

CHAPTER 24

LIGHT AND OPTICS

*Light bends and splits where unseen boundaries lie,
In waves it spreads, in rays it travels straight and shy,
From fringes born where phases softly meet,
Law shapes the paths that eyes and instruments greet*

Optics is the branch of physics that studies the behavior of light and its interaction with matter. Light exhibits both wave and particle characteristics. In this chapter, light is treated primarily as a wave, leading to the laws of geometrical and physical optics.

24.1 NATURE OF LIGHT

Light is an electromagnetic wave characterized by oscillating electric and magnetic fields perpendicular to the direction of propagation.

The speed of light in vacuum is

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

In a medium, light travels with reduced speed

$$v = \frac{c}{n}$$

where n is the refractive index of the medium.

24.2 GEOMETRICAL OPTICS

Geometrical optics describes light propagation in terms of rays and is valid when the wavelength of light is much smaller than the dimensions of optical elements.

24.2.1 LAWS OF REFLECTION

At a reflecting surface, the incident ray, reflected ray, and the normal lie in the same plane.

The law of reflection states

$$\theta_i = \theta_r$$

where θ_i and θ_r are the angles of incidence and reflection.

24.2.2 LAWS OF REFRACTION

Refraction occurs when light passes from one medium to another.

Snell's law is given by

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

where n_1 and n_2 are the refractive indices of the two media.

24.2.3 TOTAL INTERNAL REFLECTION

Total internal reflection occurs when light travels from a denser to a rarer medium and the angle of incidence exceeds the critical angle.

The critical angle θ_c satisfies

$$\sin \theta_c = \frac{n_2}{n_1}$$

where $n_1 > n_2$.

24.3 OPTICAL INSTRUMENTS

24.3.1 MIRRORS

For a spherical mirror, the mirror formula is

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

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

The magnification is

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

24.3.2 THIN LENSES

For a thin lens, the lens formula is

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

The magnification produced by a lens is

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

24.4 WAVE OPTICS

Wave optics accounts for phenomena that cannot be explained by ray theory, such as interference and diffraction.

24.4.1 INTERFERENCE OF LIGHT

Interference arises from the superposition of coherent light waves.

In Young's double-slit experiment, the path difference Δ between waves is

$$\Delta = d \sin \theta$$

Constructive interference occurs when

$$\Delta = m\lambda$$

and destructive interference occurs when

$$\Delta = \left(m + \frac{1}{2}\right)\lambda$$

where m is an integer.

24.4.2 DIFFRACTION

Diffraction is the bending of light around obstacles and apertures.

For single-slit diffraction, the condition for minima is

$$a \sin \theta = m\lambda$$

where a is the slit width.

24.5 POLARIZATION

Polarization describes the orientation of the electric field vector of light.

Unpolarized light contains waves vibrating in all directions perpendicular to propagation.

Malus' law gives the intensity of polarized light after passing through an analyzer

$$I = I_0 \cos^2 \theta$$

where θ is the angle between the polarization directions.

24.6 DISPERSION

Dispersion occurs when the refractive index depends on wavelength.

The angular deviation produced by a prism depends on wavelength according to

$$n = n(\lambda)$$

This explains the formation of spectra.

24.7 CLOSING REMARKS

Geometrical optics provides a simple and powerful description of light propagation, while wave optics reveals the interference and diffraction nature of light. Together, they form the classical foundation for modern optical science and technologies.