II PUC - CHAPTER 09
RAY OPTICS

Plane mirror:

1) The image produced by a plane mirror is virtual, erect and of unit magnification. It is laterally inverted.
2) If the object moves with a speed v towards the mirror then the image moves with speed of 2v w.r.t object.
3) Deviation produced by a plane mirror is $d = 180 - 2i$ where i is the angle of incidence.
4) **Number of images (n) formed due to two plane mirrors inclined at an angle θ:**

   a. Let $m = \frac{360}{\theta}$

   If m is even, then n = m - 1

   b. If m is odd, then n = m - 1 (for symmetric placement of object)

   n = m (for unsymmetric placement of object)

   c. If m is fraction, then n is only integer part of the number.

   e.g. If $\theta = 50^o$, then m = 7.2, ∴ n = 7
5) If the plane mirrors are parallel to each other then $\theta = 0^o$ ∴ $n = \frac{360}{\theta} - 1 = \infty$
6) Deviation of the incident ray after reflection from two plane mirrors inclined at angle θ is $d = 360^o - 2\theta$
   d is independent of angle of incidence
7) If the two plane mirrors are incline at an angle θ. If the ray is incident on one mirror at an angle of incidence i after reflection from 1st mirror falls on the 2nd mirror from where it is reflected parallel to first mirror. Then the angle of incidence $i = 2\theta - 90°$ where θ is angle between the two mirror.

Formation of images by spherical mirrors:

1) A concave mirror can form either inverted real image or erect virtual images.

Position of the object	Position of the image	Nature of the image
Between P and F	Behind mirror	Virtual, erect, magnified
At F	At infinity	Real, inverted, highly magnified
Between F and C	Away from C	Real, inverted, magnified
At C	At C	Real, inverted, same size
Away from C	Between F and C	Real, inverted, diminished
At infinity	At F	Real, inverted, highly diminished

P – Pole, F – Principal focus, C – Centre of curvature

2) Focal length f of a spherical mirror of radius curvature R is $f = \frac{R}{2}$
3) **Mirror formula:** $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ or $f = \frac{uv}{u + v}$

   f – focal length of the mirror, u – object distance, v – image distance
4) Focal length f is independent of u and v. It depends only on R.
5) 'v' versus 'u' graph for a spherical mirror is a rectangular hyperbola. Fig (1)
6) 1/v versus 1/u graph for a spherical mirror is a straight line. Fig (2)
7) 'v' versus 'u' graph for a plane mirror is a straight line with slope equal to one. Fig (3)

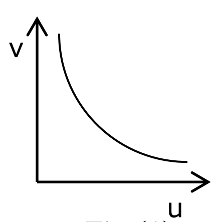


Fig (1)

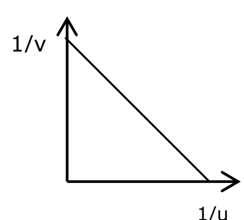


Fig (2)

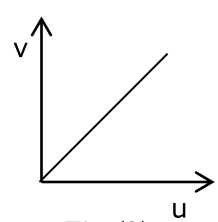


Fig (3)

8) **Linear Magnification (m):** The linear magnification is the ratio of the height of the image to that of the object.

Linear magnification $m = \frac{h_i}{h_o} = -\frac{v}{u} = \frac{f-v}{f} = \frac{f}{f-u}$

h_i – height of the image, h_o – height of the object.

9) For enlarged image $m > 1$

For diminished image $m < 1$

If the image is of the same size as that of the object then $m = 1$

10) Real image is formed in front of the mirror. It is always inverted. For inverted image m is negative.

11) Virtual image is formed behind the mirror. It is always erect. For erect image m is positive.

12) A convex mirror forms erect, virtual and diminished image.

Refraction through plane surface:

1) ${}_1n_2 = \frac{1}{{}_2n_1} = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\sin i}{\sin r} = \frac{\lambda_1}{\lambda_2}$

${}_1n_2$ – R.I of 2nd medium w.r.t 1st medium (Ray passes from 1st medium to 2nd)

${}_2n_1$ – R.I of 1st medium w.r.t 2nd medium (Ray passes from 2nd medium to 1st)

n_1 = absolute R.I of medium 1, n_2 = absolute R.I of medium 2

i = angle of incidence in medium 1, r = angle of refraction in the medium 2.

v_1, λ_1 – velocity and wavelength of light in medium 1

v_2, λ_2 – velocity and wavelength of light in medium 2

2) Absolute R.I of a medium, $n = \frac{c}{v} = \frac{\lambda_v}{\lambda_m} = \frac{\sin i}{\sin r}$

(when the ray travels from air to a given medium)

c – velocity of light in vacuum, v – velocity of light in a given medium of R.I n

3) Angle of deviation produced during refraction: $d = i \sim r$

4) When reflected ray and refracted rays are perpendicular to each other then R.I of the medium is $n = \tan i$ where i is the angle of incidence.

