Ray Optics or Geometrical Optics

In this branch of optics, the light is considered as a ray which travels in a straight line.

It states that for each and every object, there is an image. It deals with the phenomena of reflection and refraction of light by ordinary geometrical methods.

1.1 Reflection

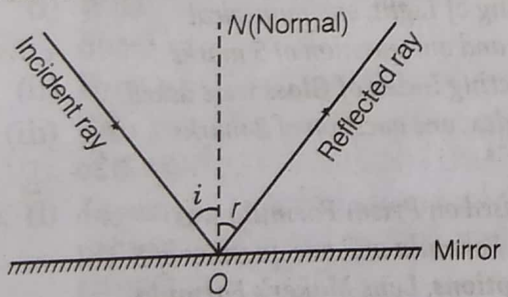
Reflection is the phenomenon of changing the path of light after incidenting on a boundary separating two media without any change in the medium.

Reflection of Light

The returning back of light in the same medium from which it has come after striking a surface is called reflection of light.

Laws of Reflection

Two laws of reflection are given as below:



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

i.e. $\angle i = \angle r$.

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

Types of Mirror

Plane Mirror

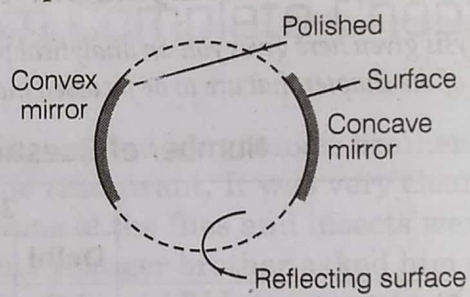
In a plane mirror, image formed is always virtual, erect equal in size as that of the object and at the same distance behind the mirror as the object is in front of the mirror. Image in a plane mirror is always laterally inverted.

Spherical Mirror

A type of mirror whose reflecting surfaces is part of a hollow sphere. Spherical mirrors are of two types.

(i) Concave spherical mirror

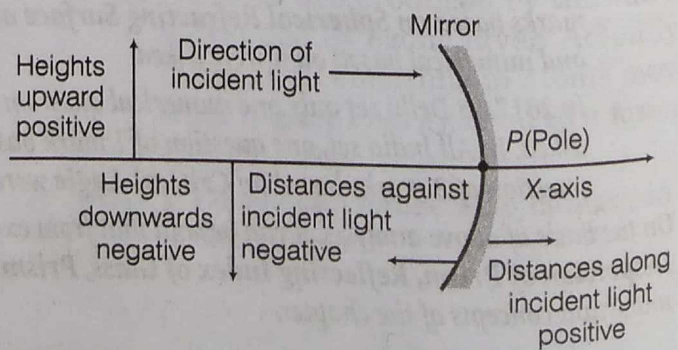
(ii) Convex spherical mirror



1.2 Sign Convention

All measurements should be taken from pole of mirror.

- All measurements along the direction of incident ray will be positive and opposite to incident ray are negative.
- All the measurements for the distances above the principal axis are taken as positive and below the principal axis are taken as negative.
- For a real object, u is negative whereas v is negative for real image and positive for virtual image.



1.3 Mirror Formula

Mirror formula is a relation between focal length of the mirror, distances of objects and image from the mirror.

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

where, f = focal length, u = distance of the object from mirror, v = distance of the image from mirror.

Focal length of mirror

$$(f)=\frac{\text{Radius of curvature }(R)}{2} \Rightarrow f=\frac{R}{2}$$

1.4 Linear Magnification

The ratio of the size of the image formed by a spherical mirror I to the size of the object O is called the linear magnification produced by the spherical mirror.

$$m=\frac{I}{O}=-\frac{v}{u}=\frac{f}{f-u}=\frac{f-v}{f}$$

where, I = height of image and O = height of object

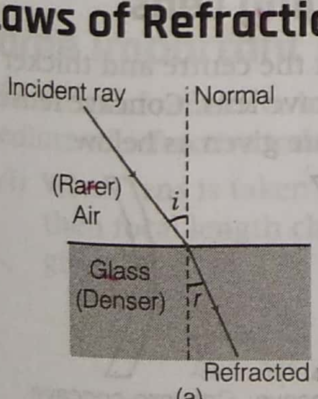
Magnification (m)

It is negative corresponding to real image and positive for virtual image.

