelength of light used

Derive expression for the refractive index of the material of a prism in terms of the angle of prism and angle of minimum deviation and plot the variation of angle of deviation Vs. angle of incidence for a prism:

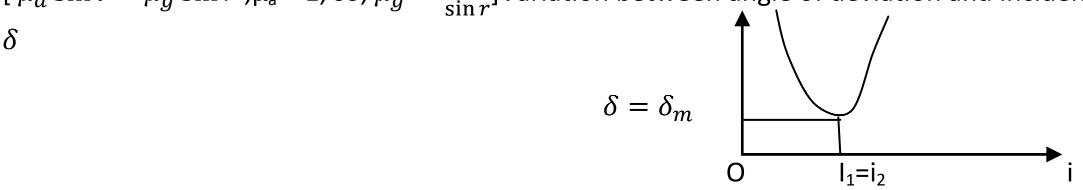
From the fig. 1 above, refraction through a prism,

When a prism is in the position of minimum deviation, a ray of light passes symmetrically (parallel to BC) as in Fig.1 above. So, $i_1 = i_2 = i$ (say) and $r_1 = r_2 = r$ (say), therefore $\delta = \delta_m$

So, from equation (3), $\delta_m = 2i - A$ or $i = \frac{A+\delta_m}{2}$ and $A = r_1 + r_2 = 2r$ or $r = \frac{A}{2}$ So, refractive index

$$\mu_g = \frac{\sin i}{\sin r} = \frac{\sin \frac{A+\delta_m}{2}}{\sin \frac{A}{2}} \quad \blacksquare$$

[$\mu_a \sin i = \mu_g \sin r$,μ_a = 1, so, $\mu_g = \frac{\sin i}{\sin r}$]Variation between angle of deviation and incidence angle:



Derivation through a prism of small angle:

Derive an expression for the angle of deviation of a small prism in terms of refractive index and angle of prism, if A and i_1 are small.

Suppose light is incident at a small angle i on the face of prism AB (Fig. 1), so angle i_1, r and r_1 will also be small angles. Now, for small angle sin i = i, sin i_1 = i_1, sin r = r and sin r_1 = r_1, hence

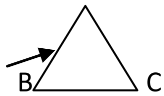
$$\mu_a \sin i_1 = \mu_g \sin r_1 \Rightarrow \mu_g = \frac{\sin i_1}{\sin r_1} = \frac{i_1}{r_1} \Rightarrow i_1 = \mu_g r_1 \ and$$

$$\mu_g \sin r_2 = \mu_1 \sin i_2 \Rightarrow \mu_g = \frac{\sin i_2}{\sin r_2} = \frac{i_2}{r_2} \Rightarrow i_2 = \mu_g r_2 \ so$$

$$\delta = i_1 + i_2 - A = \mu_g r_1 + \mu_g r_2 - A = \mu_g (r_1 + r_2) - A = \mu_g A - A = A(\mu_g - 1) \ hence$$

$$Deviation\ through\ a\ prism\ of\ small\ angle\ is\ \delta = A(\mu_g - 1) \quad \blacksquare$$

Condition for no emergence in a prism: That is, if ray of light entering the face AB and does not come out of the face AC for any value of angle i_1, TIR takes place on face AC



That is, when for all values of r_2 is greater than critical angle value.

Since, A = r_1 + r_2 or, r_2 = A – r_1, or, $r_{2\,min}$ = A – $r_{1\,max}$

Now, r_1 will be maximum when i_1 is maximum and i_1 will be maximum when its value is 90^0. So,

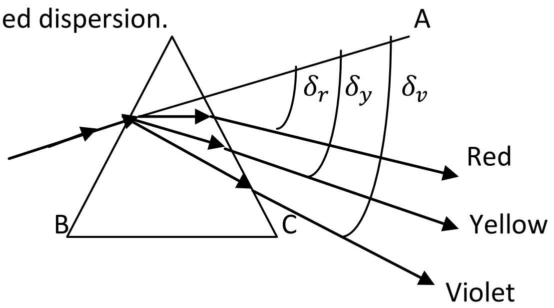
$$\mu = \frac{\sin(i_1)_{max}}{\sin(r_1)_{max}} = \frac{\sin 90^0}{\sin(r_1)_{max}} \Rightarrow \sin(r_1)_{max} = \frac{1}{\mu} = \sin\theta_c \Rightarrow (r_1)_{max} = \theta_c$$

So, $(r_2)_{min} = A - \theta_c$

Now, if minimum value of $r_2 > \theta_c$, then all values of r_2 will be greater than θ_c and TIR will take place under all condition. Thus, for condition of no emergence is $(r_2)_{min} > \theta_c \ or \ A - \theta_c > \theta_c \ or$

$$\boxed{A > 2\theta_c}$$

Dispersion of white light: If a beam of white light, which contains all colours, is sent through prism, it is separated into spectrum (orderly arrangement of increasing or decreasing order of wavelength or frequency is called spectrum) of colours. The spreading of light into its colour components is called dispersion.



Note: For certain value of incidence angle, the red light (greatest wavelength of visible light) will deviate less; i. e. angle of refraction (r) for red light will be greatest of all visible light. That is, μ is less for red light so δ will be minimum.

If δ_R, δ_Y and δ_V are the deviations for red, yellow and violet components, then average deviation is measured by δ_Y as yellow light falls in between red and violet light.
$\delta_v - \delta_r = Angular\ dispersion$

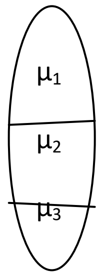
Dispersive power (ω): It is the ratio of angular dispersion to the average deviation when a white beam of light falls on it. Using the formula, $\delta = A(\mu - 1)$, [this equation is valid when A and i are small.]Hence,

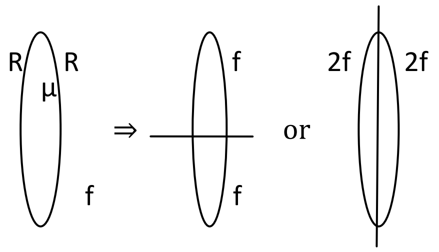
$$\omega = \frac{\delta_v - \delta_r}{\delta_y} = \frac{\mu_v - \mu_r}{\mu_y - 1}$$

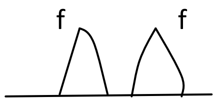
Spectrometer: It is an optical device used for producing and studying the spectra of different light colours.

Application of spectrometer: (1) to measure the angle of prism, (ii) to determine the refractive index of prism, (iii) to determine the wavelength of light and (iv) to measure the dispersive power of a prism.

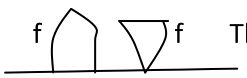
Extra points: A lens made of three different materials has three focal lengths. Thus for a given objects, there are three images.



1. 

2. 

The resultant focal length in this case is f/2

3. 

The resultant focal length will be infinity as optic axes of both parts have been inverted.

Optical Instrument: Optical instruments are used to assist the eye in viewing an object. Our eye lens has a power to adjust its focal length to see the nearer objects. The process of adjusting focal length is called accommodation.

Range of normal vision: The distance between infinity and 25 cm point is called the range of normal vision.

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

Near point: The nearest point from the eye at which an object can be seen clearly by the eyeis called its near point.

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

Power of accommodation: It is the maximum variation of its power for focussing on near and far (distant) objects. For a normal eye, the power of accommodation is 4 D.

Persistent of vision: The phenomenon of the continuation of the impression of an image on the retina for some time even after the light from the object is cut off, is called persistent of vision.

Defects of vision: a) Myopia or near sightedness, b) Hypermetropia or far sightedness, c) Presbyopia, (d) Astigmatism

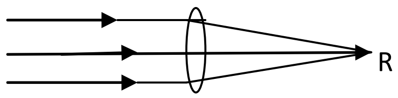
Myopia: It is a vision defect in which a person can see nearby objects clearly but cannot see the distant objects clearly beyond a certain point. This defect is common among children.

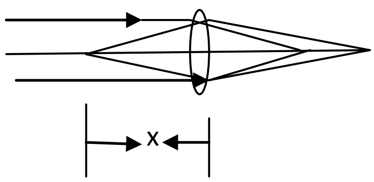
Causes of Myopia:

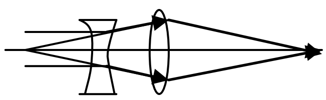
a) Elongation in size of eye ball i. e. distance of retina from the eye lens increases.
b) Decrease in focal length of the eye lens when the eye is fully relaxed.

Correction of myopia: The person has to use spectacles with a concave lens of suitable focal length.

Let x be distance from the actual far point of the myopic eye and f be the focal length of concave lens to be used.







