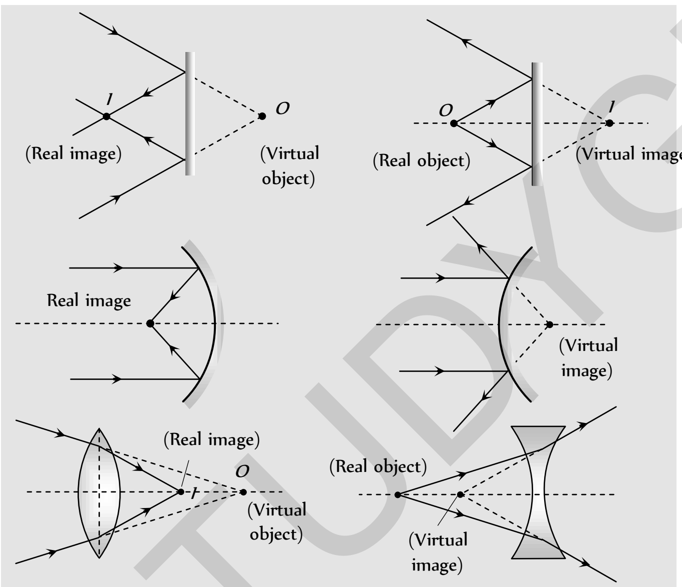
Chapter
29
Ray Optics

Real and Virtual Images

If light rays, after reflection or refraction, actually meets at a point then real image is formed and if they appears to meet virtual image is formed.



Reflection of Light

When a ray of light after incidenting on a boundary separating two media comes back into the same media, then this phenomenon, is called reflection of light.

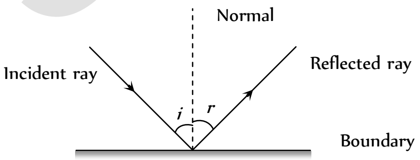


Fig. 29.1

(1) $\angle i = \angle r$

(2) After reflection, velocity, wave length and frequency of light remains same but intensity decreases.

(3) There is a phase change of π if reflection takes place from denser medium.

Reflection From a Plane Surface (Plane Mirror)

The image formed by a plane mirror is virtual, erect, laterally inverted, equal in size that of the object and at a distance equal to the distance of the object in front of the mirror.

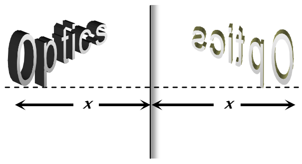


Fig. 29.2

(1) Deviation produced by a plane mirror and by two inclined plane mirrors.

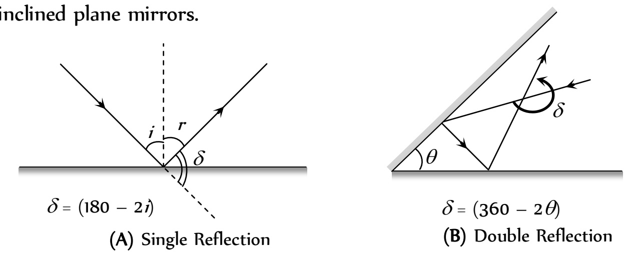


Fig. 29.3

(2) **Images by two inclined plane mirrors :** When two plane mirrors are inclined to each other at an angle θ, then number of images (n) formed of an object which is kept between them.

(i) $n = \left(\frac{360^o}{\theta} - 1\right)$; If $\frac{360^o}{\theta}$ = even integer

(ii) If $\frac{360^o}{\theta}$ = odd integer then there are two possibilities

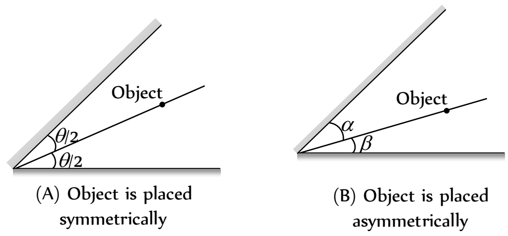


Fig. 29.4

$$n = \left(\frac{360}{\theta} - 1\right) \qquad\qquad n = \frac{360}{\theta}$$

(3) **Other important informations**

(i) When the object moves with speed u towards (or away) from the plane mirror then image also moves towards (or away) with speed u. But relative speed of image *w.r.t.* object is $2u$.

(ii) When mirror moves towards the stationary object with speed u, the image will move with speed $2u$ in same direction as that of mirror.

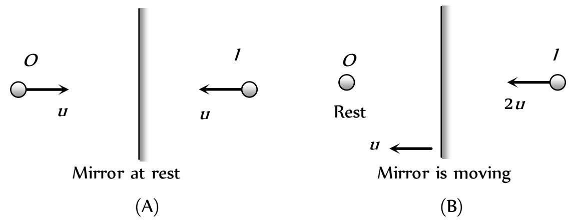


Fig. 29.5

(iii) A man of height h requires a mirror of length at least equal to $h/2$, to see his own complete image.

(iv) To see complete wall behind himself a person requires a plane mirror of at least one third the height of wall. It should be noted that person is standing in the middle of the room.

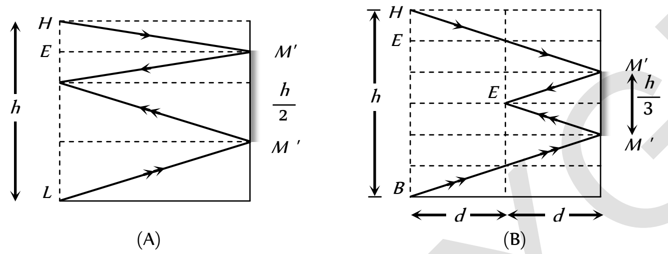


Fig. 29.6

Curved Mirror

It is a part of a transparent hollow sphere whose one surface is polished.

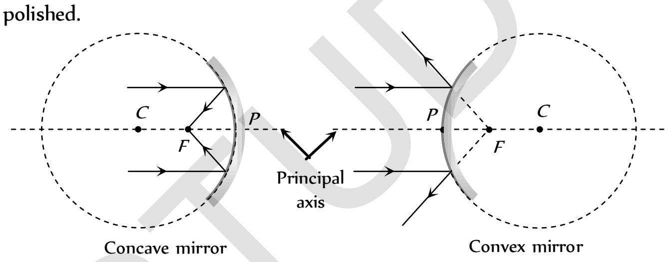


Fig. 29.7

Concave mirror converges the light rays and used as a shaving mirror, In search light, in cinema projector, in telescope, by E.N.T. specialists etc.

Convex mirror diverges the light rays and used in road lamps, side mirror in vehicles *etc.*

(1) **Terminology**

(i) Pole (*P*) **:** Mid point of the mirror

(ii) Centre of curvature (*C*) : Centre of the sphere of which the mirror is a part.

(iii) Radius of curvature (*R*): Distance between pole and centre of curvature. $(R_{concave} = -ve\,,\ \ R_{convex} = +ve\,,\ \ R_{plane} = \infty)$

(iv) Principle axis : A line passing through *P* and *C*.

(v) Focus (*F*) : An image point on principle axis for an object at ∞.

(vi) Focal length (*f*) : Distance between *P* and *F*.

(vii) Relation between *f* and *R* : $f = \dfrac{R}{2}$

$(f_{concave} = -ve\,,\ f_{convex} = +\ ve\,,\ f_{plane} = \infty\ )$

(viii) Power : The converging or diverging ability of mirror

(ix) Aperture : Effective diameter of light reflecting area. Intensity of image $\propto$ Area $\propto$ (Aperture)^2

(x) Focal plane : A plane passing from focus and perpendicular to principle axis.

(2) **Sign conventions :**

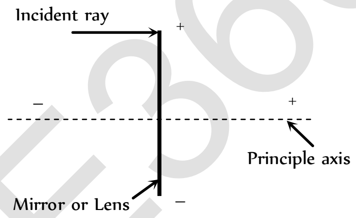


Fig. 29.8

(i) All distances are measured from the pole.

(ii) Distances measured in the direction of incident rays are taken as positive while in the direction opposite of incident rays are taken negative.

(iii) Distances above the principle axis are taken positive and below the principle axis are taken negative.

Table 29.1 : Useful sign

Concave mirror		Convex mirror
Real image ($u \geq f$)	Virtual image ($u < f$)	
Distance of object $u \to -$	$u \to -$	$u \to -$
Distance of image $v \to -$	$v \to +$	$v \to +$
Focal length $f \to -$	$f \to -$	$f \to +$
Height of object $O \to +$	$O \to +$	$O \to +$
Height of image $I \to -$	$I \to +$	$I \to +$
Radius of curvature $R \to -$	$R \to -$	$R \to +$
Magnification $m \to -$	$m \to +$	$m \to +$

Image Formation by Curved Mirrors

Concave mirror : Image formed by concave mirror may be real or virtual, may be inverted or erect, may be smaller, larger or equal in size of object.

(1) When object is placed at infinite (*i.e.* $u = \infty$)

Image

$\longrightarrow$ At *F*

$\longrightarrow$ Real

$\longrightarrow$ Inverted

$\longrightarrow$ Very small in size

$\longrightarrow$

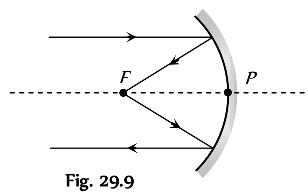


Fig. 29.9

Magnification $m << -1$

(2) When object is placed between infinite and centre of curvature (*i.e.* $u > 2f$)

Image

⟶ Between F and C
⟶ Real
⟶ Inverted
⟶ Small in size
⟶ $m < -1$

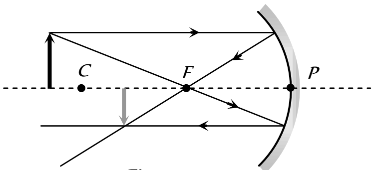


Fig. 29.10

(3) When object is placed at centre of curvature (*i.e.* $u = 2f$)

Image

⟶ At C
⟶ Real
⟶ Inverted
⟶ Equal in size
⟶ $m = -1$

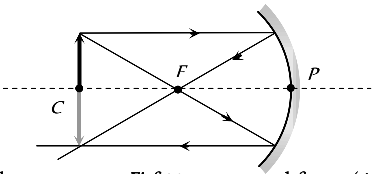


Fig. 29.11

(4) When object is placed between centre of curvature and focus (*i.e.* $f < u < 2f$)

Image

⟶ Between $2f$ and ∞
⟶ Real
⟶ Inverted
⟶ Large in size
⟶ $m > -1$

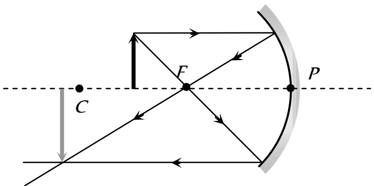


Fig. 29.12

(5) When object is placed at focus (*i.e.* $u = f$)

Image

⟶ At ∞
⟶ Real
⟶ Inverted
⟶ Very large in size
⟶ $m >> -1$

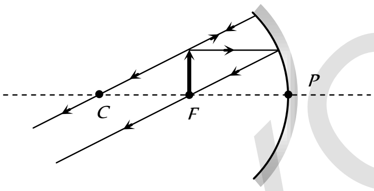


Fig. 29.13

(6) When object is placed between focus and pole (*i.e.* $u < f$)

Image

⟶ Behind the mirror
⟶ Virtual
⟶ Erect
⟶ Large in size
⟶ $m > +1$

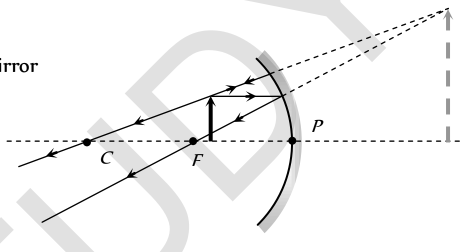


Fig. 29.14

Convex mirror : Image formed by convex mirror is always virtual, erect and smaller in size.