Lateral shift:

1) The perpendicular distance between emergent ray and direction of incident ray when a ray undergoes refraction through a parallel sided glass slab is called lateral shift.

2) Lateral shift: $L_S = \frac{t\sin(i-r)}{\cos r} = t \sec r \sin(i-r)$ t – thickness of the glass slab

3) Lateral shift is zero (minimum) for normal incidence and t (maximum) for grazing incidence ($i = 90^o$)

Normal shift:

1) Apparent shift in the position of an object along the normal when an object in one medium when viewed normally from the other medium is called normal shift and the phenomenon is called normal refraction.

2) **When the object is in the denser medium**

When the object is in the denser medium, when viewed from the rarer medium appears nearer.

a) Normal shift: $N_S = t\left[1 - \frac{1}{n}\right]$ t – real depth of the object in the denser medium of R.I n

b) R.I of the medium $n = \frac{\text{real depth}}{\text{apparent depth}}$

c) $N_S = t\left[1 - \frac{n_2}{n_1}\right]$ when the object is in the denser medium of R.I n_1 ($n_1 > n_2$)

d) If an object is viewed normally through different media of refractive indices n_1, n_2, n_3,….. the net apparent depth = $\frac{t_1}{n_1} + \frac{t_2}{n_2} + \frac{t_3}{n_3} + \ldots$

where t_1, t_2, t_3,…. are the real depths.

3) **When the object is in the rarer medium:**

When the object is in the rarer medium, when viewed from the denser medium appears far or farther.

a) Normal shift: $N_S = t(n - 1)$

t – real depth of the object in the rarer medium, n – R.I of denser medium

b) $N_S = t\left[\frac{n_2}{n_1} - 1\right]$ when the object is in the rarer medium of R.I n_1 $(n_2 > n_1)$

c) R.I of the medium $n = \frac{\text{apparent depth}}{\text{real depth}}$

d) If an object is viewed normally through different media of refractive indices n_1, n_2, n_3,….. the net apparent depth = $n_1t_1 + n_2t_2 + n_3t_3 + \ldots$ where t_1, t_2, t_3,…. are the real depths.

Critical angle:

1) Relation between R.I and critical angle, $n = \frac{1}{\sin C}$

2) Critical angle for a pair of media is $\sin c = \frac{n_2(\text{rarer})}{n_1(\text{denser})} = \frac{\sin C_1}{\sin C_2}$ $(n_2 < n_1)$

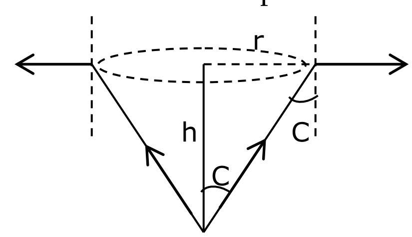
3)

Angle of incidence	Ray	Angle of deviation
$i < C$	Undergoes refraction	$d = r - i$
$i = C$	Grazes the interface	$d = 90 - i$
$i > C$	Undergoes total internal reflection	$d = 180 - 2i$

4) Light rays from a luminous point object in a denser medium of R.I n and at a depth h outline a circle of radius r given by $r = \frac{h}{\sqrt{n^2 - 1}} = h \tan C$

C – critical angle

Also $n = \frac{\sqrt{r^2 + h^2}}{r}$



Refraction at spherical surfaces:

1) $$-\frac{\text{R.I. of object space}}{\text{object distance}} + \frac{\text{R.I. of image space}}{\text{image distance}} = \frac{\text{R.I of image space - R.I of object space}}{\text{Radius of curvature}}$$

i.e. $-\frac{n_1}{u} + \frac{n_2}{v} = \frac{n_2 - n_1}{R}$

2) $\frac{n_1 \sim n_2}{R}$ is called the **power** of the spherical surface. It is a measure of the ability of a spherical refracting surface either to converge or diverge a beam passing through it.

Refraction through a prism:

1) Angle of deviation produced in a prism is $d = (i_1 + i_2) - A$

i_1 – angle of incidence, i_2 – angle of emergence, A – angle of the prism

2) Angle of the prism: $A = r_1 + r_2$

r_1 – angle of refraction at the 1st face, r_2 – angle of incidence at the 2nd face of the prism.