Normal eye, sharp image of object at infinity

Blurred image of object at infinity

And sharp image of object at far point (F)

u = ∞, v = - x so, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ or f = - x, required power P = - 1/x

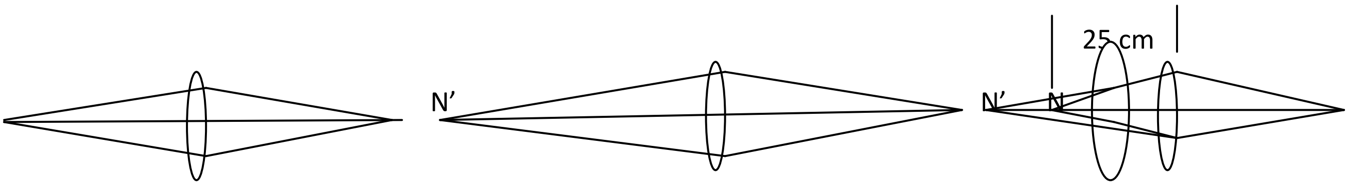
Hence focal length of concave lens put in front of the eye should be equal to distance of far point of the defective eye.

Hypermetropia: A person can see the distant object clearly and cannot see the nearby objects clearly.

Causes of Hypermetropia:

a) Contraction in the size of eye ball i. e. distance of retina from eye lens has decreased.
b) Increase in the focal length of eye lens when the eye is fully relaxed.

Corrective lens: A person has to use spectacles with a convex lens of suitable focal length.



For normal eye | Image forms behind the retina

Calculation of focal length and power of convex lens:
Let y is being the distance of near point N' from the defective eye. Now the near point N of the normal eye is 25 cm. The object placed at N, forms the virtual image at N' due the convex lens.
So, u = -D, v =-y, Using lens formula, $\frac{1}{-y} - \frac{1}{-D} = \frac{1}{f} \Rightarrow f = \frac{yD}{y-D}$ and required power is $P = \frac{y-D}{yD}$

Presbyopia: A person cannot see nearby objects as well as far objects clearly. This happens in old age. A person should use bi-focal lens. The upper half of each lens should be diverging (concave) to correct myopia and lower half should be converging (convex) to correct Hypermetropia.

Astigmatism: It is the defect in which a person cannot see simultaneously both horizontal and vertical view of an object with the same clarity.

Causes: This defect occur when cornea is not perfectly spherical shape. It may have large curvature in the vertical plane than in the horizontal plane or vice-versa.

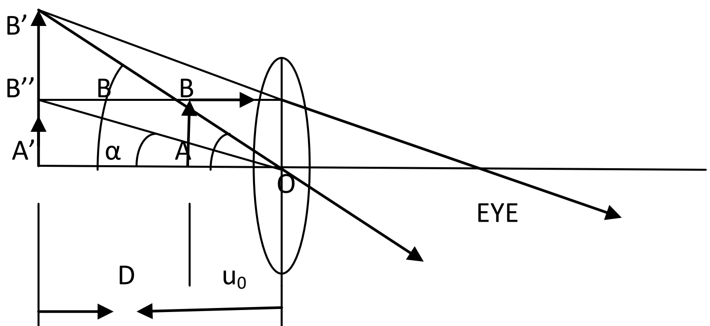
Correction: It can be corrected by a lens whose one surface is cylindrical.

Magnifying power for (M) for microscope: It is the factor by which the image on the retina can be enlarged by using the microscope or telescope.

$$M = \frac{Angle\ subtended\ by\ image\ at\ the\ least\ distance\ of\ distinct\ vision}{Angle\ subtended\ by\ object\ at\ the\ least\ distance\ of\ distinct\ vision}$$

Microscope: (i) Simple microscope and (ii) Compound microscope

Simple Microscope: A simple microscope is used for observing magnified images of tiny objects. So it is also called a magnifying glass.
It consists of a converging lens of small focal length. A virtual, erect and magnifying image is formed at the least distance of distinct vision from the eye held close to the lens.
Basically all optical instruments magnify the angular size of the object.



Magnifying power for Simple Microscope:

$$M = \frac{\beta}{\alpha} = \frac{\tan\beta}{\tan\alpha} = \frac{\frac{AB}{OA}}{\frac{AB"}{OA'}} = \frac{OA'}{OA} = \frac{-D}{-u_0} = \frac{D}{u_0} --- (1)$$

a) **For relaxed eye**, the final image should be at infinity. That is, $v_0 = \infty$, so $u_0 = f$ as $[\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{\infty} - \frac{1}{-u_0} = \frac{1}{f} \Rightarrow f = u_0]$, so magnifying power for Simple microscope for relaxed eye will be

$$M_\infty = \frac{D}{f}$$

This is also called magnifying power for normal adjustment. Here, $M_\infty > 1$ if f < D.

b) **Magnifying power when final image is at D**.

The magnifying power can be further increased by moving the object still closure to the lens. Suppose final virtual image is formed at D. Using lens formula,

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{-D} - \frac{1}{-u_0} = \frac{1}{f} \Rightarrow \frac{1}{u_0} = \frac{1}{D} + \frac{1}{f}$$

Substituting the value of $1/u_0$ in equation (1), we get

$$M_D = \left(\frac{1}{D} + \frac{1}{f}\right) D = 1 + \frac{D}{f}$$

Note: $M_D > M_\infty$ if final image is formed at 25 cm, angular magnification is increased but eye is most strained. On the other hand when final image is at infinity, magnification is slightly less than eye is relaxed. So the choice is yours whether you see bigger size with strained eye or smaller size with relaxed eye. Roughly a magnification up to 4 is trouble free.

Note: The magnifying power is expressed with unit X as 10 X magnifier if M = 10.

Uses of simple microscope:

1. Watchmakers and jewellers use magnifying glass to watch small parts of watches or fine jewellery work
2. In magnifying the printed letter in a book
3. For reading Vernier scale in laboratory

Compound Microscope: It consists of two converging lenses arranged co-axially. The one facing the object is called objective and another close to eye is called eye piece. The objective has the smaller aperture and smaller focal length than those of the eye piece.

The separation between the objective and the eye piece (called the length (L) of microscope) can be varied by appropriate screws fixed on the panel of microscope.

The object is placed beyond first focus of objective so that an inverted and real image is formed by the objective. This intermediate image acts as an object for eye piece and lies between first focus and pole of eye piece. The final magnified virtual image is formed by the eye piece.
To view an object with naked eye, the object must be placed between D and infinity. The maximum angle is subtended when it is placed at D.

Ray diagram of compound microscope when final image at D:

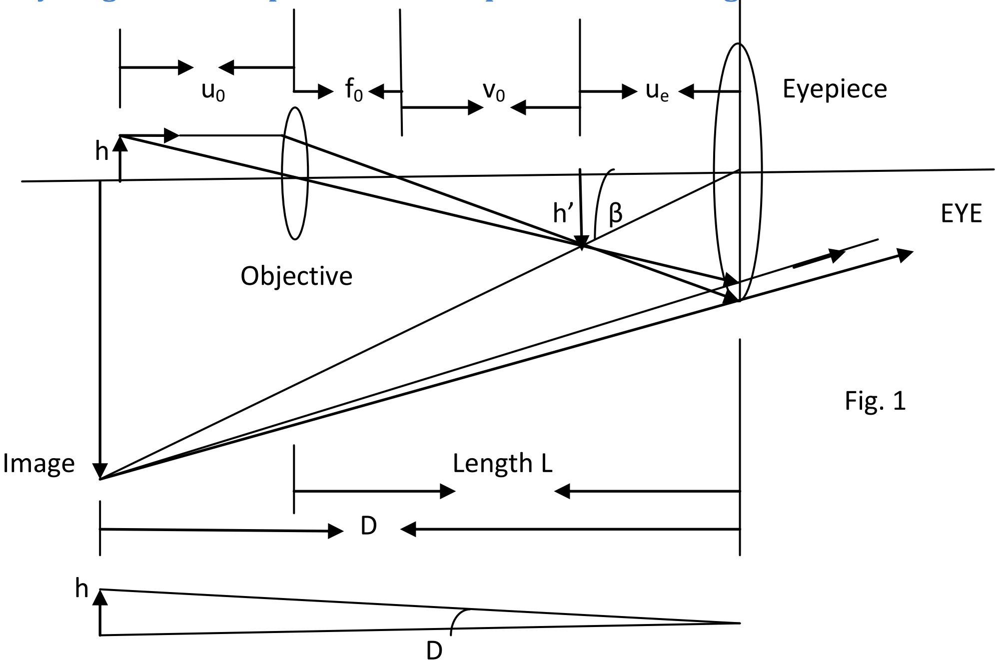


Fig. 1

Magnifying power of compound microscope

$$M = \frac{\beta}{\alpha} = \left(\frac{-h'}{u_e}\right)\left(\frac{-D}{h}\right) = \left(\frac{h'}{h}\right)\left(\frac{D}{u_e}\right)$$

Here, $\frac{h'}{h} = Linear\ magnification\ by\ the\ objective$. Thus, $m_0 = \frac{v_0}{u_0}$

