Ray Optics And Optical Instruments

Spherical Mirror

Concave spherical mirror – A spherical mirror whose reflecting surface is towards the centre of the sphere is called concave spherical mirror.
Convex spherical mirror – A spherical mirror whose reflecting surface is away from the centre of the sphere is called convex spherical mirror.
Focal length – The distance between the pole and the principal focus of the mirror is called the focal length (*f*) of the mirror.
For both the spherical mirrors the f = R/2
Mirror formula for both the mirrors is

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{2}{R}$$

For convex mirror:

Position of object	**Position of object**
At infinity	At the Focus behind the mirror
Between infinity and the pole	Between the pole and the focus behind the mirror

For concave mirror:

Position of object	**Position of object**
At infinity	C
Beyond C	Between F and C
At C	At C
Between C and F	Beyond C
Beyond C	At infinity
Between P and F	Behind mirror

Refraction

- It is the phenomenon of the change in the path of light when it passes from one medium to another.
- Refractive index:
  - Absolute refractive index of a medium = $\frac{velocity\ of\ light\ in\ vacuum}{velocity\ of\ light\ in\ the\ medium}$
  - Refractive index of medium 1 with respect to medium 2 is equal to the reciprocal of the refractive index of medium 1 with respect to medium 2.
  - When a ray of light undergoes a number of reflections and retractions, its final path gets reversed. The ray retraces its entire path.This is called the principle of reversibility of light.

- Laws of refraction:
  - On going from a rarer medium to a denser medium, a ray bends towards the normal.
  - On going from a denser medium to a rarer medium, a ray bends away from the normal.

Snell's law $for\, interface between medium 1 and 2$ **:**

$$\mu_{12} = \frac{\mu_2}{\mu_1} = \frac{\sin\, i}{\sin\, r}$$

- On account of refraction of light, a tank of water appears to be less deep than it actually is.
  - $\mu = \frac{real\, depth}{apparent\, depth}$, where μ is refractive index of water with respect to air.

- **Condition for total internal reflection:**

If a ray of light travelling from an optically denser medium to an optically rarer medium is incident at an angle greater than the critical angle for the pair of media in contact, the ray is totally reflected back into the denser medium, thereby causing total internal reflection.

$$^a\mu_b = \frac{1}{\mathrm{sinC}}$$

- **Applications of total internal reflection:**

Multiple internal reflections in diamond ($i_c \cong 24.4°$), totally reflecting prisms and mirage are some examples of total internal reflection.

Optical fibres

- Optical fibres consist of glass fibres coated with a thin layer of material with a lower refractive index 1.5; this is called **cladding**.
- The central part of the fibres,called **core**, is made up of material with refractive index 1.7.
- Any light that is incident at an angle at one end comes out from the other after multiple internal reflections, even if the fibre is bent.
- Optical fibres are used for transmitting audio and video signals to long distances.
- They are used in endoscopes for medical examinations of inner parts of the body of a patient.

Spherical refracting surface

- It is a surface which forms a part of sphere of transparent refracting material.It can be convex or concave.

- The formula that governs the refraction at a spherical surface of radius of curvature R when light teravels from a medium of refractive index n_1 to medium of refractive index n_2 is $-\frac{\mathrm{n_1}}{\mathrm{u}} + \frac{\mathrm{n_2}}{\mathrm{v}} = \frac{\mathrm{n_2 - n_1}}{\mathrm{R}}$.

- Lensmaker's formula for both convex and concave lens.
  - $\frac{1}{\mathrm{f}}=\left(\mu-1\right)\left(\frac{1}{\mathrm{R}_1}-\frac{1}{\mathrm{R}_2}\right)$ where R_1 and R_2 are the radii of curvature of the two surfaces of the lens and μ is the refractive index of of material of lens with respect to the medium in which it is placed

- The relation between the object distance, image distance and focal length is known as lens formula and given as $\frac{1}{\mathrm{f}}=\frac{1}{\mathrm{v}}-\frac{1}{\mathrm{u}}$

Power of Lens

- It is defined as the ability of a lens to converge or diverge a beam of light falling on the lens.
- Conjugate foci are the two points on the axis of a lens, corresponding to positions of the object and image, such that their positions are interchangeable.
- Mathematically, power of a lens is expressed as $P=\frac{1}{f}$. Using the lens maker's formula, $P=\left(\mu-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$.
- SI unit of lens power is dioptre.
- *f* should be taken in metres.
- For the combination of n thin lenses of focal length f_1, f_2,f_3,......f_n, power, $P=\frac{1}{f_1}+\frac{1}{f_2}+\ldots\ldots\ldots\ldots\ldots\ldots\frac{1}{f_n}$

Refraction through a Prism

- When light passes through a prism , it suffers two refractions .

