# Chapter 10

# Wave Optics

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  - Maximas and minimas due to interference
  - Young's double slit experiment
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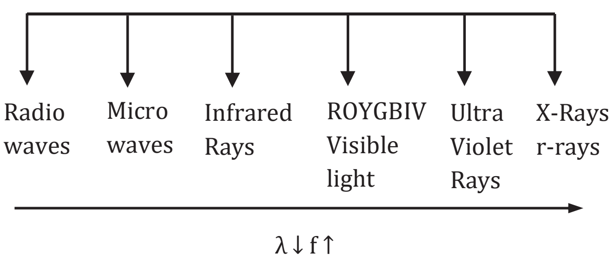
- Huygens Principle – Wavefront
  - YDSE - Intensity Variation
  - Huygens Principle - Wavefront
- YDSE- Incoherent sources and optical path length
  - YDSE- Coherent and incoherent Sources
  - Optical Path length
- YDSE- Interference pattern due to insertion of slab at slit, oblique incidence, and Bichromatic coherent light source
  - YDSE- Insertion of slab of different Refractive index at slit
  - YDSE- path difference due to oblique incidence of light from coherent source
  - Fringe pattern due to different shape of slits

## INTRODUCTION TO WAVE OPTICS AND INTERFERENCE

### Electromagnetic Spectrum




Visible light refers to the portion of the electromagnetic spectrum that we can see.

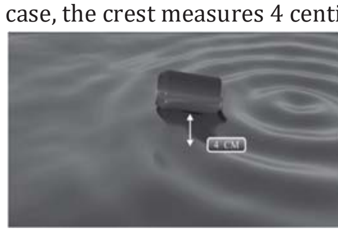
The study of light is divided into two branches:

1. Geometrical optics (applicable when the size of objects is much larger than the wavelength of light)
2. Wave optics (relevant when the size of objects is similar to the wavelength of light)

### Interference

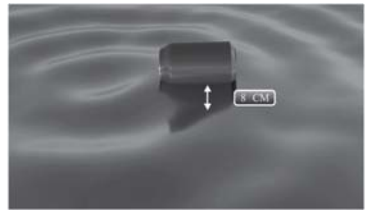
Imagine a soda can resting on the surface of calm water. If a small stone is dropped onto the right side of the can, it creates circular ripples on the water's surface.

A wave, which is essentially a series of back-and-forth motions (simple harmonic motions), has high points called crests (the maximum height) and low points called troughs (the minimum height). In this case, the crest measures 4 centimeters.

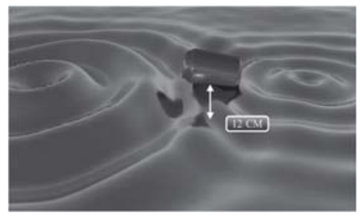



If a stone slightly heavier than the last one is dropped on the left side of the can, the can will rise by 8 centimeters because of the waves produced by the stone.

- YDSE- Bichromatic light interference
- Intereference of white light in YDSE, Lloyd's mirror and Fresenel's Biprism
  - White light in YDSE
  - LLOYD'S Mirror
  - Fresenel's Biprism
- Thin film Interference-Normal and Oblique Incidence
  - Thin film interference- Normal Incidence
  - Thin film interference- Oblique Incidence
- Diffraction
  - Diffraction
  - Fraunhofer Diffration - Single Slit
  - Fraunhofer Diffration - Circular Aperture
- Scattering and Polarization of light
  - Scattering of light
  - Rayleigh's Law of scattering
  - Polarisation
  - Polarized and unpolarized light
  - Law of Malus
  - Polarization by reflection
- Polarisation by reflection and scattering, Brewster law and Huygens Principle
  - Polarisation by reflection
  - Brewster Law
  - Polarisation by Scattering
  - Huygens Principle- Reflection, Refraction and Doppler effect
  - Validity of ray optics




Now, if both stones that were dropped separately into the water before are now dropped together on opposite sides of the can, as depicted in the illustration. Consequently, the waves produced by the stones will arrive at the can's position simultaneously, and their combined impact is anticipated. It is noted that the can is lifted by 4 centimeters plus 8 centimeters, totaling 12 centimeters.



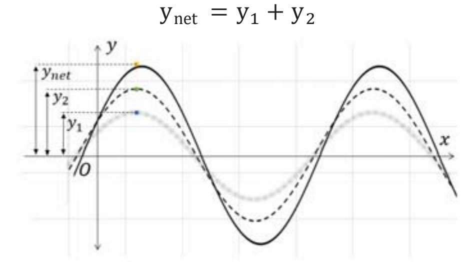

**Superposition Principle**

When multiple waves meet at a particular spot, the movement at that spot equals the combined movement of each wave taken together.