So,

$$\boxed{M = -\frac{v_0}{u_0}\left(\frac{D}{u_e}\right)}$$

Length of the microscope will be,

$$L = v_0 + u_e$$

a) For **relaxed eye**: final image should be at infinity.
So, $u_e = f_e$, therefore,

$$M_\infty = \frac{v_0}{u_0}\left(\frac{D}{f_e}\right)$$

And length of microscope $L_\infty = v_0 + f_e$

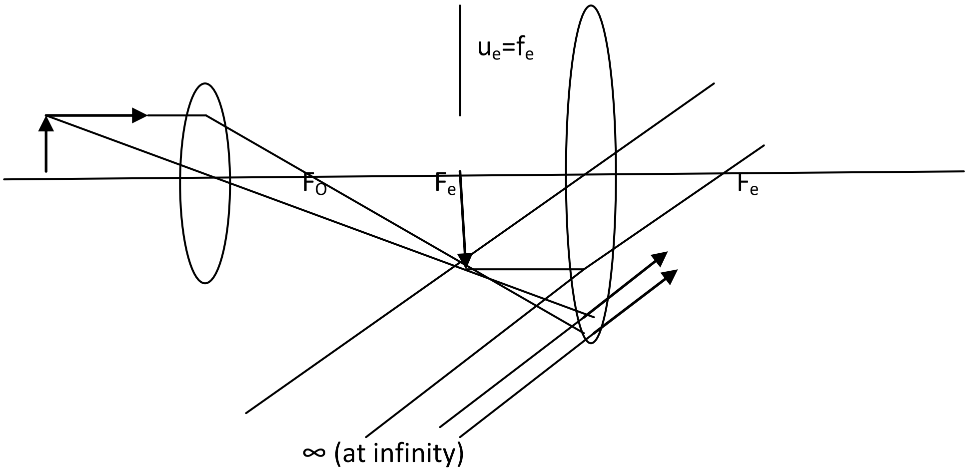
b) **Final image at D:** When the final image by eyepiece is formed at D (at near point), applying lens formula as $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ we have,

$$\frac{1}{-D} - \frac{1}{-u_e} = \frac{1}{f_e} \Rightarrow u_e = \frac{Df_e}{D + f_e}$$

Thus,

$$\boxed{\begin{aligned} M_D &= \frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right) \\ L_D &= v_0 + \frac{Df_e}{D + f_e} \end{aligned}}$$

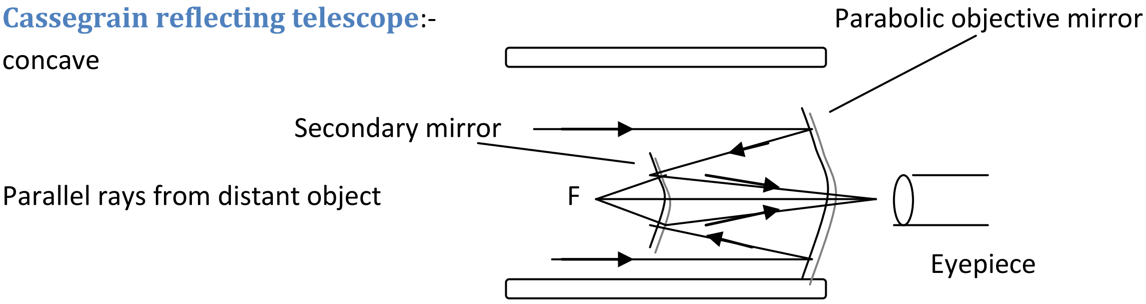
(ii) **Ray diagram of compound microscope when final image is at infinity:**



Telescope: A microscope is used to view the objects placed closed to it. To look at distant objects such as star, a planet or a distant tree etc. We use telescope. There are three types of telescope in the use.

Reflecting astronomical telescope: These telescope forms image free from chromatic aberration and spherical aberration.

Cassegrain reflecting telescope:-



The parallel rays from the distant object are reflected by the large concave mirror. They are again reflected by the small convex mirror and converged to a point I. The final image formed at I is viewed through the eye piece.AS the first image at F is inverted with respect to the distant object and second image I is erect with respect to first image F, hence final image is inverted with respect to the object.

Important advantages:

1. There is no chromatic aberration.
2. The spherical aberration is also removed.
3. The larger focal length of objective of telescope and hence larger aperture of mirror (concave) used, the reflecting telescope have high resolving power.

Let f_0 be the focal length of objective and f_e that of eyepiece,.

Final image formed at least distance of distinct vision,

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

For the final image formed at infinity,

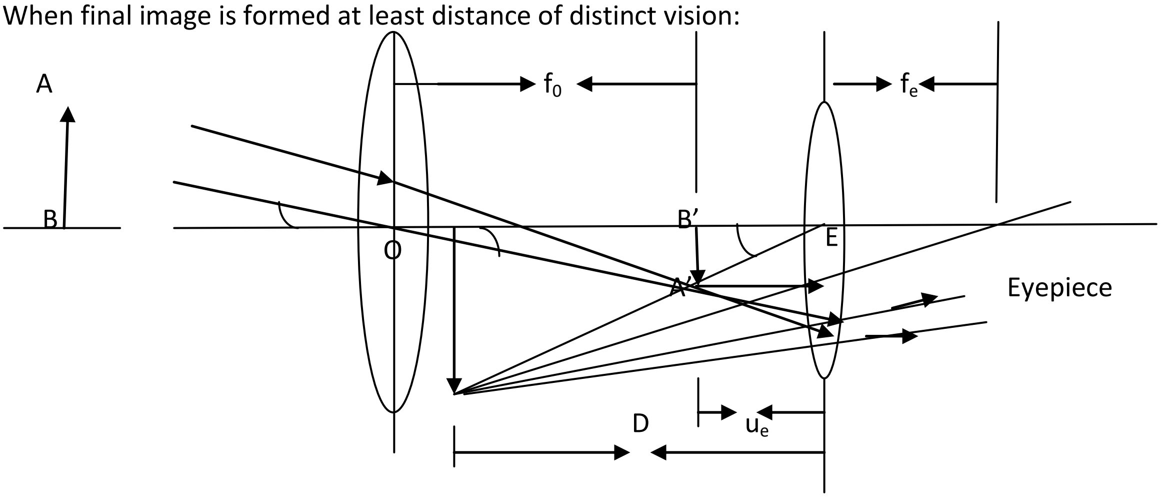
$$m = \frac{f_0}{f_e} = \frac{\frac{R}{2}}{f_e}$$

Where f_0 = R/2 and R is the radius of curvature of objective mirror.

Refracting type astronomical telescope:

Construction: It consists of two converging lenses mounted co-axially at the outer ends of two sliding tubes. One of the lenses is objective of large focal length and large aperture so that it can gather sufficient light from the distant objects. The other one is eyepiece to have small focal length.

When final image is formed at least distance of distinct vision:



Magnifying power:

$$m = \frac{\beta}{\alpha} = \frac{\tan\beta}{\tan\alpha} = \frac{\frac{A'B'}{B'E}}{\frac{A'B'}{OB'}} = \frac{OB'}{B'E} = \frac{f_0}{-u_e}$$

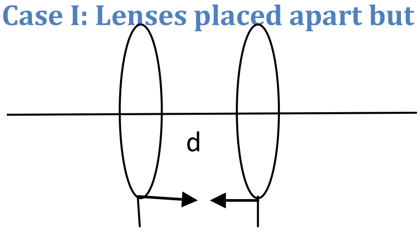
When final image is formed at least distance of distinct vision D, then v = -D, applying 1/v -1/u = 1/f

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

So, $M_D = f_0\left(\frac{D+f_e}{Df_e}\right)$

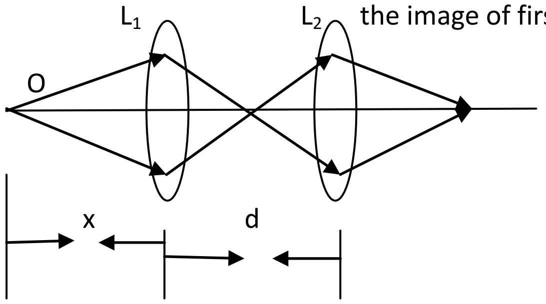
Extra points: (1) Lenses placed at a distance from each other:

Case I: Lenses placed apart but object at infinity



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

Case II: Lenses placed apart and object at finite distance



the image of first lens will act as an object for the second lens.

Let the image formed at y to the right of lens L_1.

Refraction at the first lens:, here, u = -x, f = f_1 and v = y, so $\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{y} = \frac{1}{f_1} + \frac{1}{-x}$

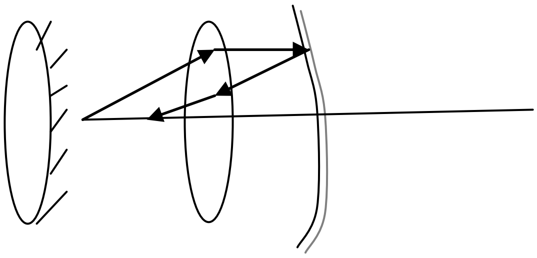
So, y can be determined.