- The net deviation suffered by the ray when it passes through the prism of angle *A* is given by *δ*.

- Relation between the angle of incidence *i* , angle of emergence *e*, the angle of prism and the net deviation is given by $A+\delta=i+e$.

- The deviation of the light ray through the prism is minimum when angle of incidence i is $i=\frac{A+\delta_{\mathrm{m}}}{2}$.
  - For the minimum deviation, angle of incidence at both the surfaces of the prism are equal.

- The prism formula is given as $\mu=\frac{\sin\left(A+\delta_{\mathrm{m}}\right)/2}{\sin A/2}$.

  where δ_m is the minimum deviation of the light when passed through prism.

Dispersion through Prism

- It is the phenomenon of splitting of light into its constituent colours.

- A band of seven colours is obtained; it is known as visible spectrum.

- The reason for the dispersion is the difference in the refractive index of components of different wavelengths.

- The component with less wavelength bends more.
- The component with high wavelength bends less.

Scattering of Light

- Scattering of light takes place when the size of the scattering object is smaller compared to the wavelength of the light.
- Amount of scattering: $\propto \frac{1}{\lambda^4}$
- Blue colour has the smallest wavelength in the visible range, so it has the maximum scattering.
- The blue colour of sky is because of the scattering of blue light by the air molecules in the Earth's atmosphere. Blue light gets scattered very easily because of its shorter wavelength.
- At sunrise or sunset, the Sun looks almost reddish. This is because at the time of sunset or sunrise, the Sun is near the horizon. Blue- and violet-coloured rays are scattered in a large amount than the red-coloured rays.

Angular Dispersion

- Angular dispersion of two extreme colours violet and red:

  $\delta_v - \delta_r = A(\mu_v - \mu_r)$

Dispersive Power

- Dispersive power of a prism:

$$\omega = \frac{(\mu_v - \mu_r)}{(\mu_y - 1)}$$

The eye

- It has a convex lens of focal length about 2.5 cm.

- The focal length of can be varied somewhat so that the image is always formed on the retina.
- The ability of the eye to vary its focal length is called accommodation.
- The minimum distance upto which the eye can see the object distinctly and clearly is known as near point, it is at 25 cm from the eye for human eye.

Defects of Vision

- Myopia or $near\ sightedness$ - if the image is focussed before the retina , then a diverging corrective lens is needed.
- Hypermetropia $farsightedness$ - if the image is focussed beyond the retina $hypermetropia$, then a converging corrective lens is needed.
- Presbyopia - The defect that happens in old age that the person becomes fardsighted; to correct this defect the convex lebns is used.
- Astigmatism - The defect due to which a person is not able to see the vertical and horizontal lines distinctly ; it is corrected by using cylindrical lenses.

Simple microscope

- It consists of a convex lens of small focal length.
- Magnifying power of simple nicroscope is given by $m = \left(1 + \frac{D}{f}\right)$

Where, D= 25 cm, is the least distance of distinct vision or near point of the normal eye , f= Focal length of the convex lens

- If the image is formed at infinity then magnifying power $m = \frac{D}{f}$

Compound microscope:

- It consists of two convex lenses objective and eyepiece.
- Image formed by the objective serves as the object for eyepiece.
- The magnifying power is given by m = $m_e \cdot m_0$

Where, m_e is the magnification due to the eyepiece and is $m_o$the magnification due to the objective lens.

Telescope

- It consists of two convex lens—objective and eyepiece—with the eyepiece having less wavelength than the objective.
- The magnifying power m of a telescope is the ratio of angle β subtended at the eye by the image to angle α subtended at the eyepiece by the object.

- When image is at infinity:
  - Magnifying power, $M = -\frac{f_o}{f_e}$
- When the image is at the near point of the eye:
  - Magnifying power, $M = -\left(\frac{f_o}{f_e}\right)\left(1 + \frac{f_e}{D}\right)$
    Here, f_0 and f_e are the focal lengths of the objective and the eyepiece, respectively.

The Cassegrainian Telescope

- It is a reflecting telescope whose objective lens is replaced by a concave parabolic mirror.
- Parabolic mirrors are free from chromatic and spherical aberrations.
- The use of parabolic mirror makes the resolving power of a telescope high.
- Magnifying power, $M = \frac{R/2}{f_e}$

Here, R is the radius of the curvature of the concave mirror and f_e is the focal length of the eyepiece.