Ray Optics and Optical Instruments

9 Chapter

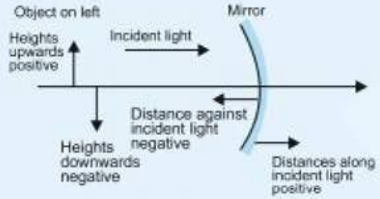
1 REFLECTION OF LIGHT

Law of Reflection

- Incident ray, reflected ray and normal to reflecting surface at the point of incidence lie in the same plane.
- Angle of incidence is equal to angle of reflection.

Sign-convention

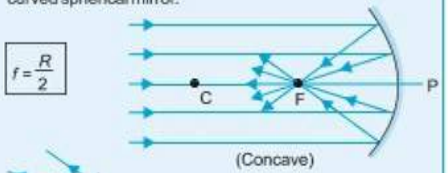
- In sign convention, all distances measured in the same direction as incidence ray are taken positive and those measured in the direction opposite of incident ray are taken negative.
- The heights taken above the principal axis are positive and below negative.



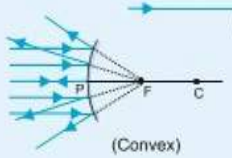
Focal Length of Spherical Mirrors

- The distance between focus and pole of a mirror is called focal length.
- Focal length is equal to half of radius of curvature of the curved spherical mirror.

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



(Concave)

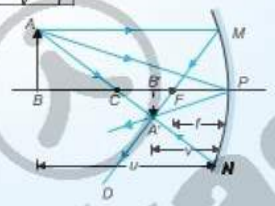


(Convex)

Image Formation by Spherical Mirrors

- The image by a mirror is real if rays after reflection actually meet and virtual if rays are not actually meeting but appear to diverge from a point.
- An incident ray passing through centre of curvature of mirror retraces its path.
- Mirror equation is $\boxed{\frac{1}{u}+\frac{1}{v}=\frac{1}{f}}$ and magnification formula

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



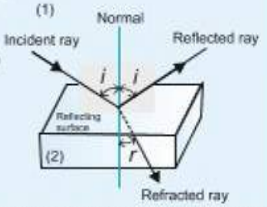
2 REFRACTION OF LIGHT

- When a beam of light encounters another transparent medium, part of light is reflected back. This called internal reflection. The rest of light enter other medium.
- When light is incident obliquely, its propagation direction changes in other medium, this phenomenon is called refraction.
- Red light travels faster than blue light in same medium.

Law of Refraction

- The incident ray, refracted ray and normal to interface at the point of incidence, all lie in same plane.
- The ratio of sine of angle of incidence to the sine of angle of refraction is constant.

$\boxed{\frac{\sin i}{\sin r} = n_{21}}$

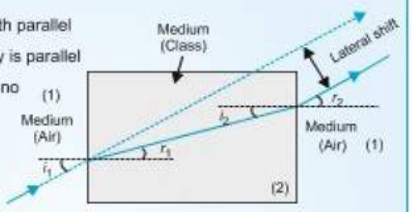


n_{21} is refractive index of second medium with respect to first.

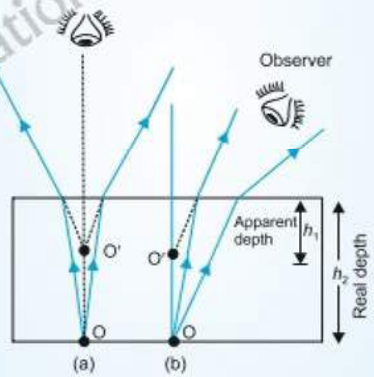
- Optical denser medium has high refractive index. Mass density of optical denser medium may be less than mass density of rarer medium.
- Elementary results from laws of refraction are

(1) $n_{32} = n_{31} \times n_{12}$

(2) For rectangular slab with parallel faces, the emergent ray is parallel to incident ray, there is no deviation but has lateral shift.

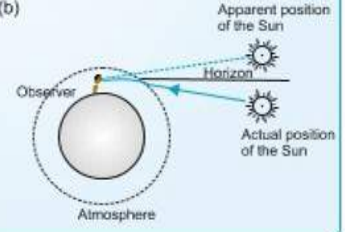


(3) Bottom of tank filled with water appears to be raised.



$$\text{Apparent depth} = \frac{\text{Real depth}}{n_{21}}$$

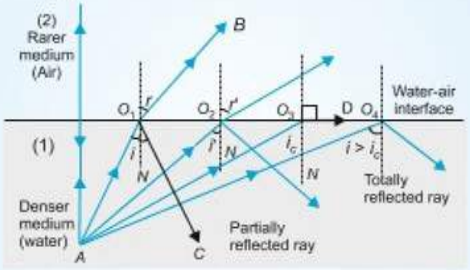
(4) Sun is visible a little before the actual sunrise and until a little after the sunset, this time difference is about 2 minute, the sun appears oval shaped.