Refraction at the second lens: here, u = -(d-y), f = f_2, let the image be at distance z to the right of lens L_2. So, using 1/v – 1/u = 1/f, we have,

$$\frac{1}{z} = \frac{1}{f_2} + \frac{1}{-(d-y)}$$

From which z can be calculated.

Silvered lenses:



(Lens-Mirror-Lens combination)

(Convex lens +concave mirror)

Using the method of superposition,

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

$$\frac{1}{-v_2} + \frac{1}{-v_1} = \frac{1}{-f_m} - - - - (2)$$

$$\frac{1}{v} - \frac{1}{v_2} = \frac{1}{-f_2} - - - - (3)$$

Arranging all three, we get

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f_m} - \frac{2}{f_L} - - - - (4)$$

This is the equation of mirror. So, silvered lens finally behave as a mirror. Here, focal length of second lens will be negative. Also, f1 = f2, So equivalent focal length as

$$\frac{1}{f_e} = \frac{1}{f_m} - \frac{2}{f_L}$$

Concept of image forming at object itself

In some unique situations, the image is formed at the same point as the object, if we apply the lens formula, we get

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

which is not possible. On the other hand, for the case of refraction across a single curved surface, the formula is

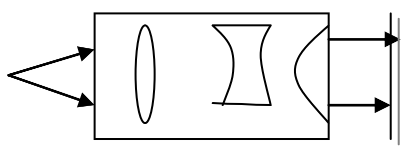
$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$

Which reduces to $\frac{\mu_2}{u} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$. The solution for which is u =R.

Therefore, object and image coincide when object is placed at the centre of curvature. Similarly in case of mirrors, the formula is, $\frac{1}{v} + \frac{1}{u} = \frac{2}{R}$ and the solution once again is u = R. Therefore, for mirrors and refraction across a single curved surface, we can say that the object and image will coincide only when the object is kept at the centre of curvature.

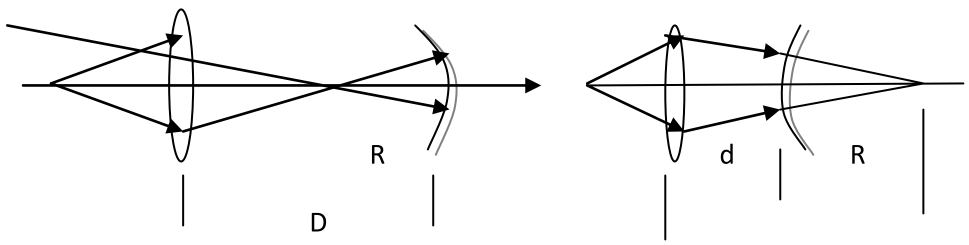
The mirror will be at the end of optical train. Three situations are possible.

Case I: A plain mirror at the end of optical train

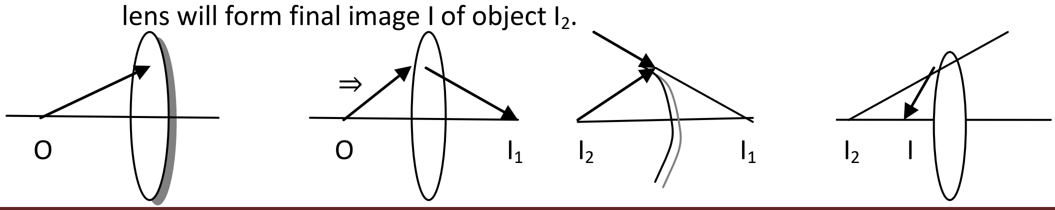


The ray strikes the mirror normally and the image after the last lens formed at infinity.

Case II: A concave mirror of radius of curvature R and case III: A lens with convex mirror



1. **Lens with one silvered surface:** If the back surface of lens is silvered and an object is placed in front of it, then:
   a) First, light will pass through the lens and it will form the image I_1.
   b) Image I_1 will act as an object for silvered surface which acts as a curved mirror and forms image I_2 of the object I_1.
   c) The light after reflection from the silvered surface will again pass through the lens and lens will form final image I of object I_2.



In such a situation, power of silvered lens will be

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

Where, $P_L = 1/f_L$ and $P_M = -1/f_M$ and $f_M = R/2$ and focal length of lens will be as

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

So, the system will behave as a curved mirror of focal length $F = -\frac{1}{P}$

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

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

Rayleigh has shown theoretically that in case of scattering elastic by molecules, the intensity of scattered light depends on both nature of molecules and wavelength of light. According to him, intensity of scattered light $\propto \frac{1}{\lambda^4}$.

Raman effect was based on inelastic scattering. For this CV Raman was awarded the nobel prize in 1930.

Scattering helps us in understanding the following:

1. Why sky is blue? When white light from the sun enters the earth's atmosphere, scattering takes place. As scattering is proportional to $\frac{1}{\lambda^4}$, blue is scattered most. When we look at the sky, we receive scattered light which is rich in blue and hence the sky appears blue.
2. Why sun appears red during sunset and sun rise? In the morning and evening when the sun is at horizon, due to oblique incidence light reaches after transversing maximum path in the atmosphere and so suffers maximum scattering. Now, as scattering $\propto \frac{1}{\lambda^4}$, shorter wavelength scattered most leaving the longer one. As red light has the longest wavelength in the visible region, it is scattered least. This is why sun appears red in the morning and evening.
3. Why red light is used in danger signal? Same reason as given in 2.

Defects of images: Actual image formed by an optical system is usually imperfect. The defects of images are called aberrations. The defect may be due to light or optical system.

If the defect is due to light, it is called chromatic aberration and if it is due to optical system, it is called monochromatic aberration.

Chromatic aberration: The image of an object formed by a lens is usually coioured and blurred. This defect of image is called chromatic aberration. This defects arises due to the fact that focal length of lens is different for different colours. For a lens

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

As μ is maximum for violet and minimum for red, violet is focussed nearest to the lens while red is farthest from it. The difference between f_R and f_V is a measure of longitudinal chromatic aberration. Thus, LCA = $f_R - f_V$ = -df

Differentiating the equation (1) above,

$$-\frac{df}{f^2} = d\mu\left[\frac{1}{R_1} - \frac{1}{R_2}\right] = \frac{d\mu}{f(\mu - 1)} \Rightarrow df = -\frac{f d\mu}{\mu - 1} = -\frac{f(\mu_R - \mu_V)}{\mu_y - 1} = f\frac{\mu_V - \mu_R}{\mu_y - 1} = f\omega - - - (2)$$

Where, w is the dispersive power. $\mu_y = \frac{\mu_V + \mu_R}{2}$

For a single lens, neither f nor ω are zero so we cannot have a single lens free from chromatic aberration.

Condition of achromatism: To get achromatism, we use a pair of two lenses in contact. For two thin lenses in contact,

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - - - -(3)$$

Differentiating equation (1), we get

$$\frac{-dF}{F^2} = \frac{-df_1}{{f_1}^2} + \frac{-df_2}{{f_2}^2} - - - -(4)$$

The combination will be free from chromatic aberration if dF = 0 that is,

$$\frac{df_1}{{f_1}^2} + \frac{df_2}{{f_2}^2} = 0 - - - -(5)$$

From equation (2), df = fω so,

$$\frac{\omega_1}{f_1} + \frac{\omega_2}{f_2} = 0 - - - -(6)$$

The equation (6) is the condition of achromatism. The following conclusions can be drawn from equation (6):

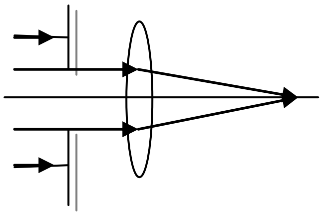
1. AS ω_1 and ω_2 are positive quantities, f_1 and f_2 can be of opposite sign, i. e. if one lens is convex, the other must have concave lens.
2. If ω_1=ω_2 i. e. both lenses are of same material, the F = ∞. Thus combination behaves as a plane glass plate. So we can conclude that both lenses should be of different material.
3. Dispersive power of crown glass is less than that of flint glass.
4. If we want the combination to behave a convergent lens then convex lens should have lesser focal length or its dispersive power should be more. Thus, convex lens should be made of flint glass and concave lens of crown. Similarly, for combination to behave as diverging lens, convex is made of crown glass and concave of flint glass.

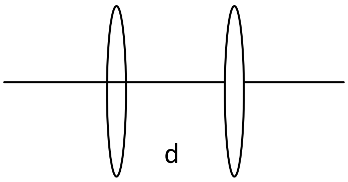
Monochromatic aberration: Spherical, coma, curvature and astigmatism.

Spherical aberration (in lenses or mirrors): The inability of a lens to form a point image of an axial point object. The spherical aberrations can never be eliminated but can be minimised.