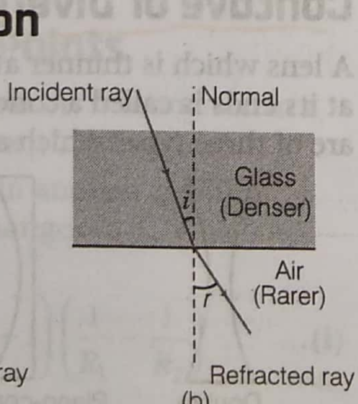
1.5 Refraction

The phenomenon of changing in the path of light as it goes from one transparent medium to another is called refraction.

Laws of Refraction



(a)



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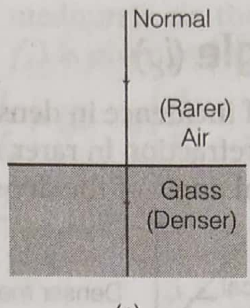


(c)

Two laws of refraction are given as below:

(i) The incident ray, refracted ray and the normal to the refracting surface at the point of incidence lie in the same plane.

(ii) The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for the two given media. This constant is denoted by μ and is called the **relative refractive index**.

$${}_1\mu_2=\frac{\sin i}{\sin r} \quad \text{(Snell's law)}$$

where, μ is refractive index of the second medium with respect to first medium.

Refractive Index in Terms of Wavelength

The refractive index (μ) of a material is the ratio of the speed of light (c) in vacuum to the speed of light in the medium (v).

Mathematically, if refractive index is given by the relation $\mu=\dfrac{\text{Speed of light in the vacuum}}{\text{Speed of light in the medium}}=\dfrac{c}{v}$

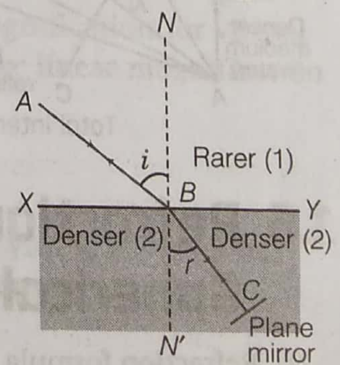
It is also referred to as **absolute refractive index** of the substance.

Principle of Reversibility of Light

Principle of reversibility of light states that when final path of a ray of light after suffering any number of reflections and refractions is reversed, the ray retraces its path, exactly.

$$\Rightarrow \quad {}_1\mu_2 \times {}_2\mu_1 = 1$$

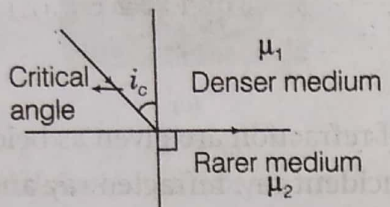
$$\Rightarrow \quad {}_2\mu_1=\frac{1}{{}_1\mu_2}$$



Principle of reversibility of light

Critical Angle (i_c)

It is the angle of incidence in denser medium for which angle of refraction in rarer medium is 90° is called the critical angle of the denser medium.

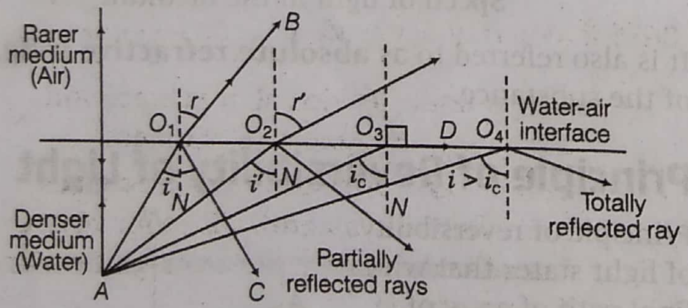


i.e. $\mu = \dfrac{1}{\sin i_c}$ $\left[\text{when } i = i_c, r = 90° \quad \dfrac{\sin i_c}{\sin 90°} = {}_2\mu_1 = \dfrac{1}{{}_1\mu_2}\right]$

where, μ = refractive index of denser medium w.r.t. rarer medium.