3) R.I of the material of the prism: $n = \frac{\sin i_1}{\sin r_1} = \frac{\sin i_2}{\sin r_2}$

4) For minimum deviation position of the prism $i_1 = i_2 = i$ and $r_1 = r_2 = r$

where $i = \frac{A + D}{2}$ and $r = \frac{A}{2}$

A – Angle of the prism and D – Angle of minimum deviation

5) R. I of the prism when it is in the minimum deviation position: $n = \dfrac{\sin\left(\dfrac{A+D}{2}\right)}{\sin\left(\dfrac{A}{2}\right)}$

6) If n_2 and n_1 are the refractive indices of the material of the prism and its surroundings respectively, then

$_1n_2 = \dfrac{n_2}{n_1} = \dfrac{\sin\left(\dfrac{A+D}{2}\right)}{\sin(A/2)}$

If $n_2 > n_1$, then the ray inside the prism bends towards the base.
If $n_1 > n_2$, then the ray inside the prism bends away from the base.

7) For equilateral prism ($A = 60^o$)
If $n = \sqrt{2}$ then $D = 30^o$
If $n = \sqrt{3}$ then $D = 60^o$

8) Angle of deviation produced by a thin prism surrounded by air: $d = A\,(n - 1)$
A- angle of the prism, n – mean R.I of the material of the prism.

9) Angle of deviation produced by a thin prism surrounded by a medium of R.I n_s is
$d = A\left[\dfrac{n}{n_s} - 1\right]$ where A- angle of the prism, n – mean R.I of the material of the prism

10) When a prism is immersed in water its deviation decreases nearly 4 times.

Lenses:

1) **Lens formula:** $\dfrac{1}{f} = -\dfrac{1}{u} + \dfrac{1}{v}$

f is the focal length of the lens, u and v is the object and image distance.

2) **Lens Makers Formula:** $\dfrac{1}{f} = \left(\dfrac{n_2}{n_1} - 1\right)\left(\dfrac{1}{R_1} - \dfrac{1}{R_2}\right)$

n_1 is the refractive index of the medium in which the lens is placed and n_2 is the refractive index of the material of the convex lens. R_1 and R_2 are the radii of curvature of the surface of the lens.
If $n_2 > n_1$, the nature of the lens is convex
If $n_1 > n_2$, the nature of the lens is concave
If $n_1 = n_2$, then focal length becomes infinity.

3) In the case of a lens in air $\dfrac{1}{f} = (n-1)\left(\dfrac{1}{R_1} - \dfrac{1}{R_2}\right)$

4) R.I of lens: $n = 1 + \dfrac{R_1 R_2}{f(R_1 - R_2)}$

5) Focal length of equiconvex lens $f = \dfrac{R}{2(n-1)}$

Focal length of equiconcave lens $f = \dfrac{-R}{2(n-1)}$

6) Focal length of plano-convex lens, $f = \dfrac{R}{(n-1)}$

Focal length of plano-concave lens, $f = \dfrac{-R}{(n-1)}$

7) Power of the lens is measured as the reciprocal of the focal length.
Power = $\dfrac{1}{\text{focal length}}$ i.e. $P = \dfrac{1}{f}$

8) When a lens is immersed in water its focal length increases nearly 4 times and power decreases nearly 4 times.

Formation of image by a lens:

1) **Formation of image by a concave lens:**

Position of the object	Position of the image	Nature of the image
Any position	Between lens and F	Virtual, diminished, erect

2) **Formation of image by a convex lens:**

Position of the object	Position of the image	Nature of the image
Between O and F	Same side as that of object	Virtual, enlarged, erect
At F	At infinity	Real, inverted, highly magnified (∞)
Between F and 2F	Beyond 2F	Real, inverted, magnified
At 2F	At 2F	Real, inverted, unit magnification
Beyond 2F	Between F and 2F	Real, inverted, diminished
At ∞	At F	Real, inverted, highly diminished

O – Optic centre, F – Principal focus

3) **Linear magnification:** A measure of the extent to which an optical system enlarges or reduces an image. The linear magnification is the ratio of the height of the image to that of the object.

Linear magnification $m = \frac{h_i}{h_o} = \frac{v}{u} = \frac{f-v}{f} = \frac{f}{f+u}$

h_i – height of the image, h_o – height of the object.