(1) When object is placed at infinite (*i.e.* $u = \infty$)

Image

⟶ At F
⟶ Virtual
⟶ Erect
⟶ Very small in size
⟶ Magnification $m << +1$

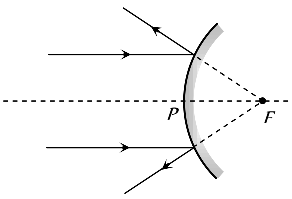


Fig. 29.15

(2) When object is placed any where on the principal axis

Image

⟶ Between P and F
⟶ Virtual
⟶ Erect
⟶ Small in size
⟶ Magnification $m < +1$

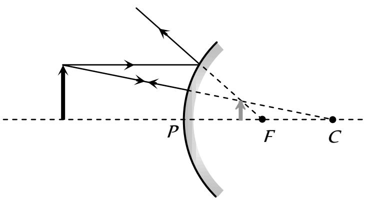


Fig. 29.16

Mirror Formula and Magnification

For a spherical mirror if u = Distance of object from pole, v = distance of image from pole, f = Focal length, R = Radius of curvature, O = Size of object, I = size of image

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

(2) **Lateral magnification :** When an object is placed perpendicular to the principle axis, then linear magnification is called lateral or transverse magnification.

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

(* Always use sign convention while solving the problems)

Axial magnification : When object lies along the principle axis then its axial magnification $m = \frac{I}{O} = \frac{-(v_2 - v_1)}{(u_2 - u_1)}$

If object is small; $m = -\frac{dv}{du} = \left(\frac{v}{u}\right)^2 = \left(\frac{f}{f-u}\right)^2 = \left(\frac{f-v}{f}\right)^2$

Areal magnification : If a $2D$-object is placed with it's plane perpendicular to principle axis. It's Areal magnification

$$m_s = \frac{\text{Area of image } (A_i)}{\text{Area of object} (A_o)} \Rightarrow m_s = m^2 = \frac{A_i}{A_o}$$

Refraction of Light

The bending of the ray of light passing from one medium to the other medium is called refraction.

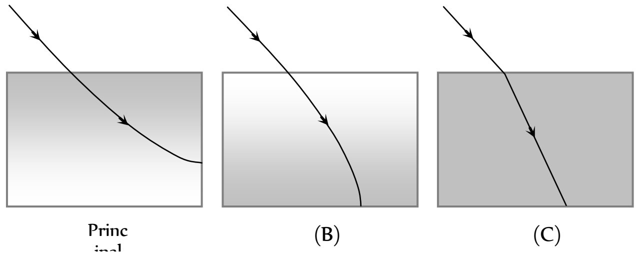


Fig. 29.17

(1) The refraction of light takes place on going from one medium to another because the speed of light is different in the two media.

(2) Greater the difference in the speeds of light in the two media, greater will be the amount of refraction.

(3) A medium in which the speed of light is more is known as optically rarer medium and a medium is which the speed of light is less, is known as optically denser medium.

(4) When a ray of light goes from a rarer medium to a denser medium, it bends towards the normal.

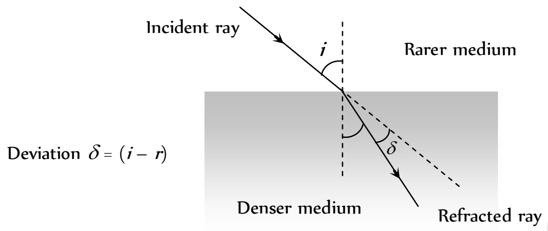


Fig. 29.18

(5) When a ray of light goes from a denser medium to a rarer medium, it bends away from the normal.

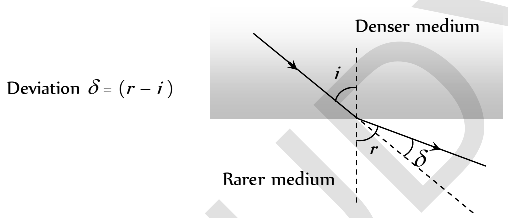


Fig. 29.19

(6) **Snell's law :** The ratio of sine of the angle of incidence to the angle of refraction (r) is a constant called refractive index

i.e. $\dfrac{\sin i}{\sin r} = \mu$ (a constant). For two media, Snell's law can be written as ${}_1\mu_2 = \dfrac{\mu_2}{\mu_1} = \dfrac{\sin i}{\sin r}$

$\Rightarrow \mu_1 \times \sin i = \mu_2 \times \sin r$ *i.e.* $\mu \sin\theta =$ constant

Also in vector form : $\hat{\boldsymbol{i}} \times \hat{\boldsymbol{n}} = \mu(\hat{\boldsymbol{r}} \times \hat{\boldsymbol{n}})$

Refractive Index

(1) Refractive index of a medium is that characteristic which decides speed of light in it.

(2) It is a scalar, unit less and dimensionless quantity.

(3) **Absolute refractive index :** When light travels from vacuum to any transparent medium then refractive index of medium *w.r.t.* vacuum is called it's absolute refractive index *i.e.* ${}_{\text{vacuum}}\mu_{\text{medium}} = \dfrac{c}{v}$

Absolute refractive indices for glass, water and diamond are respectively $\mu_g = \dfrac{3}{2} = 1.5$, $\mu_w = \dfrac{4}{3} = 1.33$ and $\mu_D = \dfrac{12}{5} = 2.4$

(4) **Relative refractive index :** When light travels from medium (1) to medium (2) then refractive index of medium (2) *w.r.t.* medium (1) is called it's relative refractive index *i.e.* ${}_1\mu_2 = \dfrac{\mu_2}{\mu_1} = \dfrac{v_1}{v_2}$ (where v_1 and v_2 are the speed of light in medium 1 and 2 respectively).

(5) When we say refractive index we mean absolute refractive index.

(6) The minimum value of absolute refractive index is 1. For air it is very near to 1. ($\cong 1.003$)

(7) Cauchy's equation : $\mu = A + \dfrac{B}{\lambda^2} + \dfrac{C}{\lambda^4} + \ldots\ldots$

($\lambda_{\text{Red}} > \lambda_{\text{violet}}$ so $\mu_{\text{Red}} < \mu_{\text{violet}}$)

(8) If a light ray travels from medium (1) to medium (2), then

$${}_1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$$

(9) **Dependence of Refractive index**

(i) Nature of the media of incidence and refraction.

(ii) Colour of light or wavelength of light.

(iii) Temperature of the media : Refractive index decreases with the increase in temperature.

Table 29.2 : Indices of refraction for various substances, Measured with light of vacuum wavelength λ_0 = 589 *nm*

Substance	Refractive index	Substance	Refractive index
Solids at 20°*C*		**Liquids at 20°*C***	
Diamond (*C*)	2.419	Benzene	1.501
Fluorite (CaF_2)	1.434	Carbon disulfide	1.628
Fused quartz (SiO_2)	1.458	Carbon tetrachloride	1.461
Glass, crown	1.52	Ethyl alcohol	1.361
Glass, flint	1.66	Glycerine	1.473
Ice (H_2O) (at 0°*C*)	1.309	Water	1.333
Polystyrene	1.49	**Gases at 0°*C*, 1 *atm***	
Sodium chloride	1.544	Air	1.000293
Zircon	1.923	Carbon dioxide	1.00045

(10) **Reversibility of light and refraction through several media**

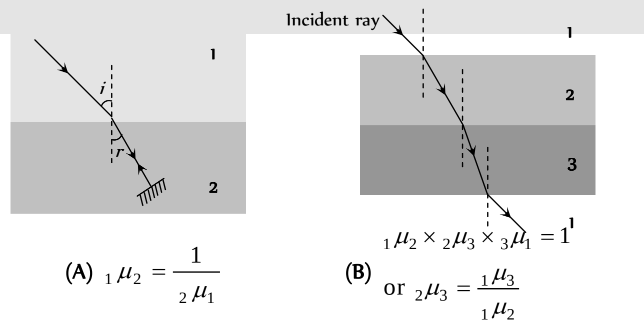


Fig. 29.20

Real and Apparent Depth

If object and observer are situated in different medium then due to refraction, object appears to be displaced from it's real position.

(1) **When object is in denser medium and observer is in rarer medium**

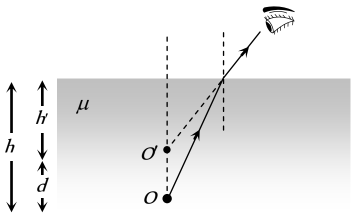


Fig. 29.21

(i) $\mu = \dfrac{\text{Real depth}}{\text{Apparent depth}} = \dfrac{h}{h'}$

(ii) Real depth > Apparent depth

(iii) Shift $d = h - h' = \left(1 - \dfrac{1}{\mu}\right)h$. For water $\mu = \dfrac{4}{3} \Rightarrow d = \dfrac{h}{4}$;

For glass $\mu = \dfrac{3}{2} \Rightarrow d = \dfrac{h}{3}$

(iv) Lateral magnification : consider an object of height x placed vertically in a medium μ such that the lower end (B) is a distance h from the interface and the upper end (A) at a distance ($h - x$) from the interface.

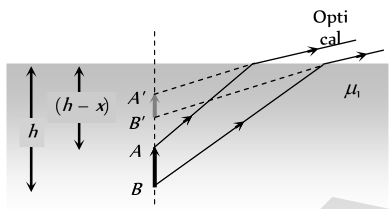


Fig. 29.22

Distance of image of B ($i.e.$ B') from the interface = $\dfrac{\mu_2}{\mu_1} h$

Distance of image of A ($i.e.$ A') from the interface $= \dfrac{\mu_2}{\mu_1}(h - x)$

Therefore, length of the image $\dfrac{\mu_2}{\mu_1} x$

or, the lateral magnification of the object $m = \dfrac{\mu_2}{\mu_1} = \dfrac{1}{\mu}$

(v) If a beaker contains various immiscible liquids as shown then

Apparent depth of bottom $= \dfrac{d_1}{\mu_1} + \dfrac{d_2}{\mu_2} + \dfrac{d_3}{\mu_3} + ...$

$\mu_{\_\_\_} = \dfrac{d_{AC}}{d_{App.}} = \dfrac{d_1 + d_2 + ...}{\dfrac{d_1}{\mu_1} + \dfrac{d_2}{\mu_2} + ...}$

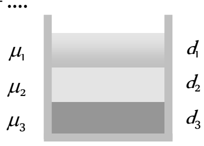
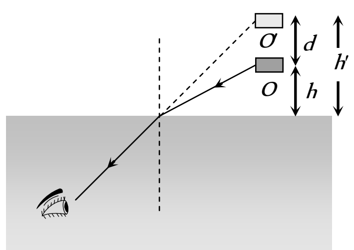


Fig. 29.23

(In case of two liquids if $d_1 = d_2$ than $\mu = \dfrac{2\mu_1\mu_2}{\mu_1 + \mu_2}$)

(2) **Object is in rarer medium and observer is in denser medium**



(i) $\mu = \dfrac{h'}{h}$

(ii) Real depth < Apparent depth.

(iii) $d = (\mu - 1)h$

(iv) Shift for water $d_w = \dfrac{h}{3}$; Shift for glass $d_g = \dfrac{h}{2}$

Refraction Through a Glass Slab

(1) **Lateral shift :** The refracting surfaces of a glass slab are parallel to each other. When a light ray passes through a glass slab it is refracted twice at the two parallel faces and finally emerges out parallel to it's incident direction $i.e.$ the ray undergoes no deviation $\delta = 0$. The angle of emergence (e) is equal to the angle of incidence (i)

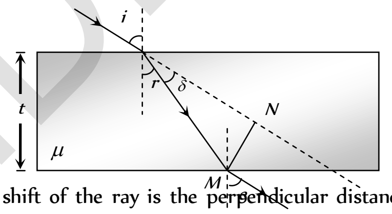


Fig. 29.25

The Lateral shift of the ray is the perpendicular distance between the incident and the emergent ray, and it is given by

***MN* = *t* sec *r* sin (*i* – *r*)**

(2) **Normal shift :** If a glass slab is placed in the path of a converging or diverging beam of light then point of convergence or point of divergence appears to be shifted as shown

Normal shift

$OO' = x = \left(1 - \dfrac{1}{\mu}\right)t$

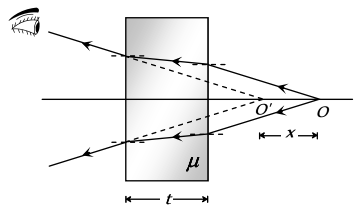


Fig. 29.26

(3) **Optical path :** It is defined as distance travelled by light in vacuum in the same time in which it travels a given path length in a medium.

