UNIT-3

GEOMETRIC OPTICS

3.1 Reflection at Plane and Curved Surface

Photometry

The branch of physics which deals with the quantitative measurement of light is called photometry. Photometry is the measurement of light. The amount of light energy emitted from source per second is called luminous flux. It is denoted by Q and its unit is lumen.

Luminous intensity is defined as the amount of luminous flux emitted by a source per unit solid angle (Ω) in that direction.

or, Luminous flux (L) = $\frac{Q}{\Omega}$

Laws of Reflection

When the ray of light incident on a plane mirror, it follows following laws;

i) The incident rays, the reflected rays and the normal lies at a point of the same plane.

ii) The angle of incidence is equal to the angle of reflection.

Deviation of Light by Plane Mirror

Let us consider plane mirror XY where incident ray AO is incident on O and reflected through OC in fig. In figure, OB is the path of the incident ray. ∠AOX is the angle of glancing angle and ∠BOC is angle of
deviation.

Angle of deviation (δ) = ∠ BOC

= ∠BOY + ∠YOC

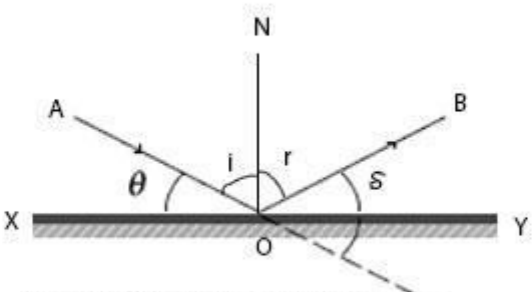
= ∠XOA + ∠ 90°-r

= θ+90°- /°

= θ+θ

δ = 2θ

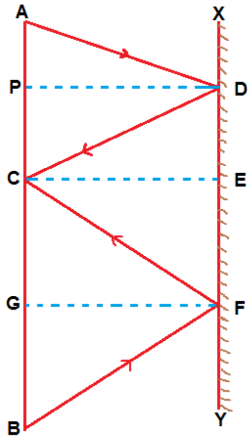
Hence, the angle of deviation of a ray by a plane mirror is equal to twice the glancing angle.



Deviation of Light by Plane Mirror

Size of the Mirror to See Full Image of Man

Consider a person AB of head H, eye C and foot B in front of mirror XY. Let the position of the eye of the person is C in fig. A ray of light AD from the head of the person gets incident on point D and reflected along DC. Similarly, to see the foot, light coming from the foot is reflected from the mirror and goes along CF.



From figure;

DF = PG

$= PC + CG$

$= \frac{1}{2}AC + \frac{1}{2}CB$

$= \frac{1}{2}(AC+CB)$

$= \frac{1}{2}AB$

Hence, the required size of the mirror is half of the size of the person.

3.2 Curved Mirror

A mirror which forms a part of a spherical reflecting surface is called the spherical mirror or curved mirror. There are two types of spherical mirrors. They are;

1) Concave mirror

2) Convex mirror

Terms used in spherical mirror;

i) Pole:

The centre of the spherical reflecting surface of a mirror is called a pole.

ii) Centre of a curvature:

Centre of curvature of a spherical mirror is the centre of the sphere of which the mirror is a part.

iii) Radius of curvature:

The radius of curvature of spherical mirror is the radius of the sphere of which the mirror is a part.

iv) Principal axis:

A line passing through the center of curvature and pole of the spherical mirror is called the principal axis.

Relation between R and f

Consider a concave mirror of focal length (f) and radius of curvatures (R) as in fig. let a ray of light AB incident on a concave mirror at B and reflected through focus F.

From figure;

∠SAC=i

∠CAF = r

∠ACB = θ = ∠i {Opposite angle}

From laws of reflection;

∠SAC = ∠CAF

In triangle ACF;

∠CAF = ∠ACB = θ

Hence CF = FA

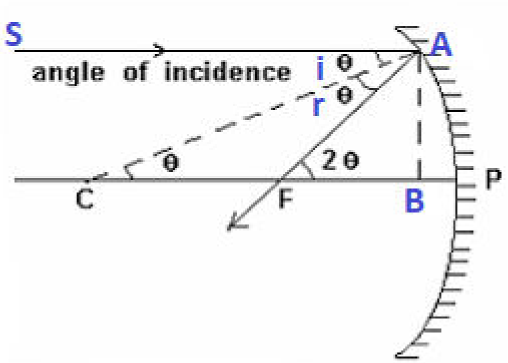
CF= FP

Now, PC = CF+FP

C = f + f

C = 2f

f = $\frac{C}{2}$



Mirror Formula

Mirror formula for concave mirror

Consider an object AB placed in front of a concave mirror at position A beyond the centre of curvature of the mirror in fig. Ray of light coming from B incident on D and reflected through B. Another ray from B passing through the centre of curvature, reflected from G and coming back along GB. Hence the image is formed at A'B'

Hence, PF = f, PC = 2f, A'P = v, AP = u

From triangle, ΔA'B'F and ΔDEF,

$\frac{A'B'}{DE} = \frac{A'F}{FE}$

$\frac{A'B'}{AB} = \frac{A'F}{FP}$……………. (i) Small aperture.