1.5 Total Internal Reflection (TIR)

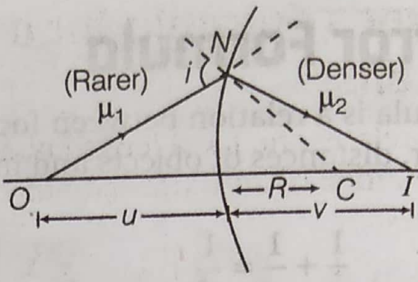
When a ray of light travelling from denser medium to rarer medium is incident at the interface of two medium at an angle greater than the critical angle for the two media, the ray is totally reflected back to denser medium. This phenomenon is called Total Internal Reflection. It occurs only when angle of incidence in denser medium is greater (not equal) than critical angle, i.e. $i > i_c$.



Total Internal Reflection

1.6 Refraction at a Spherical Surface

(i) Refraction formula for refraction by convex or concave spherical refracting surface is given by



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

where μ_1, μ_2 are refractive index of rarer and denser media and u, v and R are to be taken with their proper signs.

(ii) When refraction takes place from denser to rarer medium, then

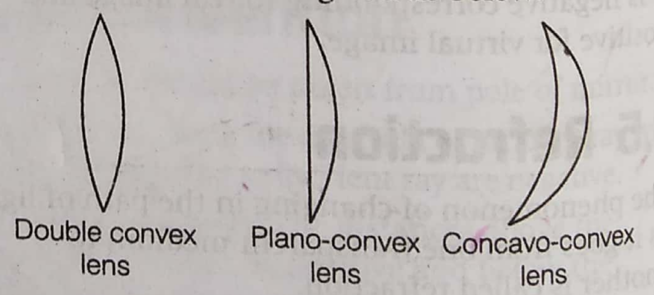
$$\frac{\mu_1}{v} - \frac{\mu_2}{u} = \frac{\mu_1 - \mu_2}{R}.$$

1.7 Lens

Lens is a transparent medium bounded by two surfaces of which one or both surfaces are spherical.

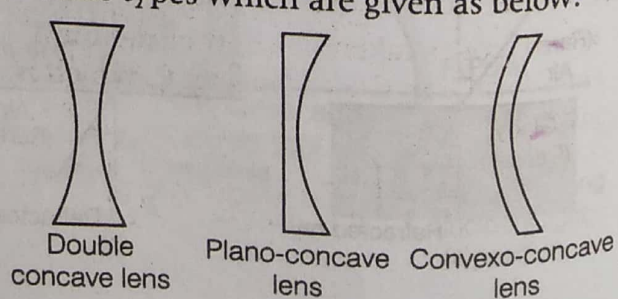
Convex or Converging Lens

A lens which is thicker at the centre and thinner at its end is called convex lens. Convex lenses are of three types which are given as below:



Concave or Diverging Lens

A lens which is thinner at the centre and thicker at its ends is called a concave lens. Concave lenses are of three types which are given as below:

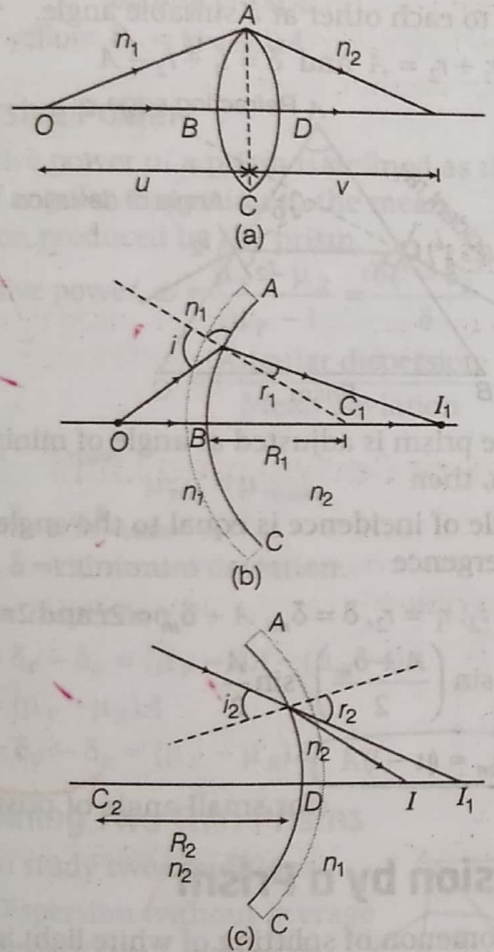


Lens Maker's Formula for a Convex Lens

This formula relates the focal length of a lens to the refractive index of lens and radii of curvature of two surfaces.