Time taken by light ray to pass through the medium $= \dfrac{\mu x}{c}$; where x = geometrical path and μx = optical path

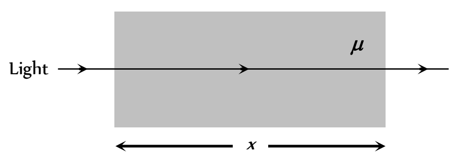
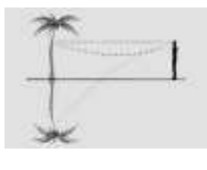


Fig. 29.27

Total Internal Reflection (TIR)


When a ray of light goes from denser to rarer medium it bends away from the normal and as the angle of incidence in denser medium increases, the angle of refraction in rarer medium also increases and at a certain angle, angle of refraction becomes 90°, this angle of incidence is called critical angle (C).

When Angle of incidence exceeds the critical angle than light ray comes back in to the same medium after reflection from interface. This phenomenon is called Total internal reflection (TIR).

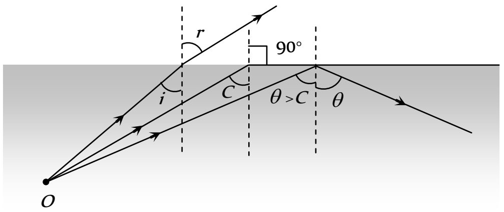


Fig. 29.28

(1) $\mu = \dfrac{1}{\sin C} = \operatorname{cosec} C$ where $\mu \rightarrow {}_{\text{Rarer}}\mu_{\text{Denser}}$

(2) **Conditions for TIR**

(i) The ray must travel from denser medium to rarer medium.

(ii) The angle of incidence i must be greater than critical angle C

(3) **Dependence of critical angle**

(i) Colour of light (or wavelength of light) : Critical angle depends upon wavelength as $\lambda \propto \dfrac{1}{\mu} \propto \sin C$

(a) $\lambda_R > \lambda_V \Rightarrow C_R > C_V$

(b) $\sin C = \dfrac{1}{{}_R\mu_D} = \dfrac{\mu_R}{\mu_D} = \dfrac{\lambda_D}{\lambda_R} = \dfrac{v_D}{v_R}$ (for two media)

(ii) Nature of the pair of media : Greater the refractive index lesser will be the critical angle.

(a) For (glass- air) pair $\rightarrow C_{\text{glass}} = 42^o$

(b) For (water-air) pair $\rightarrow C_{\text{water}} = 49^o$

(c) For (diamond-air) pair $\rightarrow C_{\text{diamond}} = 24^o$

(iii) Temperature : With temperature rise refractive index of the material decreases therefore critical angle increases.

Common Examples of TIR

(1) **Looming :** An optical illusion in cold countries

(2) **Mirage :** An optical illusion in deserts

Fig. 29.29

(3) **Brilliance of diamond :** Due to repeated internal reflections diamond sparkles.

(4) **Optical fibre :** Optical fibres consist of many long high quality composite glass/quartz fibres. Each fibre consists of a core and cladding.

(i) The refractive index of the material of the core (μ) is higher than that of the cladding (μ).

(ii) When the light is incident on one end of the fibre at a small angle, the light passes inside, undergoes repeated total internal reflections along the fibre and finally comes out. The angle of incidence is always larger than the critical angle of the core material with respect to its cladding.

(iii) Even if the fibre is bent, the light can easily travel through along the fibre

(iv) A bundle of optical fibres can be used as a 'light pipe' in medical and optical examination. It can also be used for optical signal transmission. Optical fibres have also been used for transmitting and receiving electrical signals which are converted to light by suitable transducers.

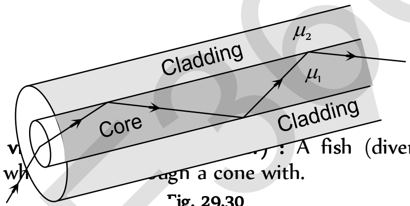


Fig. 29.30

(5) **Field of v**...) : A fish (diver) inside the water can see the wh... ugh a cone with.

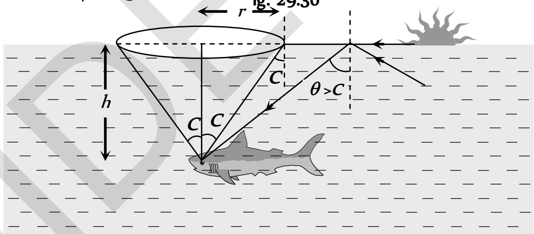


Fig. 29.31

(a) Apex angle $= 2C = 98^o$

(b) Radius of base $r = h \tan C = \dfrac{h}{\sqrt{\mu^2 - 1}}$; for water $r = \dfrac{3h}{\sqrt{7}}$

(c) Area of base $A = \dfrac{\pi h^2}{(\mu^2 - 1)}$; for water $a = \dfrac{9\pi}{7}h^2$

(6) **Porro prism :** A right angled isosceles prism, which is used in periscopes or binoculars. It is used to deviate light rays through 90^o and 180^o and also to erect the image.

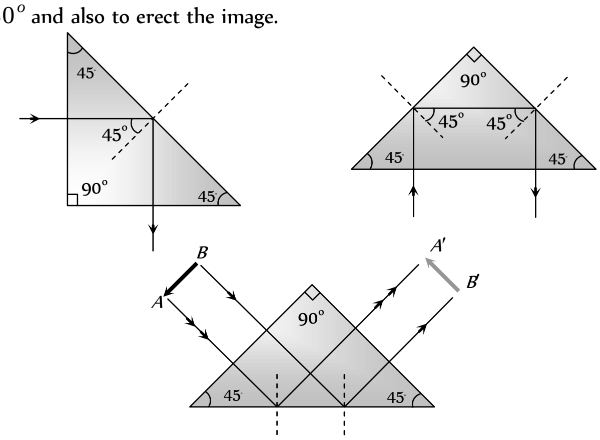


Fig. 29.32

Refraction From Spherical Surface

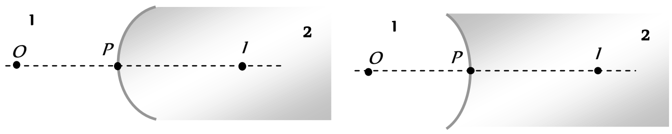


Fig. 29.33

(1) **Refraction formula :** $\dfrac{\mu_2 - \mu_1}{R} = \dfrac{\mu_2}{v} - \dfrac{\mu_1}{u}$

Where μ_1 = Refractive index of the medium from which light rays are coming (from object).

μ_2 = Refractive index of the medium in which light rays are entering.

u = Distance of object, v = Distance of image, R = Radius of curvature

(2) **Lateral magnification :** The lateral magnification m is the ratio of the image height to the object height

or $m = \left(\dfrac{h_i}{h_0}\right) = \left(\dfrac{\mu_1}{\mu_2}\right)\left(\dfrac{v}{u}\right)$

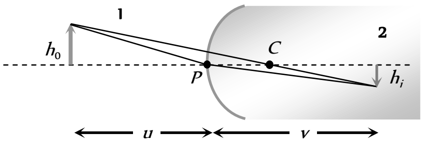


Fig. 29.34

Lens

(1) Lens is a transparent medium bounded by two refracting surfaces, such that at least one surface is curved. Curved surface can be spherical, cylindrical etc.

(2) Lenses are of two basic types convex which are thicker in the middle than at the edges and concave for which the reverse holds.

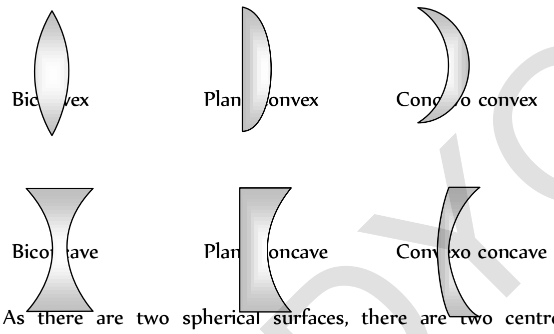


Fig. 29.35

(3) As there are two spherical surfaces, there are two centres of curvature C_1 and C_2 and correspondingly two radii of curvature R_1 and R_2

(4) The line joining C_1 and C_2 is called the principal axis of the lens. The centre of the thin lens which is on the principal axis, is called the optical centre.

(5) A ray passing through optical centre proceeds undeviated through the lens.

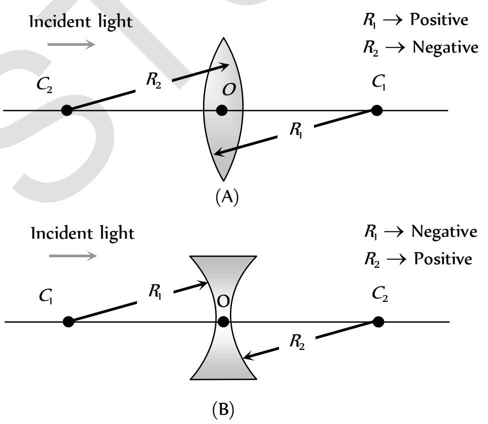


Fig. 29.36

(6) **Principal focus :** We define two principal focus for the lens. We are mainly concerned with the second principal focus (F). Thus wherever we write the focus, it means the second principal focus.

First principal focus : An object point for which image is formed at infinity.

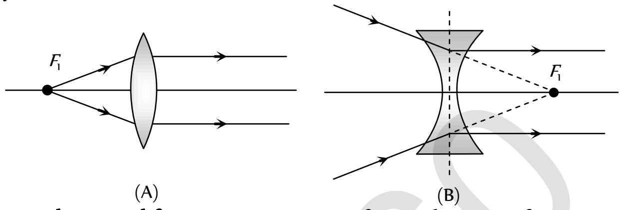


Fig. 29.37

Second principal focus : An image point for an object at infinity.

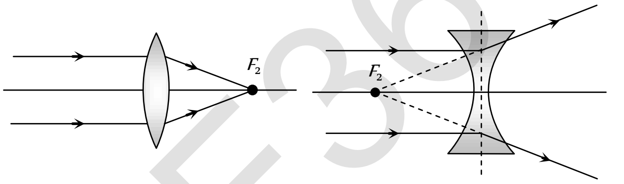


Fig. 29.38

Focal Length, Power and Aperture of Lens

(1) **Focal length (f) :** Distance of second principle focus from optical centre is called focal length

$f_{\text{convex}} \rightarrow$ positive, $f_{\text{concave}} \rightarrow$ negative, $f_{\text{plane}} \rightarrow \infty$

(2) **Aperture :** Effective diameter of light transmitting area is called aperture. $\text{Intensity of image} \propto (\text{Aperture})^2$

(3) **Power of lens (P) :** Means the ability of a lens to deviate the path of the rays passing through it. If the lens converges the rays parallel to the principal axis its power is positive and if it diverges the rays it is negative.

Power of lens $P = \dfrac{1}{f(m)} = \dfrac{100}{f(cm)}$; Unit of power is Diopter (D)

$P_{\text{convex}} \rightarrow \text{positive}, P_{\text{concave}} \rightarrow \text{negative}, P_{\text{plane}} \rightarrow \text{zero}$.

Rules of Image Formation by Lens

Convex lens : The image formed by convex lens depends on the position of object.