Again, from Δ ABC and ΔA'B'C;

$\frac{A'B'}{AB} = \frac{A'C}{CA}$…………(ii)

From (i) for (ii);

$\frac{A'F}{FP} = \frac{A'C}{CA}$

$\frac{A'P-FP}{FP} = \frac{CP-A'P}{AP-CP}$

$\frac{v-f}{f} = \frac{2f-v}{u-2f}$

$uv - uf - 2fv + 2f^2 = 2f^2 - uf$

$uv = uf + vf$

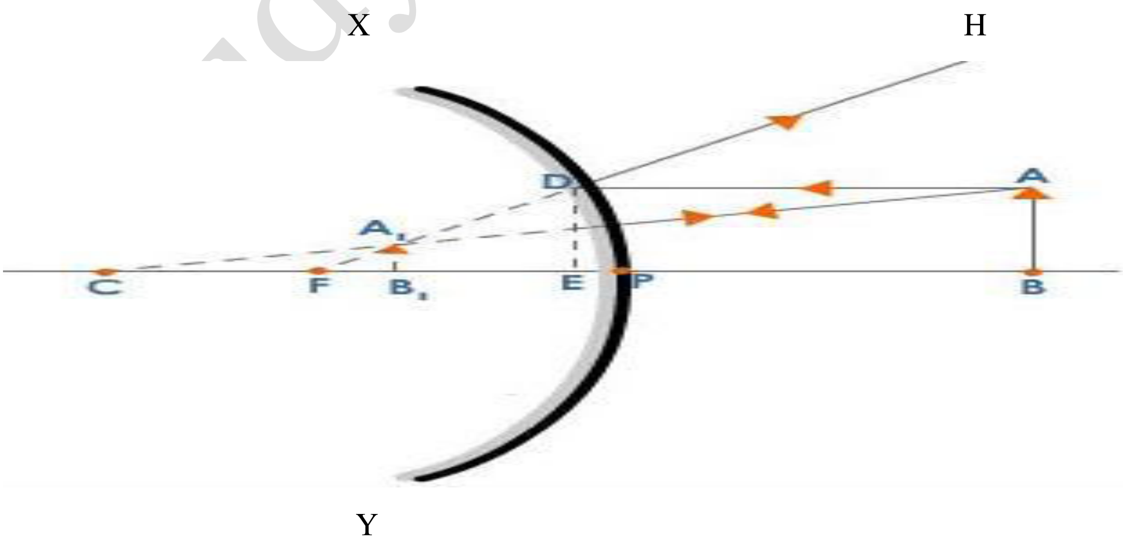
Dividing above equation by uvf,

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

This is the mirror formula for concave mirrors.

Mirror Formula for Convex Mirror

Consider an object AB placed in front of a convex mirror of focal length f and centre of curvature c as shown in figure. An incident ray AD parallel to the principal axis get reflected from D to through DX, so that it appears to be coming from focus (f), Another ray AG reflected back through GA so that it appears to be coming from the centre of curvature.



Hence, two lines HF and AC intersect at point A which represents the image of the point A. so. A'B represents the image of the object AB,

Here, PB = u, PB' = - v

PF = -f, PC = -2f.

Draw DE

From figure, in ΔA'BF and ΔDEF,

$$\frac{DE}{EF} = \frac{A'B'}{B'F}$$

or, $$\frac{AB}{EF} = \frac{A'B'}{B'F}$$

or, $$\frac{AB}{A'B'} = \frac{EF}{B'F} \ldots\ldots\ldots\ldots(i)$$

Similarly; in triangle ΔABC and ΔA'B'C,

$$\frac{AB}{BC} = \frac{A'B'}{B'C}$$

or, $$\frac{AB}{A'B'} = \frac{BC}{B'C} \ldots\ldots\ldots\ldots(ii)$$

From (i) and (ii).

$$\frac{BC}{B'C} = \frac{EF}{B'F}$$

$$\frac{BP+PC}{PC-PB'} = \frac{PF}{PF-PB'}$$

$$\frac{u-2f}{-2f+v} = \frac{-f}{-f+v}$$

$-uf + 2f^2 + uv - 2fv = +2f^2 - vf$

$uv = uf + fv$

Dividing above equation by uvf, we get,

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

This is the mirror formula for convex mirrors.