3 TOTAL INTERNAL REFLECTION

- If angle of incidence, for light traveling from denser to rarer medium is greater than certain angle called critical angle for the media, no light is transmitted.

$\sin i_c = \frac{1}{n_{12}}$ n_{12}: refractive index of denser medium w.r.t rarer medium.

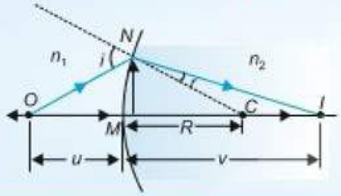


- Higher is value of refractive index, smaller will be critical angle.

Substance	Ref. index	Critical angle
Water	1.33	48.75°
Flint glass	1.62	37.31°
Diamond	2.42	24.41°

Phenomenon based on TIR are
- Mirage
- Sparkling of diamond
- Special prisms of flint glass to bend light by 90° and 180°
- Optical fibre for communication

4 REFRACTION AT SPHERICAL SURFACES



$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$

R = radius of curvature of the curved spherical surface. It holds for any curved surface (for paraxial approximation).

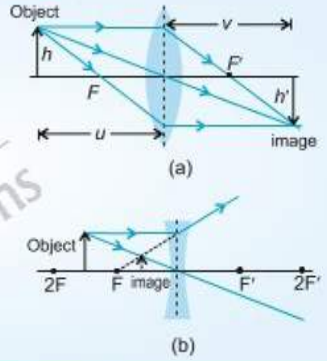
5 REFRACTION BY LENSES

- A lens is a transparent optical medium bounded by two surfaces.
  At least one surface should be spherical.
- After two refraction through a lens, image is formed.
  The thin lens formula becomes

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

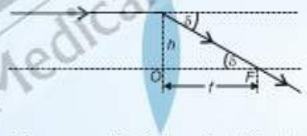
$m = \frac{\text{Size of image}}{\text{Size of object}} = \frac{h'}{h} = \frac{v}{u} = \frac{f}{f+u} = \frac{f-v}{f}$

- Formula is valid for convex and concave lenses and magnification produced by lens (for paraxial approximation)



6 POWER OF THIN LENS

- It is measure of its convergence or divergence ability.



- The power P of a lens is defined as the tangent of the angle by which it converges or diverges a beam of light parallel to the principal axis falling at unit distance from the optical centre.
- A lens of shorter focal length bends incident ray more and has high power.

$P = \frac{1}{f}$

- Its SI unit is dioptre (D)

$1D = 1\ m^{-1}$

- It is positive for converging lens and negative for diverging lens.

Lens maker's formula

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

- n is relative refractive index of glass with respect to surrounding and R_1 and R_2 are radii of curvature of two surfaces.
- A converging lens in a transparent liquid of refractive index greater than lens glass behaves like a diverging lens and vice versa.

7 THIN LENSES IN CONTACT

- When thin lenses are kept in contact

$P = P_1 + P_2 + P_3 + \ldots$

$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + \ldots$

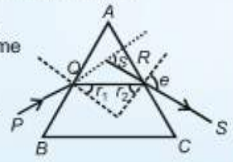
- Net power is individual power's algebraic sum. Some terms may be positive (convex) and some terms may be negative (concave) on right hand side.
- This combination helps to get diverging or converging lens combination of desired magnification.

8 REFRACTION THROUGH A PRISM

- For any triangular prism angle between incidence ray and emergent ray is called angle of deviation

$\delta = i + e - A$

- δ remains same if i and e are interchanged.

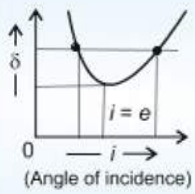


When $\delta = D_m$

$i = e$, $D_m = 2i - A$

$r = r_1 = r_2$ or $r_1 = A/2$

The refracted ray inside prism becomes parallel to its base.



- Refractive index of prism is calcutated by formula.