The spherical aberration can be minimised

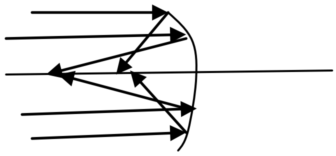
1. ***By using stops means cutting off either paraxial or marginal rays***.

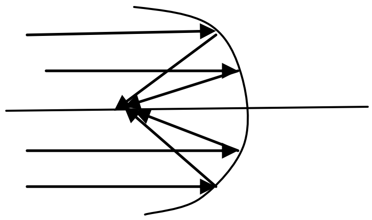




By using two thin lenses separated by a distance $d = f_1 - f_2$.

2. ***By using parabolic*** mirrors





3. ***By using lens of large focal length***-It is found that spherical aberration varies as the cube of the focal length. That is, $Spherical\ aberration \propto \frac{1}{f^3}$, so if f is large, spherical aberration will be reduced.
4. Using Plano convex lens-If its curved surface faces the incident or emergent rays. This is why in telescope; the curved surface faces the object while in microscope the curved surface is towards the image.
5. By using crossed lens-For a single lens with object at infinity, spherical aberration is found to be minimum, that is, a lens satisfies the below ratio is called crossed lens.

$$\frac{R_1}{R_2} = \frac{2\mu^2 - \mu - 4}{\mu(2\mu + 1)}$$

Regarding Eye, points are worth noting:

1. The human eye is most sensitive to yellow – green light (λ =5550Ǎ).
2. The persistence of vision is 1/10 s, that is, if time interval between two consecutive light pulses is less than 0.1 s, eye cannot distinguish them separately.
3. By the eye lens, real, inverted and diminished image is formed at retina.
4. While testing eye through reading chart if doctor finds it to 6/12, it implies that you can read a letter from 6 m which the normal eye can read from 12 m. Thus, 6/6 normal eye sight.

Looming: It is also due to TIR. This phenomenon is observed in cold deserts and opposite to that of mirage.

Twinkling of stars: Due to fluctuations in refractive index of atmosphere, the refraction of light (reaching to our eyes from stars) becomes irregular and the light sometimes reaches the eye and sometimes it does not. This gives rise to twinkling of stars.

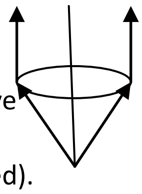
In case of lens camera:

1. The ratio of focal length to the aperture of lens is called f-number of the camera. If f-number of camera is f/11it implies that aperture is 1/11 of its focal length. Movie cameras have very low f-number such as f/1.5.
2. $Time\ of\ exposure \propto \frac{1}{(aperture)^2}$

Resolving power of Microscope: It is defined as the reciprocal of distance between two objects which can be just resolved. It depends on the wavelength λ of the light, the refractive index μ of the medium between the object and objective and angle θ subtended by a radius of the objective on one of the objects. Limit of resolution d is given by $d = \frac{\lambda}{2\mu \sin\theta}$ and resolving power (R) is the reciprocal of limit is resolution and is given by

$R = \frac{1}{\Delta d} = \frac{2\mu \sin\theta}{\lambda}$

objective



To increase R, the objective and objects are immersed in oil (μ increased).

μ sin θ = Numerical aperture, For eye: μ sin θ = 0.004

Resolving power of telescope: It is defined as the reciprocal of angular separation between two distant objects which are just resolved by a telescope. It is given by

$$R = \frac{1}{\Delta\theta} = \frac{a}{1.22\lambda}$$

Limit of resolution is $d\theta = \frac{1.22\lambda}{a}$, Here a is the diameter (aperture) of the objective. That is why, telescope with larger objective aperture are used.

Resolving power of human eye: The diameter of pupil of human eye is about 2 mm. If we take λ =5000 Ă the dθ = 1' so human eye can see two objects separated by 30 cm just resolved from a distance of 1 km.

The below table shows the comparison of microscope and telescope in terms of its magnification and length between objective and eye piece:

Parameters	Simple Microscope	Compound microscope	Refracting or astronomical telescope
M	$= \frac{D}{u_0}$	$= \frac{v_0}{u_0}\left(\frac{D}{u_e}\right)$	$= \frac{f_0}{u_e}$
L		$= v_0 + u_e$	$= f_0 + u_e$
M_D	$= 1 + \frac{D}{f}$	$= \frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$	$= \frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$
L_D		$= v_0 + \frac{Df_e}{D + f_e}$	$= f_0 + \frac{Df_e}{D + f_e}$
M_∞	$= \frac{D}{f}$	$= \frac{v_0}{u_0}\left(\frac{D}{f_e}\right)$	$= \frac{f_0}{f_e}$
L_∞		$= v_0 + f_e$	$= f_0 + f_e$

Ch-9 -Ray Optics: Derivations and Numerical

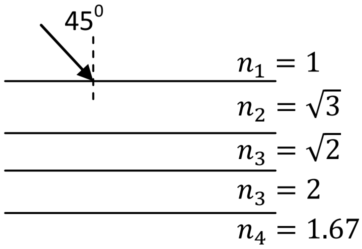
Derivations:

1. For a fixed incident light ray, show that reflected ray turns angle 2 θ in the same sense if the mirror rotated an angle θ.
2. Derive f = R/2 in case of concave and convex mirrors.
3. Derive mirror formula using concave and convex mirror by making suitable ray diagram when object is placed (i) between F and centre of curvature(C), (ii) at C, (iii) P and F.[AI 09C]
4. Deduce the position of image by using mirror formula in case of concave mirror when object is placed between (i) F and 2F (ii) 2F and infinity. [AI 11]
5. Derive lens formula using convex and concave lens at different position of object by showing ray diagram.
6. Obtain relation between refractive index, position of object and image and radius of curvature when refraction takes place through curved spherical surface and ray of light passing from (i) rarer medium to denser medium (ii) denser medium to rarer medium.[D 8C, 11C]
7. Obtain the expression of lateral magnification when refraction takes place at curved convex surface and light ray passes from rarer to denser medium.
8. State the conditions for total internal reflection of the light to take place at an interface separating two transparent media. Hence derive the expression for the critical angle in terms of the speed of light in two media. [CBSE D 2000]
9. Derive the lens maker formula using double thin concave lens and double thin convex lens by making ray diagram of each.
10. Define power of a lens. Derive the combined focal length when (i) two convex lens (ii) one convex and another concave lens is placed coaxially and in contact with each other.[F 12]
11. Obtain an expression among refractive index, angle of prism and minimum deviation in a equilateral prism. [D 11 C]
12. Deduce the necessary condition when no emergent ray passes through a surface of prism.
13. Obtain minimum deviation in case of small angle of prism and incidence angle is small.
14. Find out the relation between the refractive index μ of the glass prism and ∠A for the case when angle of prism A is equal to angle of minimum deviation (δ_m). Hence obtain the value of refractive index for the angle of prism A = 60^0 [Ans. √3] [D 15]
15. State necessary condition for producing total internal reflection of light. Draw ray diagram to show how specially designed prisms make use of total internal reflection to obtain inverted image of the object by deviation of rays (i) through 90^0 and (ii) through 180^0. [AI 11]
16. Draw a plot showing variation of power of lens, with the wavelength of incident light.[CBSE OD 08]
17. Draw a labelled ray diagram for the formation of image by a compound microscope. Derive an expression for its total magnification (or magnifying power) when the final image is formed (i) at the near point and (ii) at infinity. Suggest two ways by which resolving power of a microscope can be increased.
18. Explain with the help of a lebelled ray diagram, how is image formed in an astronomical refracting type telescope? Derive an expression for its magnifying power.

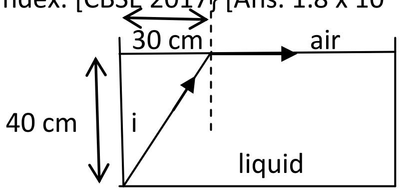
Numerical:

19. A man approaches a vertical plane mirror at a speed of 2 m/s. At what rate does he approach his image? [Ans. 4 m/s]
20. An object is placed (i) 10 cm, (ii) 5 cm in front of a concave mirror of radius of curvature 15 cm, find the position, nature and magnification of the image in each case. [NCERT}
    [Answer: When object distance is at 10 cm:-Position of image: -30 cm, nature of image: real, inverted and magnified, magnification: -3, when object distance is at 5 cm:-position of image: 15 cm, Nature: virtual and behind the mirror, magnification: 3]
21. An object 6 mm is placed 16.5 cm to the left of the vertex of a concave spherical mirror having a radius of curvature of 22 cm. (a) Draw principal ray diagram showing formation of the image, (b) Determine the position, size, orientation and nature (real or virtual) of the image. [Ans. 33 cm to the left of vertex, 12 mm tall, real and inverted]
22. An object 9 mm tall is placed 12 cm to the left of the vertex of a convex spherical mirror having a radius of curvature of 20 cm. (a) Draw principal ray diagram showing formation of the image, (b) Determine the position, size, orientation and nature (real or virtual) of the image. [Ans. 5.46 cm to the right of vertex, 4.09 mm tall, erect and virtual]
23. When the distance of an object from a concave mirror is decreased from 15 cm to 9 cm, the image gets magnified 3 times than that in first case. Calculate the focal length of the mirror. [Ans. -6 cm]
24. An object AB is kept between centre of curvature and infinity in front of a concave mirror. (a) Complete the ray diagram showing the image formation of the object. (b) How will the position and intensity of the image be affected if the lower half of the mirror's reflecting surface is painted black? [All India 2012][Ans. There will be no change in the position of the image, but the intensity of the image will be reduced on painting the lower half of the mirror black.]
25. Suppose while sitting in a parked car, you notice a jogger approaching towards you in the side view mirror of R = 2 m. If the jogger is running at a speed of 5 m/s, how fast the image of the jogger appear to move when the jogger is (a) 39 m, (b) 29 m, (c) 19 m and (d) 9 m away? [NCERT]
26. A point object is placed 60 cm from the pole of a concave mirror of focal length 10 cm on the principal axis. (a) Find Position of image [Ans. -12 cm],(b) If the object is shifted 1 mm towards the mirror along principal axis, find the shift in image. [Ans. – 1/25 mm]
27. A concave mirror has a radius of curvature of 24 cm. How far an object from the mirror if an image is formed (i) virtual and 3 times the size of the object, (ii) real and three times the size of the object.
28. A ray of light fall on a glass plate of refractive index μ = 1.732. What is the angle of incidence of the ray if the angle between the reflected and refracted rays is 90^0? [Ans. 60^0]
29. A ray of light of frequency 5×10^{14} Hz is passed through a liquid. The wavelength of light measured inside the liquid is found to be 450×10^{-9} m. Calculate the refractive index of the liquid. [1.33][Himachal 98}
30. A light of wavelength 6000 A^0 in air, enters a medium with refractive index 1.5. What will be the frequency and wavelength of light in that medium? [IIT 97][Ans. 4000 A^0]
31. The refractive index of glass is 1.5 and that of water is 1.3. If the speed of light in water is 2.25×10^8 m/s, what is the speed of light in glass? [1.95×10^8 m/s][ISCE 96]

32. Find the angle of light ray in the medium of refractive index $\sqrt{2}$ as shown in the below fig. [Ans. 30^0]

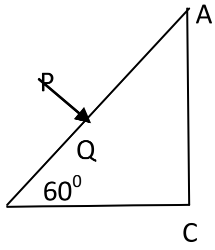


33. A ray of light is incident at an angle of 60^0 on one face of a rectangular glass slab of thickness 0.1 m and refractive index 1.5. Calculate the lateral shift.[Ans. 0.0513]
34. The apparent depth of an object at the bottom of a tank filled with a liquid of refractive index 1.3 is 7.7 cm. What is the actual depth of liquid in the tank?[Ans. 10.01 cm, [CBSE 91]
35. The velocity of light in glass is 2 x 108 m/s and that in air is 3 x 10^8 m/s. By how much would an ink dot appear to be raised when covered by a glass plate 6 cm thick?[Ans. 2 cm][Punj99]
36. A vessel contains water up to a height of 20 cm and above it an oil up to another 20 cm. The refractive indices of water and oil are 1.33 and 1.30 respectively. Find the apparent depth of vessel when viewed from above. [Ans. 30.4 cm]
37. An object lies 100 cm inside water (μ=4/3). It is viewed through air nearly normally. Find the apparent depth of the object. [Ans. 75 cm]
38. Find the lateral shift of a light ray while it passes through a parallel glass of thickness 10 cm placed in air. The angle of incidence in air is 60^0 and angle of refraction in glass is 45^0. [Ans. $10\sqrt{2}$ sin 15^0]
39. Find the value of critical angle for a material of refractive index $\sqrt{3}$. [Ans. 35.3^0][CBSE F94]
40. Calculate the speed of light in a medium whose critical angle is 30^0.[CBSE 10][1.5 x 10^8 m/s]
41. In the following ray diagram, calculate the speed of light in liquid of unknown refractive index. [CBSE 2017} [Ans. 1.8 x 10^8 m/s]

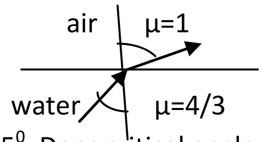


42. Define critical angle. What will be the angle of refraction in rarer medium if the angle of incidence in a denser medium of refractive index $\sqrt{2}$ is 45^0?
43. Will the ray of refractive index 1.52 falls normally on right angled prism (45^0 -90^0 -45^0), emerge through a prism? Justify it.
44. Calculate the critical angle for glass air surface, if a ray of light which is incident in air on the glass surface is deviated through 15^0, when angle of incidence is 45^0.[CBSE 2003][Ans. 45^0]
45. A glass slab is immersed in water. Find the critical angle of glass –water interface. Given $a_{\mu_g} = 1.5 \; and \; a_{\mu_w} = 1.33$ [Punjab, 96][Ans. $62^0\ 28'$]
46. The critical angle of incident ray in a glass slab placed in air is 45^0. What will be the critical angle when it is immersed in water of refractive index 1.33? [Ans. 70^0 36']
47. Determine the value of angle of incidence for a ray of light travelling from a medium of refractive index $\mu_1 = \sqrt{2}$ in to the medium of refractive index $\mu_2 = 1$ so that it just grazes along the surface of separation. [CBSE F 17][Ans. 45^0]

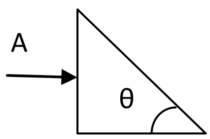
48. The velocity of light in liquid 1.5 x 10^8 m/s and in air, it is 3 x 10^8 m/s. If a ray of light passes from this liquid into air, calculate the value of critical angle. [Punjab, 99][Ans. 30^0]
49. An optical fibre (μ=1.72) is surrounded by a glass coating (μ=1.5). Find the critical angle for total internal reflection at the fibre-glass interface. [Ans. 60.7^0]
50. A ray PQ incident normally on the refracting face BA is refracted in the prism. BAC made of material of refractive index 1.5. Complete the path of ray through the prism. From which face will the ray emerge? Justify your answer. {Ans. since $i < i_c$ so the ray will emerge from face AC.][CBSE OD 16]



51. Find the maximum angle of refraction when a ray of light is refracted from glass (μ=1.5) to air. [Ans. 90^0]
52. A ray of light is incident at an angle of 60^0 on the face of a prism having refracting angle 30^0. The ray emerging out of a prism makes an angle 30^0 with the incident ray. Show that the emergent ray is perpendicular to the face through which it emerges. [Ans. show $i_2 = 0^0$]
53. Determine the refractive index of glass with respect to water. Given, μ_g=3/2, μ_w=4/3 [Ans. 9/8]
54. Find the angle θ_a made by the light ray when it gets refracted As shown in the figure, given, θ_w=$\sin^{-1}$3/5 [Ans. $\sin^{-1}$(4/5)]

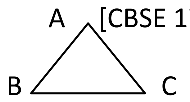


55. Calculate the speed of light in a medium whose critical angle is 45^0. Does critical angle for a given pair of media depend on the wavelength of the incident light.[Patna 15}[Ans. 2.1 x 10^8 m/s]
56. Velocity of light in glass is 2 x 10^8 m/s and that in air is 3 x 10^8 m/s. If the ray of light passes from glass to air, calculate the value of critical angle. [F 15] [Ans. 41.8^0]
57. Find the maximum angle that can be made in glass medium (μ=1.5) if light ray is refracted from glass to vacuum.[Ans. $\sin^{-1}$(2/3)
58. Find the angle of refraction in a medium (μ=2) if light is incident in vacuum making an angle equal to twice the critical angle. [Note: Since light is in rarer medium, TIR does not take place.][Ans. $\sin^{-1}$(√3/4)]
59. Find the value of critical angle for a material of refractive index √2. [Ans. 45^0]
60. Calculate the speed of light in a medium whose critical angle is 30^0. [1.5 x 10^8 m/s][CBSE OD10]
61. What should be the value of angle θ so that light entering normally through the surface AC of a prism (μ=3/2) does not cross the second refracting surface AB? [Ans. θ<$\cos^{-1}$(2/3)]