3.3 Refraction of Light

i) Refraction at plane surface

Introduction

When light travels from one medium another, it bends and also changes the speed. It is because of the optical density of the medium. When light travels from rarer medium to denser medium it bends towards normal and when light travels from denser medium to rare medium, it bends away from normal.

Laws of Refraction

When light travels from one medium to another, it follows the following laws;

- The incident ray, normal and refracted ray all lie at the point of the same plane.
- The ratio of sine of the angle of incident to the sine of the angle of refraction is constant and is called the refractive index of second medium w.r. to first medium.

This is also known as Snell's law. It is denoted by u and defined as,

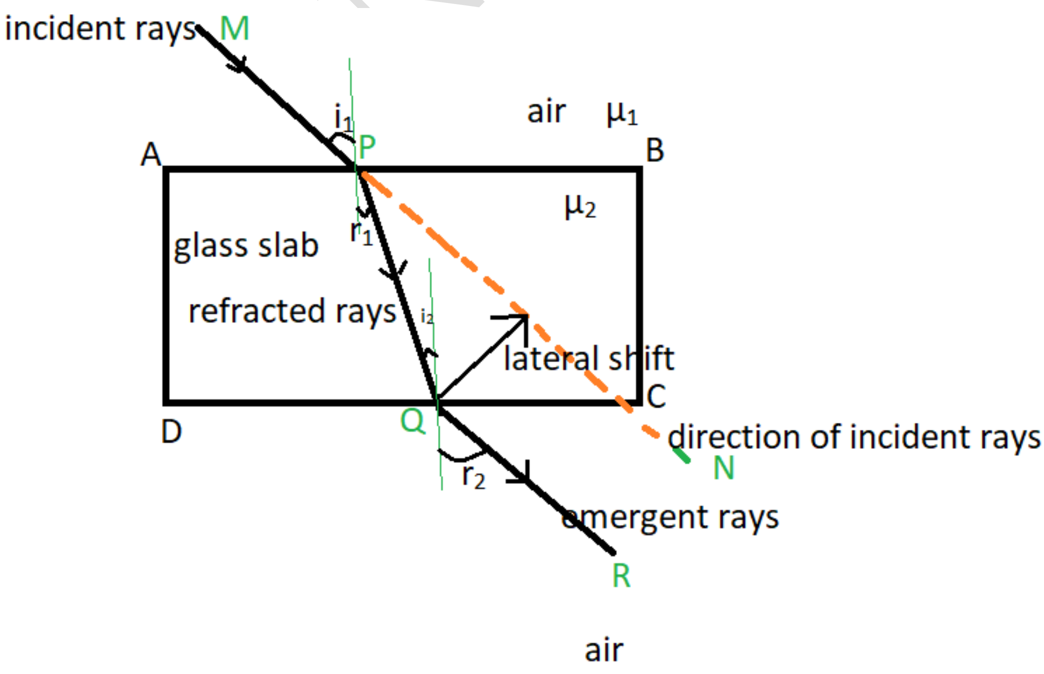
$$\mu = \frac{\sin i}{\sin r}$$

Lateral Shifts (δ):

Consider a glass slab ABCD, where a ray of light MP incident on P and refracted through PQ. Ray of light incident again on the lower part of the CD surface of the glass slab. Hence light coming out from Q and goes through QR as shown in figure.

Draw MPN.

From figure,



QR is called an emergent ray. PN is the path of the incident ray. The distance perpendicular or minimum distance between emergent ray and the path of incident ray is called Lateral shift. Here QS is lateral shift.

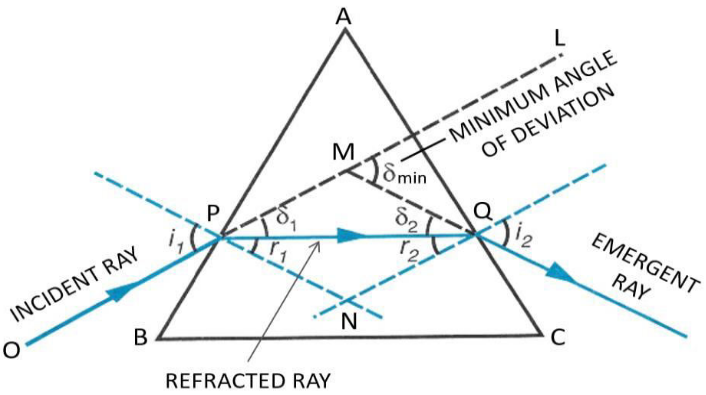
ii) Refraction through Prism

Introduction

A prism is a wedge shaped block of glass having three rectangular faces and two triangle faces. Two faces of prism through which light pores are called refracting faces of prism. The angle between the refracting faces of the prism is called the angle of prism.