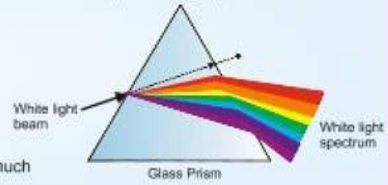
$$n_{21} = \frac{n_2}{n_1} = \frac{\sin\left(\frac{A + D_m}{2}\right)}{\sin(A/2)}$$

- For small angle thin prism

$D_m = (n_{21} - 1)A$

- It implies thin prism don't deviate light much

Dispersion by a prism

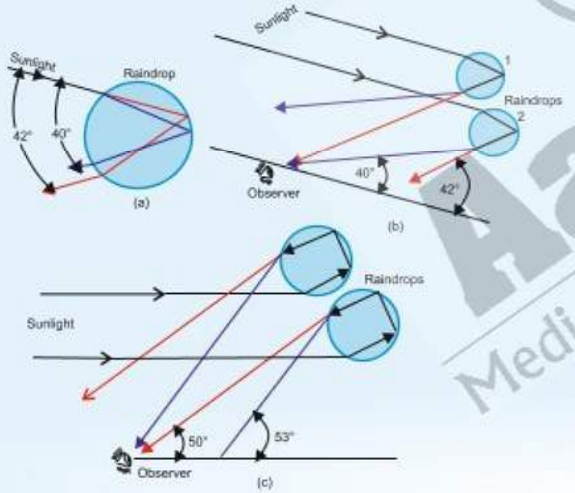


9 NATURAL PHENOMENA DUE TO SUNLIGHT

Dispersion of Light

- The phenomenon of splitting of light into constituent colours is known as dispersion.
- Dispersion takes place due to different refractive index of medium for different wavelengths.
- Chromatic aberration in thick lenses is due to dispersion.
- Rainbow is an example of dispersion of light (sun) by water drops
- In vacuum speed of light is independent of wavelength. So Vacuum is non dispersive medium.

Rainbow



Rainbow: (a) The sun rays incident on a water drop get refracted twice and reflected internally by a drop; (b) Enlarge view of internal reflection and refraction of a ray of light inside a drop form primary rainbow; and (c) Secondary rainbow is formed by rays undergoing internal reflection twice inside the drop.

10 OPTICAL INSTRUMENTS

Eye Defects Cure

- Myopia → Concave lens
- Hypermetropia → Convex lens
- Astigmatism → Cylindrical lens

Simple Microscope

- Microscope : A simple magnifier or microscope is a converging lens of high power.
- Angular magnification is equal to ratio of angular size of image to angular size of object
- Final image at near point

$$m = \left[1 + \frac{D}{f}\right]$$

- Final image at infinity

$$m = \frac{D}{f}$$

Compound Microscope

- For large magnification objective and eye piece should have low focal length
- Final image at near point

$$m = m_o \times m_e = \frac{v_o}{u_o}\left[1 + \frac{D}{f_e}\right]$$

- Final image at infinity

$$m = \frac{v_o}{u_o}\left(\frac{D}{f_e}\right)$$

Telescope

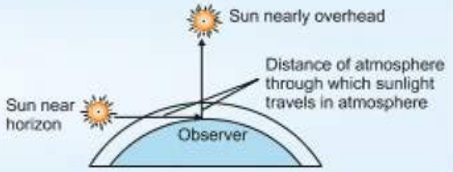
- It is used to provide angular magnification for distant objects
- Final image at infinity

$$m = \frac{f_o}{f_e} \text{ and } L = f_o + f_e$$

- Final image at near point

$$m = \frac{f_o}{f_e}\left[1 + \frac{f_e}{D}\right] \text{ and } L = f_o + \frac{Df_e}{D + f_e}$$

Scattering of light: Light of shorter wavelength is scattered much more than of longer wavelength. Amount of scattering is inversely proportional to fourth power of wavelength.



Sharpen Your Understanding

1. Which of the following statements is wrong for an image formation of a real object? [NCERT Pg. 315]
   (1) The magnification produced by convex mirror is always less than one
   (2) A virtual, inverted, same size image can be obtained using plane mirror
   (3) A virtual, erect, magnified image can be formed using a concave mirror
   (4) A real, inverted, same sized image can be formed using a convex mirror

2. Advanced sunset and delayed sunset is due to [NCERT Pg. 318]
   (1) Atmospheric reflection
   (2) Atmospheric refraction
   (3) Atmospheric scattering
   (4) Atmospheric dispersion

3. If μ_a, μ_b and μ_c are refractive indices of media *A*, *B* and *C* respectively such that $\mu_a > \mu_b > \mu_c$, total internal reflection can take place when a ray of light travels from [NCERT Pg. 320]
   (1) *C* to *A* (2) *C* to *B*
   (3) *B* to *A* (4) *B* to *C*