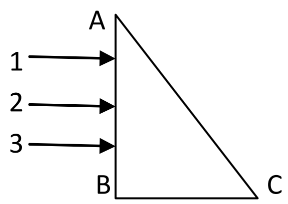


62. Light from a point source in air falls on a convex spherical glass surface (μ=1.5) of radius of curvature 20 cm. The distance of light source from glass surface is 100 cm. At what position is the image formed? [Ans. 100 cm][NCERT, CBSE OD 2016]
63. A spherical convex surface of radius of curvature 20 cm, made of glass (μ=1.5) is placed in air. Find the position of image formed, if a point object is placed at 30 cm in front of convex surface on the principal axis. [CBSE SP 18][Ans. virtual image at 180 cm in air]
64. A concave spherical surface of refractive index 3/2 is immersed in water of refractive index 4/3. If a point object lies in water at a distance of 10 cm from the pole of the refracting surface, calculate the position of image. Given that radius of curvature of spherical surface is 18 cm.[Virtual image at 10.52 cm from pole and inside the water.]
65. A concave lens of refractive index 1.5 is immersed in a medium of refractive index 1.65. What is the nature of the lens? [D 15] [Ans. Convex lens]
66. The focal length of an equiconvex lens is equal to the radius of curvature of either face. What is the refractive index of the material of the lens? [AI 15] [Ans. 1.5]
67. An equiconvex lens of focal length f is cut into two identical plane convex lenses. How will the power of each part be related to the focal length of the original lens? A double convex lens of + 5D is made of glass of refractive index 1.55 with both faces of equal radii of curvature. Find the value of its radius of curvature. [F 15] [Ans. Power half, R =22 cm]
68. The radii of curvature of both the surfaces of a lens are equal. If one of the surfaces is made plane by grinding, how will the focal length and power of the lens change? [Guwahati, 15] [Ans. focal length doubled and power halved]
69. A screen is placed 90 cm away from an object. The image of the object on the screen is formed by a convex lens at two different locations separated by 20 cm. Determine the focal length of the lens. [Guwahati 15][Ans. 21.4 cm]
70. The distance between two point sources of light is 24 cm. Find out where you would place a converging lens of focal length 9 cm, so that the images of both the sources are formed at the same point. [Ans. 6 cm from either of the object]
71. A lens of refractive index μ becomes a lens of focal length f' when immersed in a liquid of refractive index μ'. If the focal length of lens in air is f, prove that $f' = f\frac{\mu'(\mu-1)}{(\mu-\mu')}$[CBSE 13]
72. A spherical convex surface separates object and image space of refractive index 1.0 and 4/3. If radius of curvature of each surface is 10 cm, find its power.[Ans. 2.5 D]
73. A biconvex lens is cut into two equal parts transversely. Find the focal length of each part as compared to original focal length of this lens. [Ans. 2f]
74. A biconvex lens is cut into two equal parts longitudinally. Find the focal length of each part as compared to original one. [Ans. f]
75. The radius of curvature of each surface of a convex lens of refractive index 1.5 is 40 cm. Calculate its power. [Ans. 2.5 D] [CBSE Sample paper 98]
76. A double convex lens of +5D is made of glass of refractive index 1.5 with both faces of equal radii of curvature. Find the value of curvature. [Ans. 20 cm]
77. A glass of convex lens has a power of + 10 D. When this lens is totally immersed in a liquid, it acts as a concave lens of focal length 50 cm. Calculate the refractive index of the liquid. Given μ of glass = 1.5 [Ans. 1.67]

78. A ray of light passes through an equilateral glass prism such that the angle of incidence is equal to the angle of emergence and each of these angles is equal to ¾ of angle of prism. Find the angle of deviation. [Patna] [Ans. 30^0]
79. The angle of minimum deviation for a glass prism with μ = √3 equals the refracting angle of the prism. What is the angle of the prism? [Ans. 60^0]
80. A ray of light falls normally on a refracting face of a prism. Find the angle of prism if the ray just fails to emerge from the prism. (μ = 3/2) [Ans. $\sin^{-1}\frac{2}{3} = 42^0$]
81. A ray of light passing through a prism having refracting index √2 suffers minimum deviation. It is found that the angle of incidence is double the angle of refraction within the prism. What is the angle of prism? [Ans. 90^0]
82. One face of a prism with refractive angle of 30^0 is coated with silver. A ray incident on another face at an angle of 45^0 is refracted and reflected from the silver coated face and retraces its path. What is the refractive index of the prism? [Ans. √2]
83. A ray of light incident on face AB of an equilateral glass prism shows minimum deviation of 30^0. Calculate the speed of light through the prism. Find the angle of incidence at face AB so that the emergent ray grazes along the face AC. [CBSE 17]



84. Find the angle of incident ray on one of refracting surface of prism of refracting angle 60^0 so that it just suffers total internal reflection. Given that refractive index of material of prism is 1.524. [NCERT 9.22][Ans. 30^0]
85. A prism of apex angle A =60^0 has the refractive index $\mu = \sqrt{2}$. Find the angle of incidence for minimum deviation. [Ans. 45^0]
86. What should be the minimum deviation by an equilateral prism of refractive index $\sqrt{2}$. [Ans. 30^0]
87. Three rays 1, 2, 3 of different colours fall normally on one of the sides of an isosceles right angled prism (45^0-90^0-45^0) as shown. The refractive index of prism for these rays is 1.39, 1.47 and 1.52 respectively. Find which of these rays get internally reflected and which get only refracted from AC. Trace the path of rays. Justify your answer with the help of necessary calculations. [Ans. Ray 1 is refracted from AC, the ray 2 and 3 will undergo TIR, as for TIR, $i > \theta_C\ i.e. 45^0 > \theta_C\ or\ \sin 45^0 > \sin\theta_C\ hence\ \mu > 1.414$][CBSE D 09, F11, 13

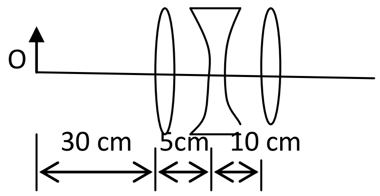


88. An object is placed 15 cm in front of a convex lens of focal length 10 cm. Find the nature and position of the image formed. Where should a concave mirror of radius of curvature 20 cm be placed so that the final image is formed of the object itself
89. A convex lens is placed in contact with a plane mirror. An axial point object, at a distance of 20 cm from this combination, has its image coinciding with itself. What is the focal length of the convex lens? Draw the ray diagram. [Ans. 20 cm] [CBSE D 2014]

90. The distance between a convex lens and a plane mirror is 15 cm. The parallel rays incident on the convex lens, after reflection from the mirror, form image at the optical centre of the lens. Draw the ray diagram and find the focal length of the lens. [Ans. 30 cm]
91. A convex lens of focal length 20 cm has a point object on its principal axis at distance of 40 cm from it. A plane mirror is placed 30 cm behind the convex lens. Locate the position of image formed by this combination. [Ans. 40 cm]
92. A convex lens and a convex mirror (of radius of curvature 20 cm) are placed co-axially and separated by 30 cm to each other. For a point object at a distance of 25 cm from the lens, the final image due to this combination coincides with the object itself. What is the focal length of the convex lens? Plot the ray diagram. [Ans. 50/3 cm]
93. A point object O is kept at distance 30 cm from the convex lens of power +4D towards its left. It is observed that when a convex mirror is kept on the right side at a distance of 50 cm from the convex lens, the image of the object O formed by the lens mirror combination coincides with the object itself. Calculate the focal length of the convex mirror. [CBSE Sample paper 15] [Ans. 50 cm]
94. A convex lens of focal length 20 cm is placed co-axially with a convex mirror of radius of curvature 20 cm. The two are kept 15 cm apart from each other. A point object is placed 60 cm in front of the convex lens. Draw a ray diagram to show the formation of the image by the combination. Determine the nature and position of the image formed. [CBSE OD 14] [Ans. 30 cm]
95. A convex lens of focal length 20 cm and a concave mirror of focal length 10 cm are placed coaxially 50 cm apart from each other. A beam of light coming parallel to the principal axis is incident on the convex lens. Find the position of the final image formed by this combination. Draw the ray diagram showing the formation of the image.[CBSE OD 14] [Ans. 15 cm from Mirror]
96. A point object is placed 60 cm in front of a convex lens of focal length 30 cm. A plane mirror is placed 10 cm behind the convex lens. Where is the image formed by this system? [Ans. At the optical centre of the convex lens.]
97. An object is placed 15 cm in front of a convex lens of focal length 10 cm. Find the nature and position of the image formed. Where a concave mirror of radius of curvature 20 cm should be placed so that the final image is formed at the position of the object itself? [CBSE OD 15] [Ans. 50 cm][AI 15]
98. A convex lens of focal length 20 cm is placed 10 cm in front of a convex mirror of radius of curvature 15 cm. Where should a point object be placed in front of the lens so that it images on to itself? [Ans. 100 cm]
99. The radius of curvature of the convex face of a Plano-convex lens is 12 cm and its refractive index is 1.5. Find the focal length of this lens. [Ans. 24 cm] The plane surface of the lens is now silvered. At what distance from the lens will parallel rays incident on the convex face converge? [Ans. v = -12 cm]
100. A Planoconvex lens with its convex surface is silvered. Calculate its focal length if radius of curvature is 30 cm and refractive index of material is 1.5. [Ans. 10 cm][F=R/2μ]
101. In a Planoconvex lens, its plane surface is silvered. Calculate its focal length.[F=R/2(μ-1)]
102. An object is placed at 20 cm in front of a convex lens with one of its surface is silvered. Find the position of image and nature of the lens.