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

μ = refractive index of material of lens w.r.t. surrounding media and R_1, R_2 = radii of curvatures of two surfaces.



Some Important Points

When lens of refractive index μ is immersed in a medium of refractive index μ', then

(i) When lens is taken in another medium, then focal length changes to f_m which is given by

$$\frac{1}{f_m} = \left(\frac{\mu}{\mu'} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \ldots\text{(i)}$$

(ii) If $\mu' = 1$, i.e. medium is air, the focal length of lens (i.e. f_a) is given by

$$\frac{1}{f_a} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \ldots\text{(ii)}$$

(iii) $\dfrac{f_m}{f_a} = \dfrac{(\mu - 1)}{\left(\dfrac{\mu}{\mu'} - 1\right)}$ [dividing Eq. (ii) by Eq. (i)]

(iv) If $\mu = \mu' \Rightarrow f_m = \infty$

$\Rightarrow$ lens behaves like a glass slab.

(v) If $\mu < \mu' \Rightarrow f_m > f_a$ and nature reversed.

(vi) If $\mu > \mu' \Rightarrow f_m > f_a$ and nature remains same.

1.7 Linear Magnification Produced by a Lens

Linear magnification of a lens is defined as, the ratio of the height of the image formed by the lens and height of the object.

$$\text{Linear magnification, } m = \frac{\text{Height of image}(I)}{\text{Height of object }(O)}$$

For Convex Lens

CASE I When image is real, $m = \dfrac{-I}{O} = \dfrac{v}{-u}$

When image is real, it is inverted and forms on the other side of object.

CASE II When image is virtual, $m = \dfrac{I}{O} = \dfrac{v}{u}$

When image is virtual, it is erect and forms on the same side of object.

Thus, it can be said convex lens gives positive linear magnification for virtual image and negative linear magnification for real image.

For Concave Lens

Concave lens always forms virtual image, linear magnification of concave lens,

$$m = \frac{I}{O} = \frac{v}{u}.$$

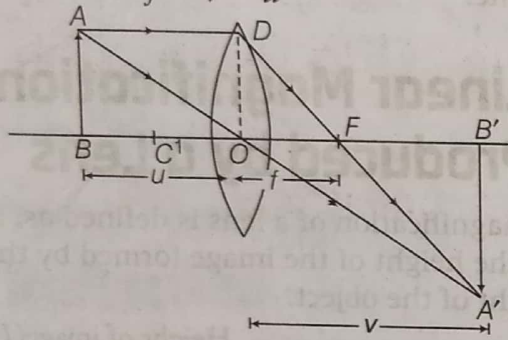
Concave lens always gives positive linear magnification. Other formula for linear magnification are

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

1.8 Thin Lens Formula

It is a relation between focal length of a lens and distances of objects and image from optical centre of the lens.

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



- Lateral or transverse magnification,

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

where, angular magnification $= \frac{\theta_0}{\theta}$

where, θ_0 = angle made by image and θ = angle made by object.

- If $|m| > 1 \Rightarrow$ image is magnified.
- If $|m| < 1 \Rightarrow$ image is diminished.
- If $|m| = 1 \Rightarrow$ image is of same size as the object.

1.9 Power of Lens

The ability of a lens to converge or diverge the rays of light incident on it is called the power of the lens.