(1) When object is placed at infinite (*i.e.* $u = \infty$)

Image

- ⟶ At F
- ⟶ Real
- ⟶ Inverted
- ⟶ Very small in size
- ⟶ Magnification $m << -1$

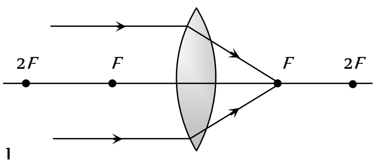


Fig. 29.39

(2) When object is placed between infinite and $2F$ (*i.e.* $u > 2f$)

Image

- ⟶ Between F and $2F$
- ⟶ Real
- ⟶ Inverted
- ⟶ Very small in size
- ⟶ Magnification $m < -1$

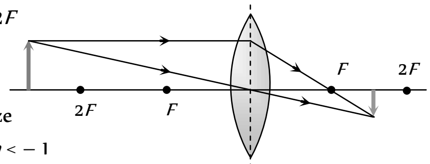


Fig. 29.40

(3) When object is placed at $2F$ (*i.e.* $u = 2f$)

Image

- ⟶ At $2F$
- ⟶
- ⟶
- ⟶
- ⟶

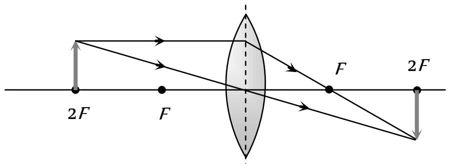


Fig. 29.41

Real

Inverted

Equal in size

Magnification $m = -1$

(4) When object is placed between F and $2F$ (*i.e.* $f < u < 2f$)

Image

→ Beyond $2F$

→ Real

→ Inverted

→ Large in size

→ Magnification $m > -1$

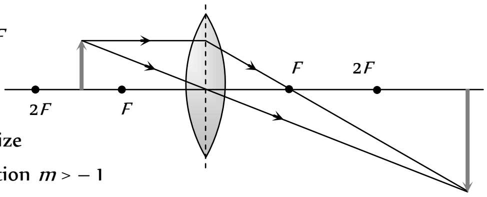


Fig. 29.42

(5) When object is placed at F (*i.e.* $u = f$)

Image

→ At ∞

→ Real

→ Inverted

→ Very large in size

→ Magnification $m >> -1$

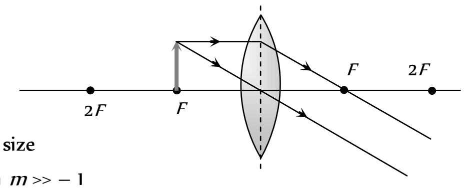


Fig. 29.43

(6) When object is placed between F and optical center (*i.e.* $u < f$)

Image

→ Same side as that of object

→ Virtual

→ Erect

→ large in size

→ Magnification $m > 1$

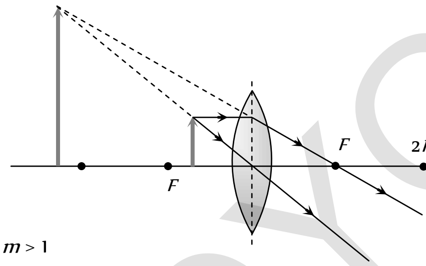


Fig. 29.44

Concave lens : The image formed by a concave lens is always virtual, erect and diminished (like a convex mirror)

(1) When object is placed at ∞

Image

→ At F

→ Virtual

→ Erect

→ Point size

→ Magnification $m << +1$

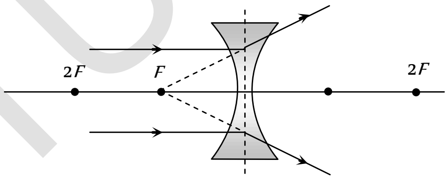


Fig. 29.45

(2) When object is placed any where on the principal axis

Image

→ Between optical centre and focus

→ Virtual

→ Erect

→ Smaller in size

→ Magnification $m < +1$

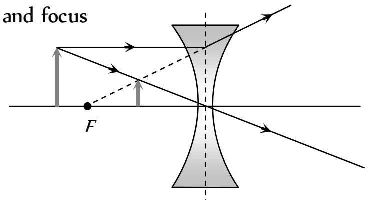


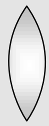
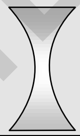
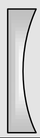
Fig. 29.46

Lens Maker's Formula and Lens Formula

(1) **Lens maker's formula :** If R_1 and R_2 are the radii of curvature of first and second refracting surfaces of a thin lens of focal length f and refractive index μ (*w.r.t.* surrounding medium) then the relation between f, μ, R_1 and R_2 is known as lens maker's formula.

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

Table 29.3 : Focal length of different lenses

Lens	Focal length	For $\mu = 1.5$
Biconvex lens $R_1 = R$, $R_2 = -R$ 	$f = \frac{R}{2(\mu - 1)}$	$f = R$
Plano-convex lens $R_1 = \infty$, $R_2 = -R$ 	$f = \frac{R}{(\mu - 1)}$	$f = 2R$
Biconcave $R_1 = -R$, $R_2 = +R$ 	$f = -\frac{R}{2(\mu - 1)}$	$f = -R$
Plano-concave $R_1 = \infty$, $R_2 = R$ 	$f = \frac{-R}{(\mu - 1)}$	$f = -2R$

(2) **Lens formula :** The expression which shows the relation between u, v and f is called lens formula.

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

Magnification

The ratio of the size of the image to the size of object is called magnification.

(1) Transverse magnification : $m = \frac{I}{O} = \frac{v}{u} = \frac{f}{f + u} = \frac{f - v}{f}$ (use sign convention while solving the problem)

(2) Longitudinal magnification : $m = \frac{I}{O} = \frac{v_2 - v_1}{u_2 - u_1}$. For very small object $m = \frac{dv}{du} = \left(\frac{v}{u}\right)^2 = \left(\frac{f}{f + u}\right)^2 = \left(\frac{f - v}{f}\right)^2$

(3) Areal magnification : $m_s = \frac{A_i}{A_o} = m^2 = \left(\frac{f}{f + u}\right)^2$,

(A_i = Area of image, A_o = Area of object)

(4) **Relation between object and image speed :** If an object moves with constant speed (V_o) towards a convex lens from infinity to focus, the image will move slower in the beginning and then faster. Also $V_i = \left(\frac{f}{f+u}\right)^2 . V_o$

Newton's Formula

If the distance of object (x) and image (x) are not measured from optical centre, but from first and second principal foci then Newton's formula states $f^2 = x_1 x_2$

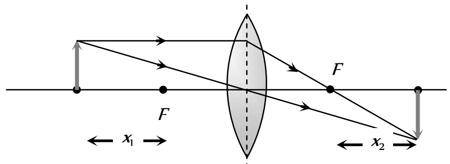


Fig. 29.47

Lens Immersed in a Liquid

If a lens (made of glass) of refractive index μ is immersed in a liquid of refractive index μ_l then its focal length in liquid, f_l is given by

$$\frac{1}{f_l} = ({}_l\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ......(i)$$

If f_a is the focal length of lens in air, then

$$\frac{1}{f_a} = ({}_a\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ......(ii)$$

$$\Rightarrow \quad \frac{f_l}{f_a} = \frac{({}_a\mu_g - 1)}{({}_l\mu_g - 1)}$$

(1) If $\mu_g > \mu_l$, then f_l and f_a are of same sign and $f_l > f_a$.

That is the nature of lens remains unchanged, but it's focal length increases and hence power of lens decreases.

(2) If $\mu_g = \mu_l$, then $f_l = \infty$. It means lens behaves as a plane glass plate and becomes invisible in the medium.

Fig. 29.48

(3) If $\mu_g < \mu_l$, then f_l and f_a have opposite signs and the nature of lens changes *i.e.* a convex lens diverges the light rays and concave lens converges the light rays.

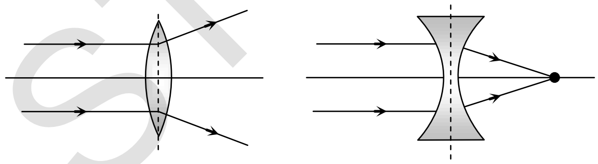


Fig. 29.49

Displacement Method

By this method focal length of convex lens is determined.

Consider an object and a screen placed at a distance D (> $4f$) apart. Let a lens of focal length f be placed between the object and the screen.

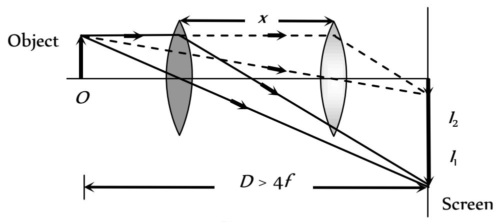


Fig. 29.50

(1) For two different positions of lens two images $(I_1 \text{ and } I_2)$ of an object are formed at the screen.

(2) Focal length of the lens $f = \frac{D^2 - x^2}{4D} = \frac{x}{m_1 - m_2}$

where $m_1 = \frac{I_1}{O}$; $m_2 = \frac{I_2}{O}$ and $m_1 m_2 = 1$.

(3) Size of object $O = \sqrt{I_1 . I_2}$

Cutting of Lens

(1) A symmetric lens is cut along optical axis in two equal parts. Intensity of image formed by each part will be same as that of complete lens. Focal length is double the original for each part.

(2) A symmetric lens is cut along principle axis in two equal parts. Intensity of image formed by each part will be less compared as that of complete lens.(aperture of each part is $\frac{1}{\sqrt{2}}$ times that of complete lens). Focal length remains same for each part.

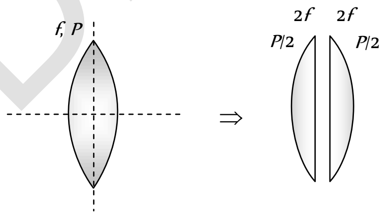


Fig. 29.51

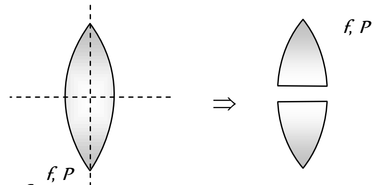


Fig. 29.52

Combination of Lens

(1) For a system of lenses, the net power, net focal length and magnification are given as follows :

$$P = P_1 + P_2 + P_3 ...., \quad \frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + ..., $$

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

(2) In case when two thin lens are in contact : Combination will behave as a lens, which have more power or lesser focal length.

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \Rightarrow F = \frac{f_1 f_2}{f_1 + f_2} \quad \text{and} \quad P = P_1 + P_2$$

(3) If two lens of equal focal length but of opposite nature are in contact then combination will behave as a plane glass plate and $F_{\text{combination}} = \infty$

(4) When two lenses are placed co-axially at a distance d from each other then equivalent focal length (F).

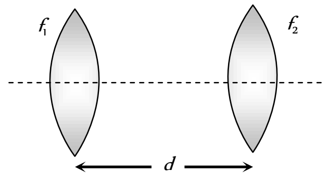


Fig. 29.53

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}-\frac{d}{f_1 f_2} \text{ and } P=P_1+P_2-dP_1P_2$$

(5) Combination of parts of a lens :

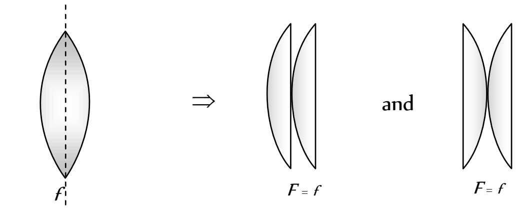


Fig. 29.54

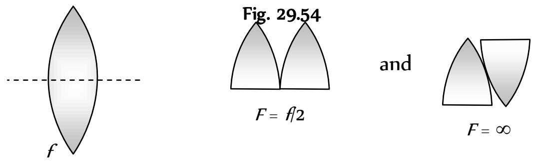


Fig. 29.55

Silvering of Lens

On silvering the surface of the lens it behaves as a mirror. The focal length of the silvered lens is $\frac{1}{F}=\frac{2}{f_l}+\frac{1}{f_m}$

where $f_l =$ focal length of lens from which refraction takes place (twice)

$f_m =$ focal length of mirror from which reflection takes place.

(i) Plano convex is silvered

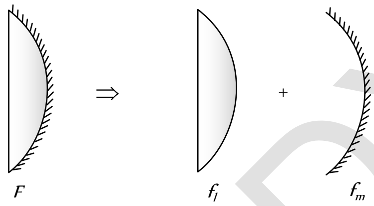


Fig. 29.56

$$f_m=\frac{R}{2},\ f_l=\frac{R}{(\mu-1)} \text{ so } F=\frac{R}{2\mu}$$

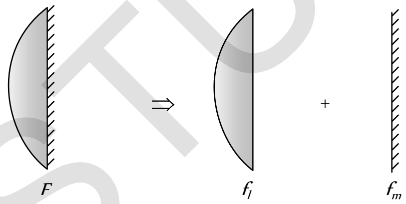


Fig. 29.57

$$f_m=\infty,\ f_l=\frac{R}{(\mu-1)} \text{ so } F=\frac{R}{2(\mu-1)}$$

(ii) Double convex lens is silvered

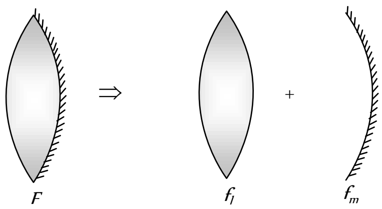


Fig. 29.58

Since $f_l=\frac{R}{2(\mu-1)},\ f_m=\frac{R}{2}$ so $F=\frac{R}{2(2\mu-1)}$

Defects in Lens

(1) **Chromatic aberration :** Image of a white object is coloured and blurred because μ (hence f) of lens is different for different colours. This defect is called chromatic aberration.