4. Which of the following concept is used in optical fibre? [NCERT Pg. 322]
   (1) Refraction of light
   (2) Scattering of light
   (3) Dispersion of light
   (4) Total internal reflection

NCERT Based MCQs

5. In the position of minimum deviation when a ray of yellow light passes through the prism, then its [NCERT Pg. 331]
   (1) Angle of incidence is less than angle of emergence
   (2) Angle of incidence is greater than emergent angle
   (3) Sum of angle of incidence and emergent angle is equal to 90°
   (4) Angle of incidence is equal to angle of emergence

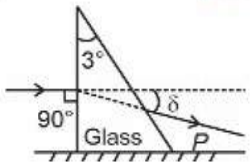
6. The focal length of a lens depends upon [NCERT Pg. 327]
   (1) Nature of material of lens
   (2) Colour of light
   (3) Medium in which lens is placed
   (4) All of these

7. A screen is placed at a distance of 40 cm away from an illuminated object. A converging lens is placed between the source and screen and it is attempted to form the image of the source on the screen. If no lens position could be found, the focal length of the lens [NCERT Pg. 347]
   (1) Should be greater than 10 cm
   (2) May be 6 cm
   (3) May be infinity
   (4) Must be less than 10 cm

8. In a compound microscope, the intermediate image is [NCERT Pg. 340]
   (1) Virtual, erect and magnified
   (2) Real, erect and magnified
   (3) Real, inverted and magnified
   (4) Virtual, erect and reduced

9. Mark the correct option among following statements.
   (1) If far point come closer to eye, the defect is farsightedness.
   (2) If near point goes ahead (away from eye), the defect is called myopia.
   (3) If defective far point is 1 m away from eye, divergent lens should be used
   (4) If near point is 1 m away from eye, divergent lens should be used
   [NCERT Pg. 337]

10. *P* is a small angled prism of angle 3° made from material of refractive index 1.2. A ray of light is incident on it as shown in figure. The angle of deviation for the rays refracted from prism is [NCERT Pg. 331]



   (1) 2° (2) 3°
   (3) 0.8° (4) 0.6°

11. When white light enters a prism, it gets split into its constituent colours. This is due to [NCERT Pg. 333]

(1) Scattering of light

(2) Dispersion of light

(3) Reflection of light

(4) Diffraction of light

12. A compound microscope consists of an objective lens of focal length 1 cm and an eye piece with focal length of 2.0 cm and tube has length 20 cm. What is its magnification? [NCERT Pg. 341]

(1) 100 (2) 200

(3) 220 (4) 250

13. With regards to a telescope, which statement is incorrect. [NCERT Pg. 340]

(1) Telescope is used to provide angular magnification of distant objects

(2) Telescope has objective lens of large power

(3) Final image of refracting telescope is inverted

(4) With larger diameter of objective fainter objects can be observed

14. Match the elements of List-I with List-II

	List-I		List-II
(A)	Simple microscope	(E)	Image magnified, inverted and virtual
(B)	Compound microscope	(F)	Image virtual, erect and high resolution
(C)	Astronomical telescope	(G)	Virtual, inverted and high resolution
(D)	Terrestrial telescope	(H)	Image virtual, erect and enlarged

[NCERT Pg. 339]

(1) A–H, B–F, C–E, D–G

(2) A–H, B–E, C–G, D–F

(3) A–H, B–E, C–F, D–G

(4) A–F, B–G, C–E, D–G

15. A simple magnifier has converging lens of focal length 2.5 cm. What is its linear magnification for the image formed at near point? [NCERT Pg. 341]

(1) 6 (2) 9

(3) 11 (4) 16

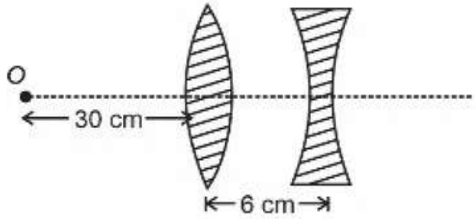
16. A prism has prism angle of 60° and its absolute refractive index is 1.76. The prism is dipped in a transparent liquid of refractive index x. If the angle of minimum deviation is found to 46° in liquid, what is x?