Refraction through a glass prism and, min deviation

Consider a ray of light OP incident at point P on the side AB of a glass prism ABC shown in figure.



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The light from P bends towards the normal. In the glass prism, the ray of light moves along PQ. At the point Q on the other refracting side AC of the prism, the light ray meets a boundary between glass and air.

The ray of light gets bent away from normal and goes along QS. The line OP and QS are produced, they meet at a point M. From figure,

∠ OPN' = i (incident ray)

$\angle QPM = \delta_1$

∠QML = D (angle of deviation)

$\angle MQP = \delta_2$

$\angle PQN = r_1$

$\angle QPN = r_2$

$\angle N_2QS$ = e (emergent ray).

Here, in triangle, ΔPQM,

$\angle QML = \angle QPM + \angle MQP$

$= (i + e) - (r_1 + r_2)$

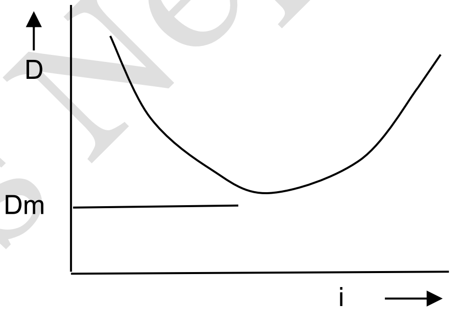
$= (i + e) - A$

$D + A = i+e$.............(ii)

Minimum Deviation

From the relation.

$D = (I+e) - A$



The angle of deviation produced by a prism depends upon the angle of incidence. It was found that, when the angle of incidence increases, the angle of deviation decreases. The angle of deviation goes on decreasing as the angle of incidence goes on increasing. At a certain angle of incidence, the angle of deviation becomes the min. When the deviation is minimum, the prism is said to be in minimum deviation position. If we draw a graph between the angle of deviation (D) and the angle of incidence (i) for a prism, a curve OX in figure is obtained.

At min deviation,

$r_1 = r_2 = r$ and $i = e$, $D=D_m$, $r_1+r_2 = A$

From, (ii)

$D_m + A = 2i$

$i = \frac{Dm + A}{2} = \frac{A + Dm}{2}$

From Snell's law,

$$\mu = \frac{sini}{sinr} = \frac{sin\left(\frac{A+Dm}{2}\right)}{sin\left(\frac{A}{2}\right)}$$

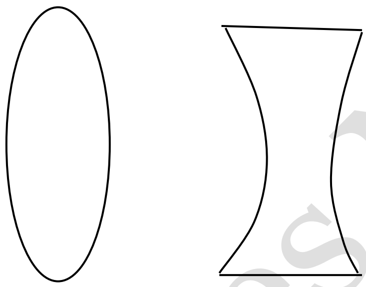
This is the relation between the angle of prism (A), min. deviation (D_m) and the refracting index (M) of a prism.

3.4 Refraction through Lenses

Introduction

Lens is a portion of transparent medium bounded by two surfaces at least one of which is a curved surface. Mostly in our daily life, convex and concave lenses are used. A lens in which thicker part is at centre as compared with edge part is called convex lens. The convex lens is also known as converging lens. A lens which is thinner at the center of comparison with the edge is called a concave lens. It is also known as a diverging lens.

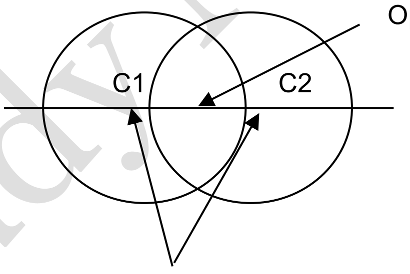
Convex and concave lenses are shown in figure.



Convex lens   Concave lens

Some Terms related to Lenses

a) Centre of curvature



Center of curvature

The center of curvature of a lens is the center of the sphere of which the lens is a part. A lens has two centers of curvatures.

Radius of curvature

The radius of curvature of the surfaces of a lens is the radius of the sphere of which the surface is a part.

Principal axis

The line passing through the two centers of curvature of a lens is called the principal axis.

Optical center

The optical center of a lens is the point in the lens through which a ray of light passes undeviated.

Principal focus

Principal focus is the point on the principal axis at which all the rays parallel to the principal axis pass through it after refraction.

Focal length

The distance between principal focus and optical centre of the lens is called focal length. It is denoted by f.