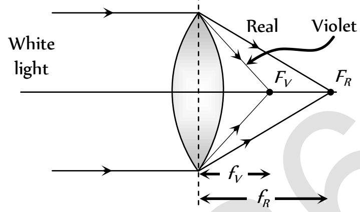


Fig. 29.59

$\mu_V>\mu_R$ so $f_R>f_V$

Mathematically chromatic aberration = $f_R-f_V=\omega f_y$

ω = Dispersive power of lens.

f = Focal length for mean colour $=\sqrt{f_R f_V}$

Removal : To remove this defect *i.e.* for Achromatism we use two or more lenses in contact in place of single lens.

Mathematically condition of Achromatism is : $\frac{\omega_1}{f_1}+\frac{\omega_2}{f_2}=0$ or $\omega_1 f_2=-\omega_2 f_1$

(2) **Spherical aberration :** Inability of a lens to form the point image of a point object on the axis is called Spherical aberration.

In this defect all the rays passing through a lens are not focussed at a single point and the image of a point object on the axis is blurred.

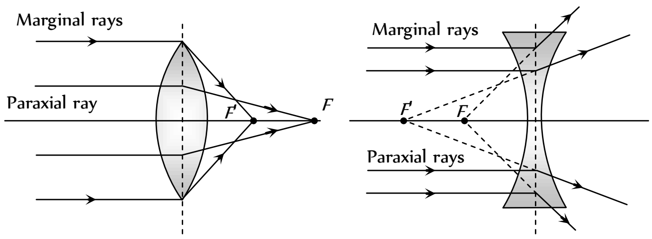


Fig. 29.60

Removal : A simple method to reduce spherical aberration is to use a stop before and infront of the lens. (but this method reduces the intensity of the image as most of the light is cut off). Also by using plano-convex lens, using two lenses separated by distance $d = F - F'$, using crossed lens.

(3) **Coma :** When the point object is placed away from the principle axis and the image is received on a screen perpendicular to the axis, the shape of the image is like a comet. This defect is called Coma.

It refers to spreading of a point object in a plane $\perp$ to principle axis.

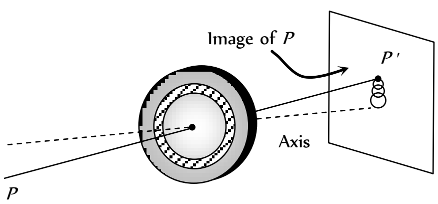


Fig. 29.61

Removal : It can be reduced by properly designing radii of curvature of the lens surfaces. It can also be reduced by appropriate stops placed at appropriate distances from the lens.

(4) **Curvature :** For a point object placed off the axis, the image is spread both along and perpendicular to the principal axis. The best image

is, in general, obtained not on a plane but on a curved surface. This defect is known as Curvature.

Removal : Astigmatism or the curvature may be reduced by using proper stops placed at proper locations along the axis.

(5) **Distortion :** When extended objects are imaged, different portions of the object are in general at different distances from the axis. The magnification is not the same for all portions of the extended object. As a result a line object is not imaged into a line but into a curve.

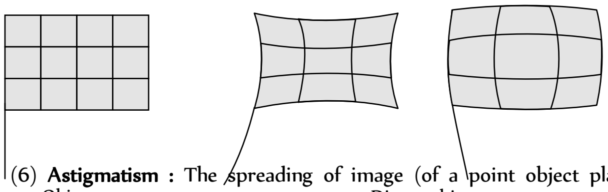


Fig. 29.62

(6) **Astigmatism :** The spreading of image (of a point object placed away from the principal axis) along the principal axis is called Astigmatism.

Prism

Prism is a transparent medium bounded by refracting surfaces, such that the incident surface (on which light ray is incidenting) and emergent surface (from which light rays emerges) are plane and non parallel.

(1) **Refraction through a prism**

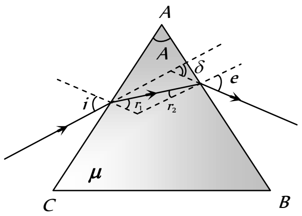


Fig. 29.63

i – Angle of incidence,
e – Angle of emergence,
A – Angle of prism or refracting angle of prism,
r_1 and r_2 – Angle of refraction,
δ – Angle of deviation

$A = r_1 + r_2$ and $i + e = A + \delta$

For surface AC $\mu = \dfrac{\sin i}{\sin r_1}$; For surface AB $\dfrac{1}{\mu} = \dfrac{\sin r_2}{\sin e}$

(2) **Deviation through a prism :** For thin prism $\delta = (\mu - 1)A$. Also deviation is different for different colour light *e.g.* $\mu_R < \mu_V$ so $\delta_R < \delta_V$.

$\mu_{\text{Flint}} > \mu_{\text{Crown}}$ so $\delta_F > \delta_C$

(i) Maximum deviation : Condition of maximum deviation is $\angle i = 90^o \Rightarrow r_1 = C,\ r_2 = A - C$

and from Snell's law on emergent surface

$$e = \sin^{-1}\left[\frac{\sin(A-C)}{\sin C}\right]$$

$$\delta_{\max} = \frac{\pi}{2} + \sin^{-1}\left[\frac{\sin(A-C)}{\sin C}\right] - A$$

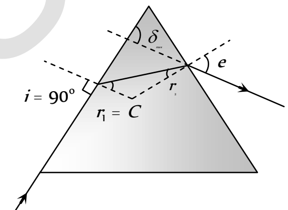


Fig. 29.64

(ii) Minimum deviation : It is observed if $\angle i = \angle e$ and $\angle r_1 = \angle r_2 = r$, deviation produced is minimum.

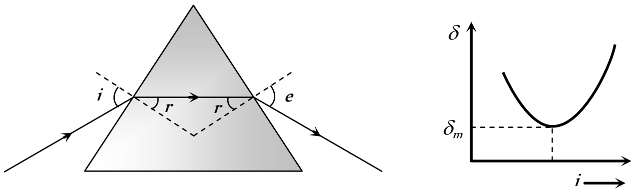


Fig. 29.65

(a) Refracted ray inside the prism is parallel to the base of the prism for equilateral and isosceles prisms.

(b) $r = \dfrac{A}{2}$ and $i = \dfrac{A + \delta_m}{2}$

(c) $\mu = \dfrac{\sin i}{\sin A/2}$ or $\mu = \dfrac{\sin\dfrac{A+\delta_m}{2}}{\sin A/2}$ (Prism formula).

(3) **Condition of no emergence :** For no emergence of light, TIR must takes place at the second surface

For TIR at second surface $r_2 > C$

So $A > r_1 + C$ (From $A = r_1 + r_2$)

As maximum value of $r_1 = C$

So, $A \geq 2C$. for any angle of incidence.

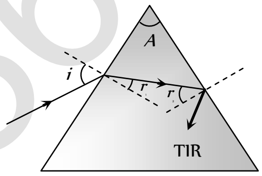


Fig. 29.66

If light ray incident normally on first surface *i.e.* $\angle i = 0°$ it means $\angle r_1 = 0°$. So in this case condition of no emergence from second surface is $A > C$.

$$\Rightarrow \sin A > \sin C \Rightarrow \sin A > \frac{1}{\mu} \Rightarrow \mu > \text{cosec } A$$

Dispersion Through a Prism

The splitting of white light into it's constituent colours is called dispersion of light.

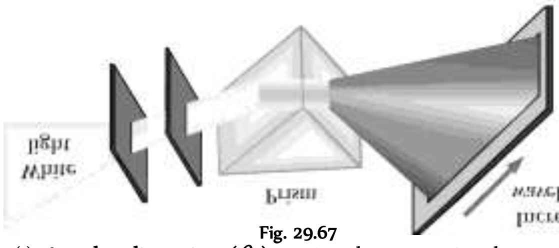


Fig. 29.67

(1) **Angular dispersion (θ) :** Angular separation between extreme colours *i.e.* $\theta = \delta_V - \delta_R = (\mu_V - \mu_R)A$. It depends upon μ and *A*.

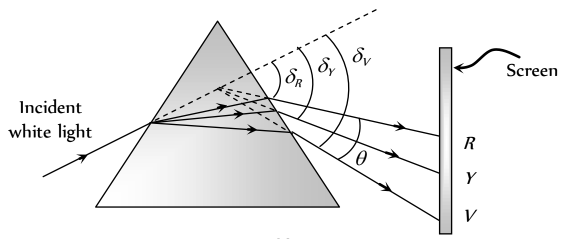


Fig. 29.68

(2) **Dispersive power (ω) :**

$$\omega = \frac{\theta}{\delta_y} = \frac{\mu_V - \mu_R}{\mu_y - 1} \quad \text{where } \left\{\mu_y = \frac{\mu_V + \mu_R}{2}\right\}$$

$\Rightarrow$ It depends only upon the material of the prism *i.e.* μ and it doesn't depends upon angle of prism *A*

(3) **Combination of prisms :** Two prisms (made of crown and flint material) are combined to get either dispersion only or deviation only.

(i) Dispersion without deviation (chromatic combination)

$$\frac{A'}{A}=-\frac{(\mu_y-1)}{(\mu'_y-1)}$$

$$\theta_{\text{net}}=\theta\left(1-\frac{\omega'}{\omega}\right)=(\omega\delta-\omega'\delta')$$

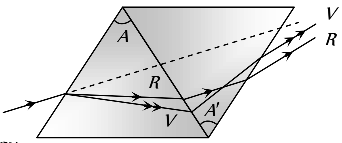


Fig. 29.69

(ii) Deviation without dispersion (Achromatic combination)

$$\frac{A'}{A}=-\frac{(\mu_V-\mu_R)}{(\mu'_V-\mu'_R)}$$

$$\delta_{\text{net}}=\delta\left(1-\frac{\omega}{\omega'}\right)$$

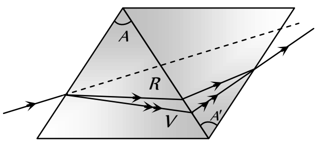


Fig. 29.70

Scattering of Light

Molecules of a medium after absorbing incoming light radiations, emits them in all direction. This phenomenon is called Scattering.

(1) **According to scientist Rayleigh :** Intensity of scattered light $\propto \frac{1}{\lambda^4}$

(2) **Some phenomenon based on scattering :** (i) Sky looks blue due to scattering.

(ii) At the time of sunrise or sunset sun looks reddish.

(iii) Danger signals are made of red colour.

(3) **Elastic scattering :** When the wavelength of radiation remains unchanged, the scattering is called elastic.

(4) **Inelastic scattering (Raman's effect) :** Under specific condition, light can also suffer inelastic scattering from molecules in which it's wavelength changes.

Rainbow

Rainbow is formed due to the dispersion of light suffering refraction and TIR in the droplets present in the atmosphere. Observer should stand with its back towards sun to observe rainbow.

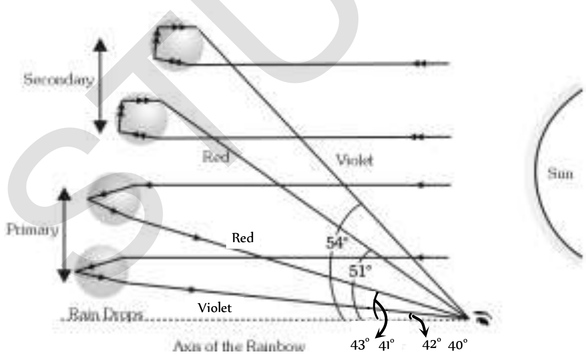


Fig. 29.71

(1) **Primary rainbow :** (i) Two refraction and one TIR. (ii) Innermost arc is violet and outermost is red. (iii) Subtends an angle of 42^o at the eye of the observer. (iv) More bright

(2) **Secondary rainbow :** (i) Two refraction and two TIR. (ii) Innermost arc is red and outermost is violet. (iii) It subtends an angle of 52.5^o at the eye. (iv) Comparatively less bright.

