

Physics Point

RAY OPTICS AND OPTICAL INSTRUMENTS

CHAPTER

9

GLIMPSES

Ray optics

The study of nature, production and propagation of light. Ray optics deals with nature and wave optics deals with wave nature of light.

Laws of reflection of light

1. The incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane.

2. \angle of incidence = \angle of reflection or $\angle i = \angle r$.

Spherical mirror

A mirror whose reflecting surface forms a part of a hollow sphere. A narrow beam of light parallel to the principal axis either actually converges to or appears to diverge from a point F on the principal axis after reflection from the mirror. This point is called principal focus of the mirror. The distance between the focus and the pole of the mirror is called its focal length (f).

New Cartesian sign convention for spherical mirrors/lenses.

- Distances measured in the direction of incident light are positive; those measured in the opposite direction are negative.
- All distances are measured from the pole/optical centre of the mirror/lens.
- The heights measured upwards and perpendicular to the principal axis are taken positive and the heights measured downwards are taken negative.

Spherical mirror formula

Object distance u , image distance v and focal length f are related as $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ or $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$.

f is $-ve$ for a concave mirror and $+ve$ for a convex mirror.

Linear or transverse magnification

$$m = \frac{\text{Height of image}}{\text{Height of object}} = \frac{h_2}{h_1} = -\frac{v}{u} = \frac{f}{f-u} = \frac{f-v}{f}$$

If m is $+ve$, the image is virtual and erect.

If m is $-ve$, the image is real and inverted.

Refraction of light

The phenomenon of bending of light from its straight line path as it passes at an angle from one transparent medium to another.

Laws of refraction of light

First law. The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane.

Second law. For a given pair of media,

$$\frac{\sin i}{\sin r} = \mu, \text{ a constant. This law is also known as Snell's law of refraction.}$$

Snell's law of refraction

Refractive index of a medium

$$\mu = \frac{\text{Speed of light in vacuum } c}{\text{Speed of light in medium } v}$$

$$\mu = \frac{\text{Wavelength of light in vacuum } \lambda_{\text{vac}}}{\text{Wavelength of light in medium } \lambda_{\text{med}}}$$

Relation between refractive indices

$$\mu_{21} = \frac{1}{\mu_{12}}, \mu_{23} = \frac{\mu_{21} \mu_{13}}{\mu_{12}}$$

Relation between real and apparent depths

$$\mu = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$\mu > 1 \Rightarrow \text{Apparent depth} < \text{Real depth}$$

Critical angle

The angle of incidence in the denser medium for which the angle of refraction becomes 90° in the rarer medium. Using $i = i_c$ and $r = 90^\circ$ in Snell's law,

$$\frac{\sin i_c}{\sin 90^\circ} = \mu \text{ or } \mu = \frac{1}{\sin i_c}$$

Total internal reflection

The phenomenon in which a ray of light travelling at an angle of incidence greater than the critical angle from a denser to a rarer medium is totally reflected back into the denser medium.

Totally reflecting prism

A $45^\circ-90^\circ-45^\circ$ prism is called a totally reflecting prism. It can deviate rays through 90° or 180° . In these prisms, light is totally reflected, reflecting properties are permanent and no multiple images are formed.

Optical fibre

A hair-thin long strand of quality glass or quartz surrounded by a glass coating of slightly lower refractive index. It works on the principle of total internal reflection. It is used as a guided medium for transmitting an optical signal from one place to another.

Spherical lens

A piece of refracting medium bounded by two surfaces, at least one of which is a curved surface. A convex lens is thicker at the centre and converges a parallel beam. A concave lens is thinner at the center and diverges a parallel beam of light.

Refraction through a spherical surface

$$(i) \text{ Refraction from rarer to denser medium } \frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R} \quad (\mu_2 > \mu_1)$$

$$(ii) \text{ Refraction from denser to rarer medium } \frac{\mu_1}{v} - \frac{\mu_2}{u} = \frac{\mu_1 - \mu_2}{R} \quad (\mu_2 > \mu_1)$$

Lens maker's formula

$$\frac{1}{f} = \left[\frac{\mu_2 - \mu_1}{\mu_1} \right] \left[\frac{1}{R_1} - \frac{1}{R_2} \right]$$

$$\text{For the lens in air, } \frac{1}{f} = (\mu - 1) \left[\frac{1}{R_1} - \frac{1}{R_2} \right]$$

Thin lens formula

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

Linear magnification produced by a lens

$$m = \frac{\text{size of image } h_2}{\text{size of object } h_1} = \frac{v}{u} = \frac{f}{f+u} = \frac{f-v}{f}$$

Power of a lens

$$P = \frac{1}{f(\text{m})} = 1 \text{ dioptre (D)} = 1 \text{ m}^{-1}$$

Lens combinations

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

For n thin lenses in contact,

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \dots + \frac{1}{f_n} \text{ or } P = P_1 + P_2 + \dots + P_n$$

Refraction through a prism

Angle of deviation is the angle between the directions of incident and emergent rays.

$$\text{Angle of prism} = \text{Angle of deviation}$$

$$= \text{Angle of incidence} + \text{Angle of emergence}$$

$$A + \delta = i + e \text{ and } A = r + r'$$

Relation between the refractive index and angle of minimum deviation

In the position of minimum deviation, refracted ray passes parallel to the base of the prism.

$$i = e, r = r' \text{ and } \delta = \delta_m$$

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin \frac{A + \delta_m}{2}}{\sin \frac{A}{2}}$$

Simple microscope

It is a convex lens of short focal length.

$$\text{For image at near point, } m = 1 + \frac{D}{f}$$

$$\text{For image at far point, } m = \frac{D}{f}$$

Compound microscope

Objective is a convex lens of very short focal length and of small aperture. Eyepiece is a convex lens of slightly larger focal length and of larger aperture.

$$\text{When the final image is formed at the near point}$$

$$m = \frac{D}{o} = \frac{v_o}{u_o} \left(1 + \frac{D}{f_e} \right) = \frac{L}{f_o} \left(1 + \frac{D}{f_e} \right)$$

When the final image is formed at infinity

$$m = \frac{L}{f_o} \times \frac{D}{f_e}$$

Astronomical telescope

Objective is a convex lens of large focal length and large aperture. Eyepiece is a convex lens of small focal length and small aperture.

When the final image is formed at the near point

$$m = \frac{D}{o} = -\frac{f_o}{f_e} \left(1 + \frac{f_e}{D} \right)$$

When the final image is formed at infinity

$$m = \frac{D}{o} = -\frac{f_o}{f_e}, L = f_o + f_e$$

Reflecting telescope

It uses a concave paraboloidal mirror of large aperture to view the distant objects.

$$m = \frac{f_o}{f_e} \left(1 + \frac{f_e}{D} \right) \quad (\text{At distance } D)$$

$$m = \frac{f_o}{f_e} = \frac{R/2}{f_e} \quad (\text{At far point}) \quad (539)$$

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