[NCERT Pg. 331]

(1) 1.1 (2) 1.3

(3) 1.4 (4) 1.5

17. Find the position of the image formed by lens combination with convex lens of focal length 10 cm and concave lens of focal length 12 cm. The object is kept at 30 cm from the convex lens as shown [NCERT Pg. 330]



(1) 36 cm to right of convex lens

(2) 36 cm to right of concave lens

(3) 16 cm to left of concave lens

(4) 20 cm to right of convex lens

18. A small pin fixed on table top is viewed from above from a distance of 40 cm. By what distance would pin appear to be raised if viewed from the same point through a 12 cm thick glass slab held parallel to the table? Refractive index of glass is 1.5

[NCERT Pg. 345]

(1) 4 cm

(2) 5 cm

(3) 6 cm

(4) 8 cm

19. Biconvex lenses are to be manufactured from glass of refractive index 1.5 with both faces of same radii of curvature. The radius of curvature required if focal length is 15 cm will be [NCERT Pg. 344]

(1) 10 cm (2) 15 cm

(3) 20 cm (4) 25 cm

20. A light pipe is made of glass fibre of refractive index 1.57. The outer covering of the pipe is made of a material of refractive index 1.36. The range of angles of incident rays with the axis of the pipe for which total internal reflection inside the pipe take place is nearly [NCERT Pg. 345]

(1) $0° < i < 38°$ (2) $0° < i < 90°$

(3) $0° < i < 60°$ (4) $0° < i < 53°$

Thinking in Context

1. The direction of propagation of an obliquely incident ($0 < i < 90$) ray of light that enter the other medium, changes at the interface of two media, this phenomenon is called _____ of light. [NCERT Pg. 316]

2. In case of light, the ratio of velocity of light in vacuum to that in medium $\left(\frac{c}{v}\right)$, is called _____ of medium. [NCERT Pg. 319]

3. The refractive index of diamond is 2.42, then its critical angle is _____. [NCERT Pg. 320]

4. When layers of air close to ground having varying temperature, with hottest layer near ground, image of tree may create an illusion to an observer that the tree is near a pool of water. This is due to phenomenon of _____. [NCERT Pg. 321]

5. A ray of light passing through first principal focus of a convex lens emerges _____ after refraction. [NCERT Pg. 327]

6. A glass lens with refractive index 1.33 disappears in a trough of water with refractive index 1.33. The statement is [NCERT Pg. 327]

(1) True

(2) False

7. Power of a convex lens is always positive and that of concave lens is negative. The statement is [NCERT Pg. 328]

(1) True

(2) False

8. Power of lens combination is equal to algebraic sum of individual powers and magnification of combination is product of magnification of lenses. The statement is

(1) True [NCERT Pg. 329]

(2) False

9. In prism theory in general any given value of angle of deviation; except $i = e$; there corresponds to two values of $\angle i$ and $\angle e$ (*i.e.* deviation angle remains same if $\angle i$ and $\angle e$ are interchanged). This statement is

(1) True [NCERT Pg. 331]

(2) False

10. Thick lenses show chromatic aberration due to _____. [NCERT Pg. 333]

11. Vacuum is a non-dispersive medium in which all colours travel with same speed. But glass is a dispersive medium. The statement is [NCERT Pg. 333]

(1) True

(2) False

12. The rainbow is a phenomenon due to combined effect of dispersion, refraction and reflection of sunlight by spherical droplets of rain water. This statement is

(1) True [NCERT Pg. 333]

(2) False

13. When light rays undergoes two internal reflections inside a rain drop, a secondary rainbow is formed and order of colours is reversed to primary rainbow. The statement is [NCERT Pg. 334]
(1) True
(2) False

14. At the sunset or sunrise, the sun looks reddish. The reddish appearance of sun near horizon is due to _____. [NCERT Pg. 335]

15. Angular magnification of a magnifier when the image formed at infinity compared to final image at near point is _____. [NCERT Pg. 337]

16. The final image formed by a compound microscope is inverted and magnified. The statement is [NCERT Pg. 338]
(1) True
(2) False

17. A telescope has objective of larger focal length and large aperture, whereas eyepiece has small focal length and small aperture. The statement is
(1) True [NCERT Pg. 339]
(2) False

❑ ❑ ❑

18. The virtual image produced by a convex mirror is generally diminished in size and located between the focus and pole.
(1) True
(2) False [NCERT Pg. 345]

19. An object placed between f and $2f$ of a concave mirror produces a real inverted image beyond $2f$.
(1) True
(2) False [NCERT Pg. 315]

20. If eye lens focusses the incoming light at a point behind the retina, a convergent lens is needed to compensate for the defect in vision. This defect is called _____ [NCERT Pg. 345]