Thus, $$P = \frac{1}{f \text{ (in m)}}$$

SI unit of power of lens = dioptre (D) = m^{-1}

Power of combination lenses in contact is given by

$$P = P_1 + P_2 + \ldots + P_n$$

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \ldots + \frac{1}{f_n}$$

NOTE Magnification by combination of lenses

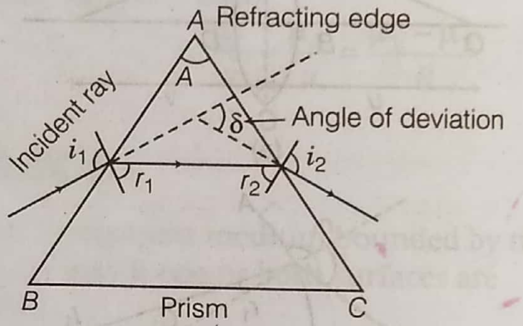
$$m = m_1 \times m_2 \times m_3 \ldots\ldots$$

1.10 Prism

Prism have got the property of bending the incident light towards its base.

A prism is a wedged shaped portion of a transparent medium bounded by two plane faces inclined to each other at a suitable angle.

We get, $r_1 + r_2 = A$ and $\delta = i_1 + i_2 - A$



When the prism is adjusted at angle of minimum deviation, then

(a) angle of incidence is equal to the angle of emergence

(b) $i_1 = i_2$, $r_1 = r_2$, $\delta = \delta_m$, $A + \delta_m = 2i$ and $2r = A$.

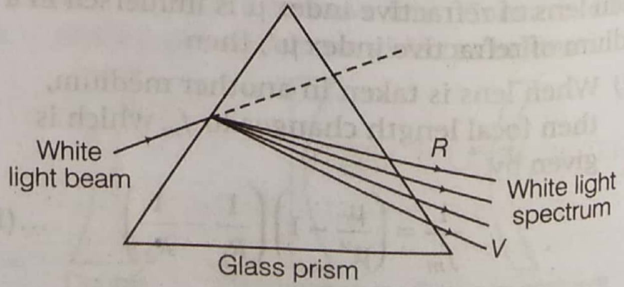
(c) $\mu = \sin\left(\frac{A + \delta_m}{2}\right) / \sin\frac{A}{2}$

$\Rightarrow \delta_m \approx (\mu - 1)A$

(for small angle of prism)

Dispersion by a Prism

The phenomenon of splitting of white light into its component colours on passing through a refracting medium is known as dispersion.



Terms Related to Dispersion of Light by Prism

Angular Dispersion

Angular dispersion produced by a prism for white light is the difference in the angles of deviation for two extreme colours i.e. violet and red.

Angular Deviations

For violet $\delta_V = (\mu_V - 1)A$

For red, $\delta_R = (\mu_R - 1)A$

and for yellow $\delta_Y = (\mu_Y - 1)A$

Dispersive Power

Dispersive power of a prism is defined as the ratio of angular dispersion to the mean deviation produced by the prism.

$$\text{Dispersive power, } \omega = \frac{\mu_V - \mu_R}{\mu_Y - 1} = \frac{\delta_V - \delta_R}{\delta} = \frac{\text{Angular dispersion}}{\text{Mean deviation}}$$

As $\lambda_{red} > \lambda_{violet}$

$\therefore$ $\mu_{red} < \mu_{violet}$

Hence, $\delta_{red} < \delta_{violet}$

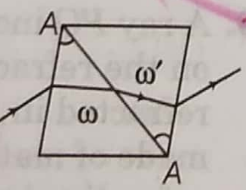
where, δ = minimum deviation.

Angular dispersion

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

Combining Two Thin Prisms

We can study two conditions



(i) Dispersion without average deviation

$$\delta_V - \delta_R = (\mu_Y - 1)\,A(\omega - \omega')$$

(ii) Average deviation without dispersion

$$\delta = (\mu_Y - 1)\,A\left[1 - \frac{\omega}{\omega'}\right]$$

Scattering of Light

Its a phenomena in which light is deflected from its path due to its interaction with the particles of the medium through which it passes.

Rayleigh Law of Scattering

It states that the intensity of light of wavelength λ present in the scattered light is inversely proportional to the fourth power of λ, provided the size of scattering particles are much smaller than λ, Mathematically scattering $\propto \frac{1}{\lambda^4}$ [for $a << \lambda$]. The bluishness of sky and reddishness of sunrise and sunset could be explained by this law.