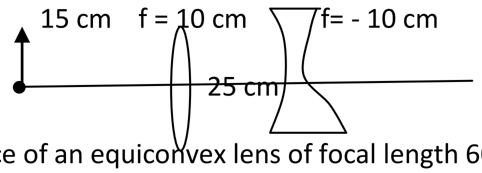
103. Three lenses with magnifications 2, 3, and 10 form a combination. What is its total magnification? [CBSE F 94 C][Ans. 60]
104. An object is placed 40 cm from a convex lens of focal length 30 cm. If a concave lens of focal length 50 cm is introduced between the convex lens and image formed such that it is 20 cm from the convex lens. Find the change in the position of image. [Chennai 15] [Ans. 100 cm on left side of concave lens]
105. Two thin lenses of focal length +10 cm and – 5 cm are kept in contact. What is the focal length and (ii) power of the combination? [Ans. (i) -10 cm (ii) -10 D] [CBSE D 93]
106. Find the position of the image formed by lens combination given as below: [NCERT]

F = + 10, -10, +30 cm

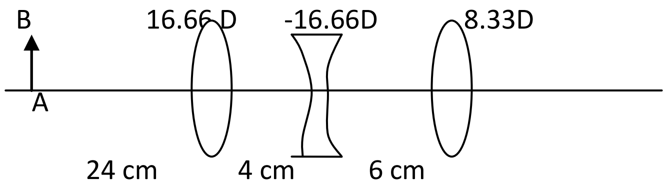


[Ans. v_1 = 15 cm, v_2=∞ and final image at v_3=30 cm]

107. Find the focal length and power of convex lens which when placed in contact with a concave lens of focal length 25 cm, forms a real image 5 times the size of the object placed 20 cm from the combination. [Ans. 10 cm, 10D]
108. An object is placed at 40 cm distance from the convex lens of focal length 15 cm. Another concave lens is placed 14 cm to the right from the convex lens. The final image is at 30 cm from concave lens. Find the focal length of the concave lens. [Ans. – 15 cm]
109. A convex lens of focal length 10 cm is placed co-axially 5 cm away from a concave lens of focal length 10 cm. If an object is placed 30 cm in front of the convex lens, find the position of the final image formed by the combined system. [Ans. ∞] [CBSE OD 09]
110. Find the position of final image formed. [Ans. 10 cm to the right of concave lens]

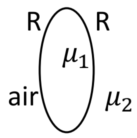


111. One face of an equiconvex lens of focal length 60 cm of glass (μ=1.5) is silvered. Does it behave like a convex mirror or concave mirror.? Determine its focal length. [Ans. 15 cm, concave mirror]
112. In the figure shown, the length of object AB is 9 cm. Find the nature and position of final image and also its length. Assume that each lens is a thin lens. [Ans. v=4 cm, I = -6 cm]

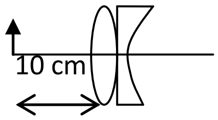


113. Two convex lenses having focal lengths 10 cm and 20 cm are separated by distance d. The combination behaves as concave lens. What should be possible value d? [Ans. d >30 cm]
114. Two thin lenses when in contact, produce a combination of power +10D. When they are 0.25 m apart, the power reduces to +6D. Find the focal length of lenses.[IIT 97], [Ans. 0.125 m, 0.5 m]

115. The focal length of an equiconvex lens is equal to the radius of curvature of either face. What is the refractive index of the material of the lens?
116. A bi-convex lens with its two faces of equal radius of curvature R is made of a transparent medium of refractive index μ_1. It is kept in contact with a medium of refractive index μ_2 as shown in the figure. (i) Find the equivalent focal length of the combination. (ii) Obtain the condition when this combination acts as a diverging lens. [CBSE Patna 15][$f = \frac{\mu_2 R}{2\mu_1 - \mu_2 - 1}$], [$\mu_1 < \frac{\mu_2+1}{2}$]

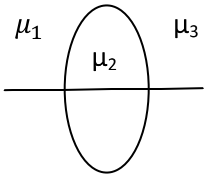


117. Find the lateral magnification produced by the combination of lenses shown below.
Focal length:10 cm -20 cm [Ans. 2]



118. A telescope has an objective of focal length 50 cm and eyepiece of focal length 5 cm. The least distance of distinct vision is 25 cm. The telescope is focussed for distant object on a scale 200 cm away from objective. (a) Calculate Separation between the objective and eyepiece [Ans. 70.73 cm] (b) The magnification produced [Ans.-2]
119. A man's shortest distance of distinct vision is 20 cm. What will be the type and power of spectacle lens which he would require to enable him to read a book at a distance of 60 cm? [Ans. f = -30 cm, P= -3.3 D] [Here, u = -60 cm, v =- 20 cm]
120. What focal length should be reading spectacles have for a person for whom least distance of distinct vision is 50 cm? [NCERT] [Here, v = -50 cm, u = -25 cm] [Ans. 50 cm]
121. A person wears glasses of power -2.5 D is the person far sighted or near sighted? What is the far point of the person without glasses?[Since corrective lens is concave lens, so near sighted person.] [v = -40 cm]
122. A giant refracting telescope has an objective lens of focal length 15 m. If an eyepiece of focal length 1 cm is used, what is the angular magnification of the telescope? [Ans. 1500][D 15]
123. Assume that light of wave length 6000 Ă is coming from a star. What is the limit of resolution of a telescope whose objective has a diameter of 100 inch? [Ans. 2.9 x 10^{-7} rad] [NCERT]
124. A telescope is used to resolve two stars separated by 4.6 x 10^{-6} rad. If the wave length of light used is 5460 Ă, what should be the aperture of the objective of the telescope? [Ans. 0.1488 m]
125. You are given two converging lenses of focal length 1.25 cm and 5 cm to design a compound microscope. If it is desired to have a magnification of 30, find out the separation between object and eye piece. [CBSE OD 15, Ans. 6.25 cm]
126. A compound microscope with an object of 1 cm focal length and eye piece of 2 cm focal length has a tube length of 20 cm. Calculate the magnifying power of the microscope if the final image is formed at the near point of the eye. [CBSE D 04, Ans. 270]
127. The total magnification produced by a compound microscope is 20, while produced by eye piece is 5. When the microscope is focussed at certain object, the distance between objective and eyepiece is 14 cm. Find the focal length of objective and eye piece. [CBSE D 14,f_0 = 2 cm, f_e = 5 cm]

128. The focal lengths of objective and eye piece of a microscope are 1.25 cm and 5 cm respectively. Find the position of the object relative to the objective in order to obtain an angular magnification of 30 in normal adjustment. [CBSE D 12, Ans. -1.46 cm]
129. A planet is observed by an astronomical refracting telescope having an objective of focal length 16 m and an eyepiece of focal length 2 cm. Find (a) the distance between the objective and eyepiece, (b) the angular magnification of the planet. [Ans. 16.02 m, -800]
130. A ray of light travelling in a transparent medium falls on a surface separating the medium from air at an angle of incidence of 45^0. The ray undergoes total internal reflection. If n is the refractive index of the medium w. r. t. air, find the value of n. [Ans. $> \sqrt{2}$]
131. A thin convergent glass lens (μ_g = 1.5) has a power of +5.0 D. When this lens is immersed in a liquid of refractive index μ_l, it acts as a divergent lens of focal length 100 cm. Find the value of μ_l. [Ans. 6/5]
132. The figure shows an equi-convex lens. What should be the condition of the refractive indices so that the lens becomes diverging? (Ans. $2\mu_2 < \mu_1 + \mu_3$][formula: $\frac{\mu_3}{v} - \frac{\mu_1}{u} = \frac{\mu_2-\mu_1}{R_1} + \frac{\mu_3-\mu_2}{R_2}$]



133. Optic axis of a thin equi-convex lens is x-axis. The co-ordinates of a point object and its images are (-40 cm, 2 cm) and (50 cm, -2 cm) respectively. Find the position of lens location. [Ans. Lens is located at x = 5 cm]
134. A convex lens A of focal length 20 cm and a concave lens B of focal length 5 cm are kept along the same axis with a distance d between them. If a parallel beam of light falling on A leaves B as a parallel beam, find the distance d. [Ans. 15 cm]
135. The angle of minimum deviation for a glass prism with $n = \sqrt{3}$ equals the refracting angle of the prism. What is the angle of prism? [Ans. 60^0]
136. Determine the position of the image produced by an optical system consisting of a concave mirror with a focal length of 10 cm and a convergent lens with a focal length of 20 cm. The distance from the mirror to the lens is 30 cm and from the lens to the object is 40 cm. [5 cm from mirror towards the lens]
137. An object is at distance of d = 2.5 cm from the surface of a glass sphere with a radius R = 10 cm. Find the position of the final image produced by the sphere. The refractive index of glass is μ =1.5 [65 cm from first face]