Optics

Optics is the branch of physics that studies the behaviour and properties of light. It is divided into **Ray Optics** (geometry of light as rays) and **Wave Optics** (light as an electromagnetic wave).

I. Ray Optics and Optical Instruments

1. Reflection of Light and Spherical Mirrors

Reflection is the phenomenon where light bounces back into the same medium after striking a polished surface.

- **Laws of Reflection:**
  1. The angle of incidence equals the angle of reflection ($i = r$).
  2. The incident ray, the reflected ray, and the normal at the point of incidence all lie in the same plane.
- **Sign Convention:** Distances measured in the direction of incident light are positive; opposite are negative. Distances above the principal axis are positive.
- **Mirror Formula:** Relates the object distance (u), image distance (v), and focal length (f): $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$
- **Magnification (m):** The ratio of the height of the image (h') to the height of the object (h): $m = \frac{h'}{h} = -\frac{v}{u}$

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2. Refraction of Light and Total Internal Reflection

Refraction is the change in direction of light as it passes from one transparent medium to another.

- **Snell's Law:** The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant: $n_{21} = \frac{\sin i}{\sin r} = \frac{n_2}{n_1}$
- **Total Internal Reflection (TIR):** When light travels from a denser to a rarer medium at an angle greater than the **critical angle (**i_c**)**, it is reflected back into the denser medium.
  - **Condition for** i_c**:** $\sin i_c = \frac{n_2}{n_1}$ (If medium 2 is air, $\sin i_c = \frac{1}{n}$).
- **Optical Fibers:** These use TIR to transmit light signals over long distances. They consist of a high-refractive index **core** and a lower-index **cladding**.

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3. Refraction at Spherical Surfaces and Lenses

- **Refraction Formula (Single Surface):** For light going from medium n_1 to n_2: $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$
- **Lens Maker's Formula:** Used to calculate the focal length of a lens based on its material and curvatures: $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$
- **Thin Lens Formula:** $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$
- **Power of a Lens (P):** The ability of a lens to converge or diverge light, measured in Dioptres (D): $P = \frac{1}{f(\text{in metres})}$
- **Combination of Lenses:** For lenses in contact, total power is $P = P_1 + P_2 + \dots$ and total magnification is $m = m_1 \times m_2 \times \dots$.

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4. Prisms and Dispersion

- **Refraction through a Prism:** A ray passing through a prism undergoes deviation (δ).

- **Angle of Minimum Deviation (δ_m):** When the angle of incidence equals the angle of emergence ($i = e$): $n = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$
- **Dispersion:** The splitting of white light into its constituent colours (VIBGYOR) because different wavelengths travel at different speeds in glass.

5. Optical Instruments

- **Simple Microscope:** Uses a single convex lens. Magnification $m = 1 + \frac{D}{f}$ (image at least distance D).
- **Compound Microscope:** Uses an objective and an eyepiece to produce high magnification: $m = m_o \times m_e \approx \frac{L}{f_o}\left(\frac{D}{f_e}\right)$
- **Astronomical Telescope:**
  - **Refracting Type:** Uses lenses. Magnifying power $m = \frac{f_o}{f_e}$.
  - **Reflecting Type (Cassegrain):** Uses a large parabolic primary mirror to eliminate chromatic aberration.

II. Wave Optics

1. Huygen's Principle and Wavefronts

- **Wavefront:** The locus of all points in a medium that vibrate in the same phase.
- **Huygen's Principle:**
  1. Every point on a wavefront acts as a source of secondary wavelets.
  2. These wavelets spread in all directions with the speed of the wave.
  3. The forward envelope of these wavelets forms the new wavefront.
- **Proofs:** By using the time taken by wavelets to travel between wavefronts, the **Laws of Reflection** ($i = r$) and **Snell's Law** ($\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$) can be mathematically proven.

2. Interference and Young's Double Slit Experiment (YDSE)

Interference is the redistribution of light energy due to the superposition of waves from **coherent sources** (sources with constant phase difference).

- **Constructive Interference:** Resultant amplitude is maximum. Path difference $\Delta x = n\lambda$.
- **Destructive Interference:** Resultant amplitude is minimum. Path difference $\Delta x = (n + \frac{1}{2})\lambda$.
- **Fringe Width (β):** The distance between two consecutive bright or dark fringes on the screen: $\beta = \frac{\lambda D}{d}$ where D is the distance to the screen and d is the separation between slits.

3. Diffraction

Diffraction is the bending of light around the corners of an obstacle or aperture into the region of the geometrical shadow.

- **Single Slit Diffraction:** For a slit of width a, the first minima occurs at: $a \sin\theta = \lambda$
- **Width of Central Maxima:** The central bright fringe is twice as wide as the secondary fringes.
    - **Angular Width:** $2\theta = \frac{2\lambda}{a}$
    - **Linear Width:** $W = \frac{2\lambda D}{a}$
- **Key Difference:** Unlike interference fringes which are of equal intensity, diffraction fringes rapidly decrease in intensity as we move away from the centre.