Colours of Objects

Colour is defined as the sensation received by the eye (rod cells of the eye) due to light coming from an object.

(1) **Colours of opaque object :** The colours of opaque bodies are due to selective reflection. *e.g.*

(i) A rose appears red in white light because it reflects red colour and absorbs all remaining colours.

(ii) When yellow light falls on a bunch of flowers, then yellow and white flowers looks yellow. Other flowers looks black.

(2) **Colours of transparent object :** The colours of transperent bodies are due to selective transmission..

(i) A red glass appears red because it absorbs all colours, except red which it transmits.

(ii) When we look on objects through a green glass or green filter then green and white objects will appear green while other black.

(3) **Colour of the sky :** Light of shorter wavelength is scattered much more than the light of longer wavelength. Since blue colour has relatively shorter wavelength, it predominates the sky and hence sky appears bluish.

(4) **Colour of clouds :** Large particles like water droplets and dust do not have this selective scattering power. They scatter all wavelengths alomost equally. Hence clouds appear to the white.

(5) **Colour triangle for spectral colours :** Red, Green and blue are primary colours.

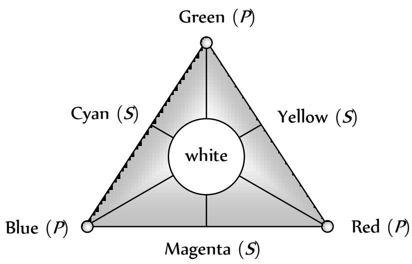


Fig. 29.72

(i) Complementary colours : Green and Magenta, Blue and Yellow, Red and Cyan.

(ii) Combination : Green + Red + Blue = White, Blue + Yellow = White, Red + Cyan = White, Green + Magenta = White

(6) **Colour triangle for pigment and dyes :** Red, Yellow and Blue are the primary colours.

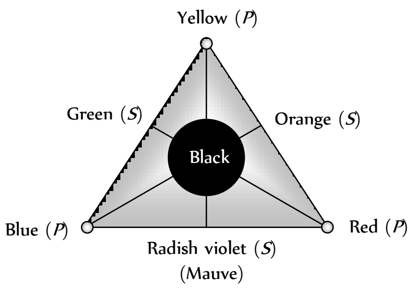


Fig. 29.73

(i) Complementary colours : Yellow and Mauve, Red and Green, Blue and Orange.

(ii) Combination : Yellow + Red + Blue = Black, Blue + Orange = Black, Red + Green = Black, Yellow + Mauve = Black

Spectrum

The ordered arrangements of radiations according to wavelengths or frequencies is called Spectrum. Spectrum can be divided in two parts Emission spectrum and Absorption spectrum.

(1) **Emission spectrum :** When light emitted by a self luminous object is dispersed by a prism to get the spectrum, the spectrum is called emission spectra.

Continuous emission spectrum

(i) It consists of continuously varying wavelengths in a definite wavelength range.

(ii) It is produced by solids, liquids and highly compressed gases heated to high temperature.

(iii) *e.g.* Light from the sun, filament of incandescent bulb, candle flame *etc.*

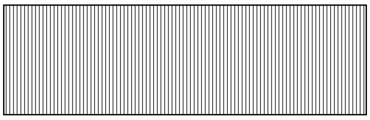


Fig. 29.74

Line emission spectrum

(i) It consist of distinct bright lines.

(ii) It is produced by an excited source in atomic state.

(iii) *e.g.* Spectrum of excited helium, mercury vapours, sodium vapours or atomic hydrogen.

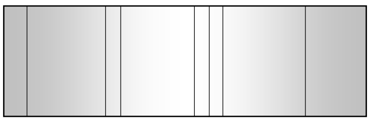


Fig. 29.75

Band emission spectrum

(i) It consist of district bright bands.

(ii) It is produced by an excited source in molecular state.

(iii) *e.g.* Spectra of molecular H_2, *CO*, NH_3 *etc.*

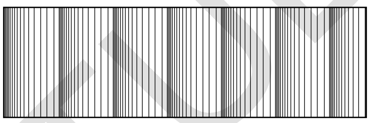


Fig. 29.76

(2) **Absorption spectrum :** When white light passes through a semi-transparent solid, or liquid or gas, it's spectrum contains certain dark lines or bands, such spectrum is called absorption spectrum (of the substance through which light is passed).

(i) Substances in atomic state produces line absorption spectra. Polyatomic substances such as H_2, CO_2 and $KMnO_4$ produces band absorption spectrum.

(ii) Absorption spectra of sodium vapour have two (yellow lines) wavelengths $D_1(5890\ Å)$ and $D_2(5896\ Å)$

(3) **Fraunhoffer's lines :** The central part (photosphere) of the sun is very hot and emits all possible wavelengths of the visible light. However, the outer part (chromosphere) consists of vapours of different elements. When the light emitted from the photosphere passes through the chromosphere, certain wavelengths are absorbed. Hence, in the spectrum of sunlight a large number of dark lines are seen called Fraunhoffer lines.

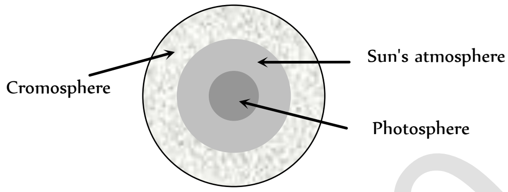


Fig. 29.77

(i) The prominent lines in the yellow part of the visible spectrum were labelled as *D*-lines, those in blue part as *F*-lines and in red part as *C*-line.

(ii) From the study of Fraunhoffer's lines the presence of various elements in the sun's atmosphere can be identified *e.g.* abundance of hydrogen and helium.

(iii) In the event of a solar eclipse, dark lines become bright. This is because of the reason that the presence of an opaque obstacle in between sun and earth cuts the light off from the central region (photo-sphere), while light from corner portion (cromosphere) is still being received. The bright lines appear exactly at the places where dark lines were present.

(4) **Spectrometer :** A spectrometer is used for obtaining pure spectrum of a source in laboratory and calculation of μ of material of prism and μ of a transparent liquid.

It consists of three parts : Collimator which provides a parallel beam of light; Prism Table for holding the prism and Telescope for observing the spectrum and making measurements on it.

The telescope is first set for parallel rays and then collimator is set for parallel rays. When prism is set in minimum deviation position, the spectrum seen is pure spectrum. Angle of prism (*A*) and angle of minimum deviation (δ_m) are measured and μ of material of prism is calculated using prism formula. For μ of a transparent liquid, we take a hollow prism with thin glass sides. Fill it with the liquid and measure (δ_m) and *A* of liquid prism. μ of liquid is calculated using prism formula.

(5) **Direct vision spectroscope :** It is an instrument used to observe pure spectrum. It produces dispersion without deviation with the help of *n* crown prisms and $(n-1)$ flint prisms alternately arranged in a tabular structure.

For no deviation $n(\mu-1)A = (n-1)\,(\mu'-1)A'$.

Human Eye

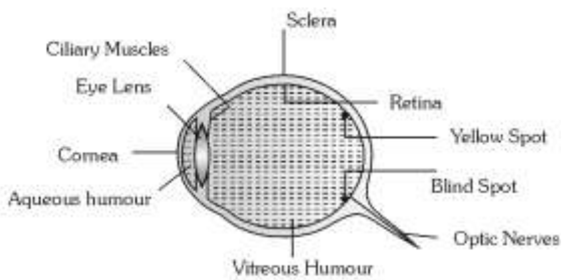


Fig. 29.78

(1) **Eye lens :** Over all behaves as a convex lens of $\mu = 1.437$

(2) **Retina :** Real and inverted image of an object, obtained at retina, brain sense it erect.

(3) **Yellow spot :** It is the most sensitive part, the image formed at yellow spot is brightest.

(4) **Blind spot :** Optic nerves goes to brain through blind spot. It is not sensitive for light.

(5) **Ciliary muscles :** Eye lens is fixed between these muscles. It's both radius of curvature can be changed by applying pressure on it through ciliary muscles.

(6) **Power of accomodation :** The ability of eye to see near objects as well as far objects is called power of accomodation.

(7) **Range of vision :** For healthy eye it is 25 *cm* (near point) to ∞ (far point).

A normal eye can see the objects clearly, only if they are at a distance greater than 25 *cm*. This distance is called Least distance of distinct vision and is represented by *D*.

(8) **Persistence of vision :** Is 1/10 *sec. i.e.* if time interval between two consecutive light pulses is lesser than 0.1 *sec.*, eye cannot distinguish them separately.

(9) **Binocular vision :** The seeing with two eyes is called binocular vision.

(10) **Resolving limit :** The minimum angular separation between two objects, so that they are just resolved is called resolving limit. For eye it is $1' = \left(\frac{1}{60}\right)^o$.

Defects in Eye

(1) **Myopia (short sightness) :** A short-sighted eye can see only nearer objects. Distant objects are not seen clearly.

(i) In this defect image is formed before the retina and Far point comes closer.

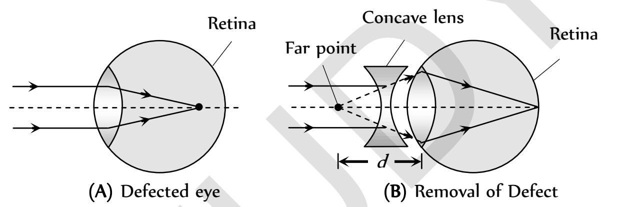


Fig. 29.79

(ii) In this defect focal length or radii of curvature of lens reduced or power of lens increases or distance between eye lens and retina increases.

(iii) This defect can be removed by using a concave lens of suitable focal length.

(iv) If defected far point is at a distance *d* from eye then

Focal length of used lens $f = -d = -$ (defected far point)

(v) A person can see upto distance $\to x$, wants to see distance $\to y$ ($y > x$) so $f = \frac{xy}{x-y}$ or power of the lens $P = \frac{x-y}{xy}$

(2) **Hypermetropia (long sightness) :** A long-sighted eye can see distant objects clearly but nearer object are not clearly visible.

(i) Image formed behind the retina and near point moves away

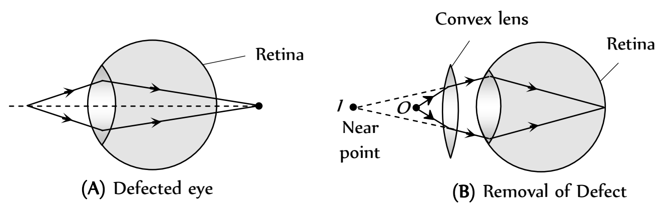


Fig. 29.80

(ii) In this defect focal length or radii of curvature of lens increases or power of lens decreases or distance between eye lens and retina decreases.

(iii) This defect can be removed by using a convex lens.

(iv) If a person cannot see before distance d but wants to see the object placed at distance *D* from eye so $f = \frac{dD}{d-D}$ and power of the lens $P = \frac{d-D}{dD}$

(3) **Presbyopia :** In this defect both near and far objects are not clearly visible. It is an old age disease and it is due to the loosing power of accommodation. It can be removed by using bifocal lens.

(4) **Astigmatism :** In this defect eye cannot see horizontal and vertical lines clearly, simultaneously. It is due to imperfect spherical nature of eye lens. This defect can be removed by using cylindrical lens (Torric lenses).

Lens Camera

(1) In lens camera a converging lens of adjustable aperture is used.

(2) Distance of film from lens is also adjustable.

(3) In photographing an object, the image is first focused on the film by adjusting the distance between lens and film. It is called focusing. After focusing, aperture is set to a specific value and then film is exposed to light for a given time through shutter.

(4) ***f*-number :** The ratio of focal length to the aperture of lens is called *f*-number of the camera.

2, 2.8, 4, 5.6, 8, 11, 22, 32 are the *f*-numbers marked on aperture.

$$f\text{-number} = \frac{\text{Focal length}}{\text{Aperture}} \Rightarrow \text{Aperture} \propto \frac{1}{f\text{-number}}$$

(5) **Time of exposure :** It is the time for which the shutter opens and light enters the camera to expose film.