4) Areal magnification $m_A = \frac{\text{area of image}}{\text{area of object}} = \frac{v^2}{u^2} = m^2$

Combination of lenses:

1) When two thin lenses of focal lengths f_1 and f_2 are in contact, then focal length of the equivalent lens is $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$

2) Power of the equivalent lens when two thin lenses are in contact is $P = P_1 + P_2$

3) Total magnification m of the combination is product of magnification of individual lenses. i.e. $m = m_1 m_2 m_3 \ldots m_n$

4) When two thins lenses of focal lengths f_1 and f_2 are seperated by a distance d, focal length f of the combination is $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$

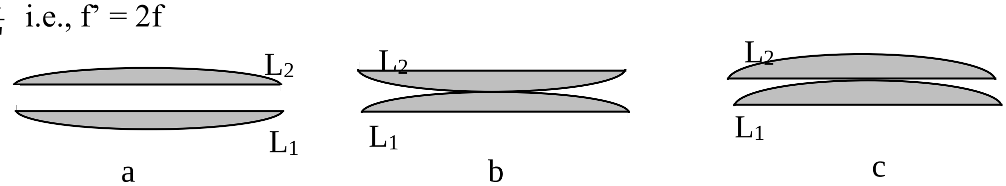
5) Power of the combination $P = P_1 + P_2 - P_1 P_2 d$

6) If Reflective index of the medium between the lens is n then the equivalent focal length is given by

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

7) If a lens of focal length f is divided into two equal parts as shown in figure (a) and each parts has a focal length f' then as

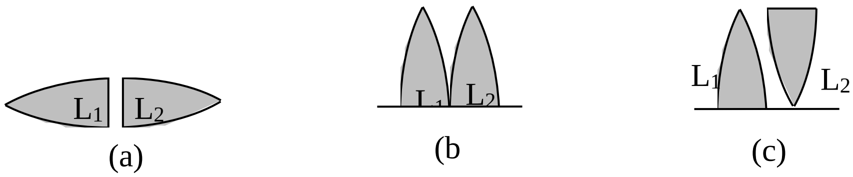
$\frac{1}{f} = \frac{1}{f'} + \frac{1}{f'}$ i.e., f' = 2f



i.e., each part will have focal length 2f.

Now if these parts are put in contact as in figure (b) or (c) the resultant focal length of the combination will be $\frac{1}{F}=\frac{1}{2f}+\frac{1}{2f}$, i.e., F = f(= initial value)

8) If a lens of focal length f is cut is two equal parts as shown in figure (a), each part will have focal length f. Now if these parts are put in contact as shown in figure (b), the resulting focal length will be



$\frac{1}{F}=\frac{1}{f}+\frac{1}{f}$, i.e, F = (f/2)

However, if the two parts are put in contact as shown in figure (c), first part will behave as convergent lens of focal length f, while the other divergent of same focal length (being thinner near the axis); so in this situation

$\frac{1}{F}=\frac{1}{f}+\frac{1}{-f}$, i.e., F = ∞ or P = 0.

9) **Silvering of one surface of the lens:**

Type of lens	Surface silvered	Focal length after silvering	Nature of the combination
Plano convex $f = \frac{R}{n-1}$	Plane	$f' = \frac{f}{2}$	Concave mirror
Plano convex $f = \frac{R}{n-1}$	Spherical	$f' = \frac{R}{2n}$	Concave mirror
Plano concave $f = \frac{R}{n-1}$	Plane	$f' = \frac{f}{2}$	Convex mirror
Plano concave $f = \frac{R}{n-1}$	Spherical	$f' = \frac{R}{2n}$	Convex mirror
Biconvex $f = \frac{R}{2(n-1)}$	One surface	$f' = \frac{R}{2(2n-1)}$	Concave mirror
Biconcave $f = \frac{R}{2(n-1)}$	One surface	$f' = \frac{R}{2(2n-1)}$	Concave mirror

Where R is the radius of curvature and n is the R.I of the material of the lens

The simple microscope (Magnifying lens):

1) Maximum magnifying power when image is formed at near point $M = 1 + \frac{D}{f}$

D = least distance of distinct vision, f – focal length of the convex lens

2) Minimum magnifying power when image is formed at infinity $M = \frac{D}{f}$

Compound Microscope:

1) Magnifying power of the objective, $M_o = \frac{v_o}{u_o}$

v_o = image distance formed by objective and u_o – object distance from the objective

2) Magnifying power of the eye-piece $M_e = 1 + \frac{D}{f_e}$

D – least distance of distinct vision, f_e – focal length of eye-piece

3) Magnifying power of the compound microscope in normal adjustment is

$$M = M_o \times M_e = \frac{v_o}{u_o}\left(1 + \frac{D}{f_e}\right) \approx \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)$$

Length of the compound microscope $L \approx v_o$ and $u_o \approx f_o$

4) Length of the compound microscope $L = v_o + u_e$ where u_e is the distance between image formed by the objective and eye-piece.

Telescope

1) Magnifying power, $M = \frac{\beta}{\alpha} = -\frac{f_o}{f_e}$ -ve sign indicates that image is inverted

2) If the image is formed at near point then magnifying power is $M = -\frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$

3) Length of the telescope is $L = f_o + f_e$.

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