(i) If intensity of light is kept fixed then for proper exposure

$$\text{Time of exposure } (t) \propto \frac{1}{(\text{Aperture})^2}$$

(ii) If aperture is kept fixed then for proper exposure

$$\text{Time of exposure } (t) \propto \frac{1}{[\text{Intensity}(I)]^2}$$

$$\Rightarrow I\,t = \text{constant} \Rightarrow I_1 t_1 = I_2 t_2$$

(iii) Smaller the *f*-number larger will be the aperture and lesser will be the time of exposure and faster will be the camera.

(6) **Depth of focus :** It refers to the range of distance over which the object may lie so as to form a good quality image. Large *f*-number increase the depth of focus.

Microscope

It is an optical instrument used to see very small objects. It's magnifying power is given by

$m = \dfrac{\text{Visual angle with instrument}(\beta)}{\text{Visual angle when object is placed at least distance of distinct vision}(\alpha)}$

(1) **Simple microscope**

(i) It is a single convex lens of lesser focal length.

(ii) Also called magnifying glass or reading lens.

(iii) Magnification's, when final image is formed at D and ∞ (*i.e.* m_D and m_∞) $\quad m_D = \left(1+\dfrac{D}{f}\right)_{\max}$ and $m_\infty = \left(\dfrac{D}{f}\right)_{\min}$

(iv) If lens is kept at a distance *a* from the eye then $m_D = 1+\dfrac{D-a}{f}$ and $m_\infty = \dfrac{D-a}{f}$

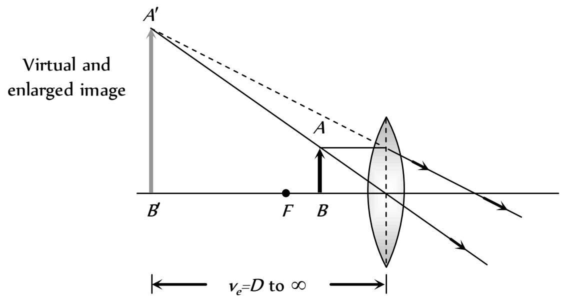


Fig. 29.81

(2) **Compound microscope**

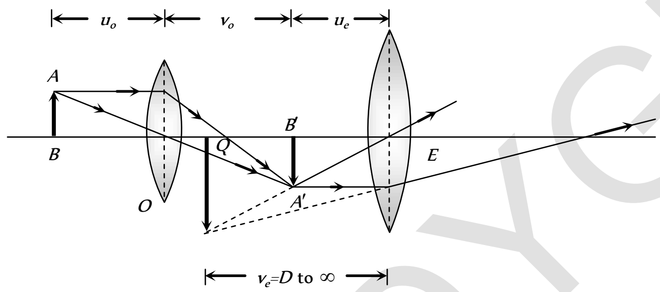


Fig. 29.82

(i) Consist of two converging lenses called objective and eye lens.

(ii) $f_{\text{eye lens}} > f_{\text{objective}}$ and $(\text{diameter})_{\text{eye lens}} > (\text{diameter})_{\text{objective}}$

(iii) Intermediate image is real and enlarged.

(iv) Final image is magnified, virtual and inverted.

(v) u_o = Distance of object from objective (o), v_o = Distance of image $(A'B')$ formed by objective from objective, u_e = Distance of $A'B'$ from eye lens, v_e = Distance of final image from eye lens, f_o = Focal length of objective, f_e = Focal length of eye lens.

(vi) **Final image is formed at *D* :** Magnification $m_D = -\dfrac{v_o}{u_o}\left(1+\dfrac{D}{f_e}\right)$ and length of the microscope tube (distance between two lenses) is $L_D = v_o + u_e$.

Generally object is placed very near to the principal focus of the objective hence $u_o \cong f_o$. The eye piece is also of small focal length and the image formed by the objective is also very near to the eye piece.

So $v_o \cong L_D$, the length of the tube.

Hence, we can write $m_D = \dfrac{-L}{f_o}\left(1+\dfrac{D}{f_e}\right)$

(vii) **Final image is formed at ∞ :** Magnification

$m_\infty = -\dfrac{v_0}{u_0}\cdot\dfrac{D}{f_e}$ and length of tube $L_\infty = v_0 + f_e$

In terms of length $m_\infty = \dfrac{(L_\infty - f_o - f_e)D}{f_o f_e}$

(viii) For large magnification of the compound microscope, both f_o and f_e should be small.

(ix) If the length of the tube of microscope increases, then its magnifying power increases.

(x) The magnifying power of the compound microscope may be expressed as $M = m_o \times m_e$; where m_o is the magnification of the objective and m_e is magnifying power of eye piece.

Astronomical Telescope (Refracting Type)

By astronomical telescope heavenly bodies are seen.

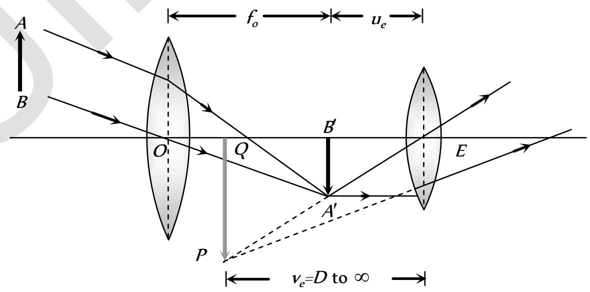


Fig. 29.83

(1) $f_{\text{objective}} > f_{\text{eyelens}}$ and $d_{\text{objective}} > d_{\text{eye lens}}$.

(2) Intermediate image is real, inverted and small.

(3) Final image is virtual, inverted and small.

(4) Magnification : $m_D = -\dfrac{f_0}{f_e}\left(1+\dfrac{f_e}{D}\right)$ and $m_\infty = -\dfrac{f_o}{f_e}$

(5) Length : $L_D = f_0 + u_e$ and $L_\infty = f_0 + f_e$

Terrestrial Telescope

It is used to see far off object on the earth.

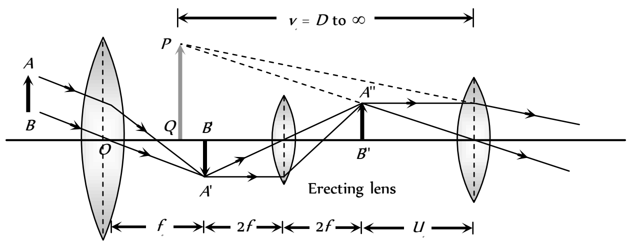


Fig. 29.84

(1) It consists of three converging lens : objective, eye lens and erecting lens.

(2) It's final image is virtual, erect and smaller.

(3) Magnification : $m_D = \frac{f_0}{f_e}\left(1+\frac{f_e}{D}\right)$ and $m_\infty = \frac{f_0}{f_e}$

(4) Length : $L_D = f_0 + 4f + u_e$ and $L_\infty = f_0 + 4f + f_e$

Galilean Telescope

It is also type of terrestrial telescope but of much smaller field of view.

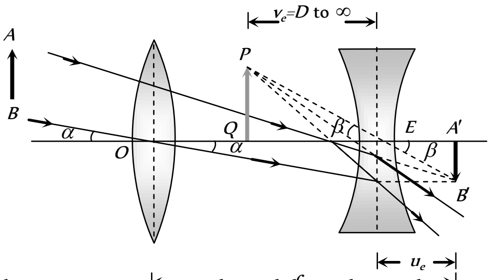


Fig. 29.85

(1) Objective is a converging lens while eye lens is diverging lens.

(2) Magnification : $m_D = \frac{f_0}{f_e}\left(1-\frac{f_e}{D}\right)$ and $m_\infty = \frac{f_0}{f_e}$

(3) Length : $L_D = f_0 - u_e$ and $L_\infty = f_0 - f_e$

Reflecting Telescope

Reflecting telescopes are based upon the same principle except that the formation of images takes place by reflection instead of by refraction.

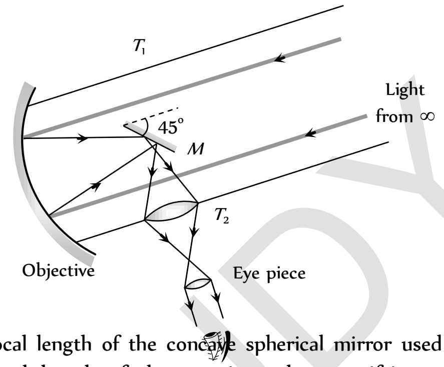


Fig. 29.86

If f_o is focal length of the concave spherical mirror used as objective and f_e the focal length of the eye-piece, the magnifying power of the reflecting telescope is given by $m = \frac{f_o}{f_e}$

Further, if D is diameter of the objective and d, the diameter of the pupil of the eye, then brightness ratio (β) is given by $\beta = \frac{D^2}{d^2}$

Resolving Limit and Resolving Power

(1) **Microscope :** In reference to a microscope, the minimum distance between two lines at which they are just distinct is called Resolving limit (RL) and it's reciprocal is called Resolving power (RP)

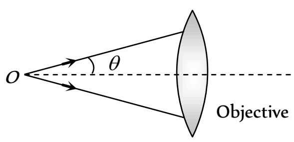


Fig. 29.87

$$R.L. = \frac{\lambda}{2\mu\sin\theta} \text{ and } R.P. = \frac{2\mu\sin\theta}{\lambda} \Rightarrow R.P. \propto \frac{1}{\lambda}$$

λ = Wavelength of light used to illuminate the object,

μ = Refractive index of the medium between object and objective,

θ = Half angle of the cone of light from the point object, $\mu\sin\theta$ = Numerical aperture.

(2) **Telescope :** Smallest angular separations ($d\theta$) between two distant objects, whose images are separated in the telescope is called resolving limit. So resolving limit $d\theta = \frac{1.22\lambda}{a}$

and resolving power $(RP) = \frac{1}{d\theta} = \frac{a}{1.22\lambda} \Rightarrow R.P. \propto \frac{1}{\lambda}$ where a = aperture of objective.

Binocular

If two telescopes are mounted parallel to each other so that an object can be seen by both the eyes simultaneously, the arrangement is called 'binocular'. In a binocular, the length of each tube is reduced by using a set of totally reflecting prisms which provide intense, erect image free from lateral inversion. Through a binocular we get two images of the same object from different angles at same time. Their superposition gives the perception of depth along with length and breadth, *i.e.*, binocular vision gives proper three-dimensional (3*D*) image.

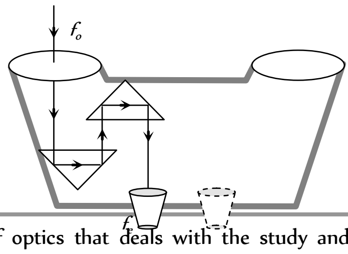


Fig. 29.88

Photometry

The branch of optics that deals with the study and measurement of the light energy is called photometry.

(1) **Radiant flux (R) :** The total energy radiated by a source per second is called radiant flux. It's S.I. unit is **Watt (W)**.

(2) **Luminous flux (ϕ) :** The total light energy emitted by a source per second is called luminous flux. It represents the total brightness producing capacity of the source. It's S.I. unit is **Lumen (lm)**.

(3) **Luminous efficiency (η) :** The Ratio of luminous flux and radiant flux is called luminous efficiency *i.e.* $\eta = \frac{\phi}{R}$.

Table 29.4 : Luminous flux and efficiency

Light source	Flux (lumen)	Efficiency (lumen/watt)
40 W tungsten bulb	465	12
60 W tungsten bulb	835	14
500 W tungsten bulb	9950	20
30 W fluorescent tube	1500	50

(4) **Luminous Intensity (L) :** In a given direction it is defined as luminous flux per unit solid angle *i.e.*

$$L = \frac{\phi}{\omega} \rightarrow \frac{\text{Light energy}}{\sec \times \text{solid angle}} \xrightarrow{\text{S.I. unit}} \frac{\text{lumen}}{\text{steradian}} = \text{candela}\,(Cd)$$

The luminous intensity of a point source is given by : $L = \frac{\phi}{4\pi} \Rightarrow \phi = 4\pi \times (L)$

(5) **Illuminance or intensity of illumination (*I*) :** The luminous flux incident per unit area of a surface is called illuminance. $I = \frac{\phi}{A}$. It's S.I. unit is $\frac{\text{Lumen}}{m^2}$ or Lux (*lx*) and it's C.G.S. unit is Phot.

$$1\,\text{Phot} = 10^4\,\text{Lux} = \frac{1\,\text{Lumen}}{cm^2}$$

(i) Intensity of illumination at a distance r from a point source is $I = \frac{\phi}{4\pi r^2} \Rightarrow I \propto \frac{1}{r^2}$.

(ii) Intensity of illumination at a distance r from a line source is $I = \frac{\phi}{2\pi r l} \Rightarrow I \propto \frac{1}{r}$

(iii) In case of a parallel beam of light $I \propto r^0$.

(iv) The illuminance represents the luminous flux incident on unit area of the surface, while luminance represents the luminous flux reflected from a unit area of the surface.

(6) **Relation Between Luminous Intensity (*L*) and Illuminance (*I*) :** If S is a unidirectional point source of light of luminous intensity L and there is a surface at a distance r from source, on which light is falling normally.

(i) Illuminance of surface is given by : $I = \frac{L}{r^2}$

(ii) For a given source L = constant so $I \propto \frac{1}{r^2}$; This is called. Inverse square law of illuminance.

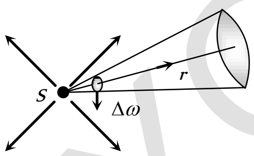


Fig. 29.89

(7) **Lambert's Cosine Law of Illuminance :** In the above discussion if surface is so oriented that light from the source falls, on it obliquely and the central ray of light makes an angle θ with the normal to the surface, then

(i) Illuminance of the surface $I = \frac{L\cos\theta}{r^2}$

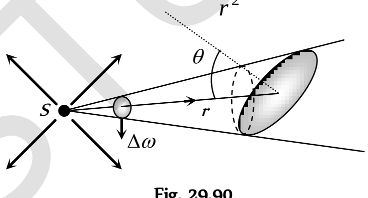


Fig. 29.90

(ii) For a given light source and point of illumination (*i.e.* L and r = constant) $I \propto \cos\theta$ this is called Lambert's cosine law of illuminance. $\Rightarrow I_{\max} = \frac{L}{r^2} = I_o (\text{at}\,\theta = 0^o)$

(iii) For a given source and plane of illuminance (*i.e.* L and h = constant)

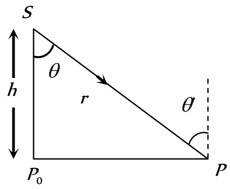


Fig. 29.91

$\cos\theta = \frac{h}{r}$ so $I = \frac{L}{h^2}\cos^3\theta$

or $I = \frac{Lh}{r^3}$ *i.e.* $I \propto \cos^3\theta$ or $I \propto \frac{1}{r^3}$

(8) **Photometer and Principle of Photometry :** A photometer is a device used to compare the illuminance of two sources.

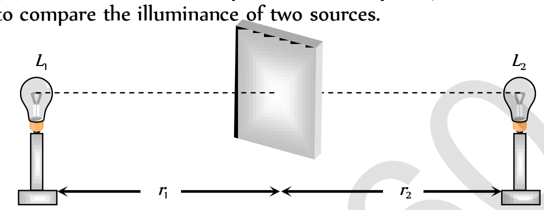


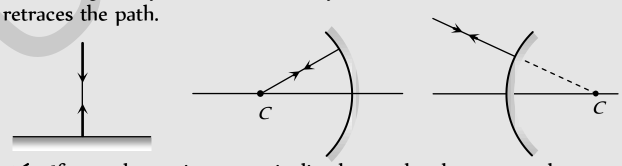
Fig. 29.92

Two sources of luminous intensity L_1, and L_2 are placed at distances r_1 and r_2 from the screen so that their flux are perpendicular to the screen. The distance r_1 and r_2 are adjusted till $I_1 = I_2$. So $\frac{L_1}{r_1^2} = \frac{L_2}{r_2^2} \Rightarrow \frac{L_1}{L_2} = \left(\frac{r_1}{r_2}\right)^2$; This is called principle of photometry.

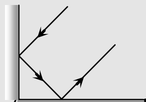
Tips & Tricks

✍ After reflection velocity, wavelength and frequency of light remains same but intensity decreases.

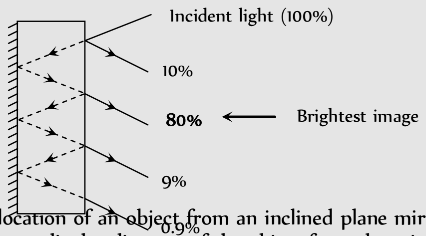
✍ If light ray incident normally on a surface, after reflection it retraces the path.



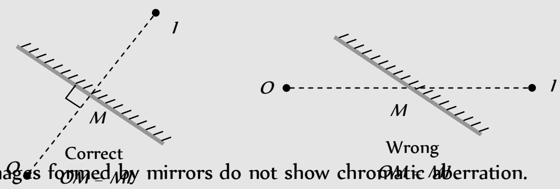
✍ If two plane mirrors are inclined to each other at 90°, the emergent ray is anti-parallel to incident ray, if it suffers one reflection from each. Whatever be the angle to incidence.



✍ We observe number of images in a thick plane mirror, out of them only second is brightest.



✍ To find the location of an object from an inclined plane mirror, you have to see the perpendicular distance of the object from the mirror.



✍ Images formed by mirrors do not show chromatic aberration.

✍ In concave mirror, minimum distance between a real object and it's real image is zero. (*i.e.* when $u = v = 2f$)

✍ If a spherical mirror produces an image '*m*' times the size of the object (m = magnification) then u, v and f are given by the followings

$$u=\left(\frac{m-1}{m}\right)f,\quad v=-(m-1)f \text{ and } f=\left(\frac{m}{m-1}\right)u$$

✍ Focal length of a mirror is independent of material of mirror and medium in which it is placed and wavelength of incident light

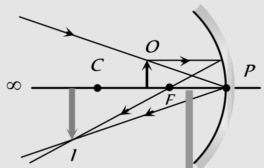
✍ Divergence or Convergence power of a mirror does not change with the change in medium.

✍ If an object is moving at a speed v towards a spherical mirror along it's axis then speed of image away from mirror is

$$v_i=-\left(\frac{f}{u-f}\right)^2 .v_o$$

✍ When object is moved from focus to infinity at constant speed, the image will move faster in the beginning till object moves from f to $2f$, and slower later on, towards the mirror.

✍ As every part of mirror forms a complete image, if a part of the mirror is obstructed, full image will be formed but intensity will be reduced.



✍ In case of refraction of light frequency (and hence colour) and phase do not change (while wavelength and velocity will change).

✍ *In the refraction intensity of incident light decreases as it goes from one medium to another medium.*

✍ A transparent solid is invisible in a liquid of same refractive index (Because of No refraction).

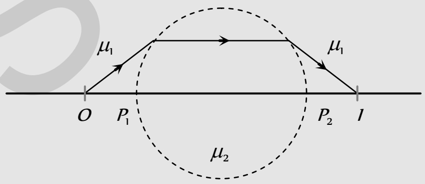
✍ When a glass slab is kept over various coloured letters and seen from the top, the violet colour letters appears closer (Because $\lambda_V<\lambda_R$ so $\mu_V>\mu_R$ and from $\mu=\dfrac{h}{h'}$ if μ increases then h' decreases i.e. Letter appears to be closer)

✍ Minimum distance between an object and it's real image formed by a convex lens is $4f$.

✍ Component lenses of an achromatic doublet cemented by canada blasam because it is transparent and has a refractive index almost equal to the refractive index of the glass.

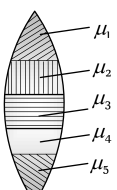
✍ Parabolic mirrors are free from spherical aberration.

✍ If a sphere of radius R made of material of refractive index μ_2 is placed in a medium of refractive index μ_1, then if the object is placed at a distance $\left(\dfrac{\mu_1}{\mu_2-\mu_1}\right)R$ from the pole, the real image formed is equidistant from the sphere



✍ The lens doublets used in telescope are achromatic for blue and red colours, while these used in camera are achromatic for violet and green colours. The reason for this is that our eye is most sensitive between blue and red colours, while the photographic plates are most sensitive between violet and green colours.

✍ **Composite lens :** If a lens is made of several materials then



Number of images formed = Number of materials used

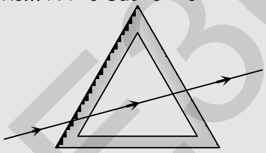
Here no. of images = 5

✍ For the condition of grazing emergence through a prism. Minimum angle of incidence $i_{min}=\sin^{-1}\left[\sqrt{\mu^2-1}\,\sin A-\cos A\right]$.

✍ If a substance emits spectral lines at high temperature then it absorbs the same lines at low temperature. This is Kirchoff's law.

✍ When a ray of white light passes through a glass prism red light is deviated less than blue light.

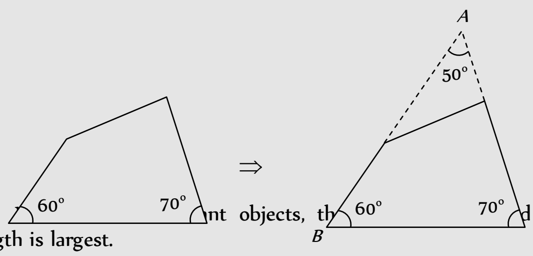
✍ For a hollow prism $A\neq 0$ but $\delta=0$



✍ If an opaque coloured object or crystal is crushed to fine powder it will appear white (in sun light) as it will lose it's property of selective reflection.

✍ Our eye is most sensitive to that part of the spectrum which lies between the F line (sky green) and the C-line (red) of hydrogen, and the mean refractive index of this part is nearly equal to the refractive index for the D line (yellow) of sodium. Hence for the dispersive power, the following formula is internationally accepted $\omega=\dfrac{\mu_F-\mu_C}{\mu_D-1}$

✍ Sometimes a part of prism is given and we keep on thinking whether how should we proceed ? To solve such problems first complete the prism then solve as the problems of prism are solved



✍ nt objects, th d it's focal length is largest.

✍ Minimum separation (d) between objects, so they can just resolved by a telescope is : $d=\dfrac{r}{R.P.}$

Where r = distance of objects from telescope.

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

✍ If objective and eye lens of a telescope are interchanged, it will not behave as a microscope but object appears very small.

✍ In a telescope, if field and eye lenses are interchanged magnification will change from (f_o/f_e) to (f_e/f_o), *i.e.,* it will change from m to $(1/m)$, i.e., will become $(1/m)$ times of its initial value.

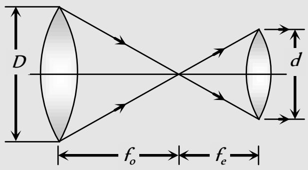
✍ As magnification produced by telescope for normal setting is (f_o/f_e), so to have large magnification, f_o must be as large as practically possible and f_e small. This is why in a telescope, objective is of large focal length while eye piece of small.

✍ In a telescope, aperture of the field lens is made as large as practically possible to increase its resolving power as resolving power of a telescope $\propto (D/\lambda)$. Large aperture of objective also helps in improving the brightness of image by gathering more light from distant object. However, it increases aberrations particularly spherical.

✍ For a telescope with increase in length of the tube, magnification decreases.

✍ In case of a telescope if object and final image are at infinity then :

$$m = \frac{f_o}{f_e} = \frac{D}{d}$$



✍ If we are given four convex lenses having focal lengths $f_1 > f_2 > f_3 > f_4$. For making a good telescope and microscope. We choose the following lenses respectively.

Telescope $f_1(o), f_4(e)$ Microscope $f_4(o), f_3(e)$

✍ If a parrot is sitting on the objective of a large telescope and we look towards (or take a photograph)of distant astronomical object (say moon) through it, the parrot will not be seen but the intensity of the image will be slightly reduced as the parrot will act as obstruction to light and will reduce the aperture of the objective.

✍ The luminous flux of a source of (1/685) watt emitting monochromatic light of wavelength 5500 Å is called 1 lumen.

✍ While solving the problems of photometry keep in mind.

$R \propto \phi \propto L$ (As $\phi = \eta R = 4\pi L$)

$$\Rightarrow \frac{R_1}{R_2} = \frac{\phi_1}{\phi_2} = \frac{L_1}{L_2}$$