$$\vec{y}_{net} = \vec{y}_1 + \vec{y}_2 + \vec{y}_3 \dots \dots + \vec{y}_n$$

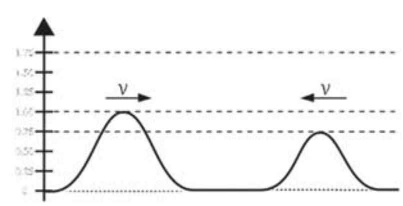
From the figure, we can say:

$$\vec{y}_{net} = \vec{y}_1 + \vec{y}_2$$

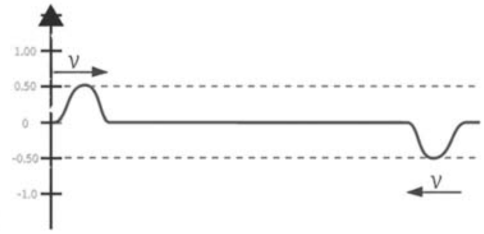



When two wave pulses, one measuring 1 unit and the other 0.75 unit, move towards each other at equal speeds, they merge at a specific spot. The resulting wave will measure 1.75 units, obtained by adding the sizes of the individual waves.

After the superposition, the shape of wave pulses remain unaffected.



When two wave pulses, one with a magnitude of +0.5 unit and the other with -0.5 unit, travel towards each other at identical speeds, upon overlapping, the resulting wave's magnitude will be (0.5 - 0.5) = 0 unit. This implies that the pulses cancel each other out upon overlapping, and the shape of the wave pulses remains unchanged afterward.




## Interference

Interference involves the superposition of waves. When two or more waves overlap, they combine by adding up their individual displacements.
Let the two waves coming from sources $S_1 \& S_2$ be

$$y_1 = A_1 \sin(\omega t + kx_1)$$
$$y_2 = A_2 \sin(\omega t + kx_2) \text{ respectively.}$$

Due to superposition

$$y_{net} = y_1 + y_2$$
$$y_{net} = A_1 \sin(\omega t + kx_1) + A_2 \sin(\omega t + kx_2)$$

Phase difference between $y_1 \& y_2 = k(x_2 - x_1)$

i.e., $\Delta\phi = k(x_2 - x_1)$

As $\Delta\phi = \frac{2\pi}{\lambda}\Delta x$

(where $\Delta x =$ path difference & $\Delta\phi =$ phase difference)

$$A_{net} = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos\phi}$$
$$A_{net}{}^2 = A_1^2 + A_2^2 + 2A_1A_2\cos\phi$$
$$\therefore I_{net} = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi (\text{ as } I \propto A^2)$$

When the two displacements are in phase, then the resultant amplitude will be sum of the two amplitude & $I_{net}$ will be maximum, this is known of constructive interference.
For $I_{net}$ to be maximum

$\cos\phi = 1 \Rightarrow \phi = 2n\pi$ where $n = \{0,1,2,3,4,5 \ldots \ldots \ldots ..\}$

$\frac{2\pi}{\lambda}\Delta x = 2n\pi \Rightarrow \Delta x = n\lambda$

For constructive interference

$$I_{net} = (\sqrt{I_1} + \sqrt{I_2})^2$$

When $I_1 = I_2 = I$

$$I_{net} = 4I$$
$$A_{net} = A_1 + A_2$$

When superposing waves are in opposite phase, the resultant amplitude is the difference of two amplitudes & $I_{net}$ is minimum; this is known as destructive interference.
For $I_{net}$ to be minimum,

$$\cos\Delta\phi = -1$$

$$\Delta\phi = (2n+1)\pi \text{ where } n = \{0,1,2,3,4,5 \dots\dots\dots..\}$$

$$\frac{2\pi}{\lambda}\Delta x = (2n+1)\pi \Rightarrow \Delta x = (2n+1)\frac{\lambda}{2}$$

For destructive interfence

$$I_{net} = (\sqrt{I_1} - \sqrt{I_2})^2$$

If $I_1 = I_2$

$$I_{net} = 0$$

$$A_{net} = A_1 - A_2$$

Generally,

$$I_{net} = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$$

If $I_1 = I_2 = I$

$$I_{net} = 2I + 2I\cos\phi$$

$$I_{net} = 2I(1+\cos\phi) = 4I\cos^2\frac{\Delta\phi}{2}$$

$$\text{Ratio of } I_{max} \& I_{min} = \frac{(\sqrt{I_1}+\sqrt{I_2})^2}{(\sqrt{I_1}-\sqrt{I_2})^2}$$

**Ex.** Light from two source, each of same frequency and travelling in same direction, but with intensity in the ratio 4 : 1 interfere. Find ratio of maximum to minimum intensity.

**Sol.** $\frac{I_{max}}{I_{min}} = \left(\frac{\sqrt{I_1}+\sqrt{I_2}}{\sqrt{I_1}-\sqrt{I_2}}\right)^2 = \left(\frac{\sqrt{\frac{I_1}{I_2}}+1}{\sqrt{\frac{I_1}{I_2}}-1}\right)^2 = \left(\frac{2+1}{2-1}\right)^2 = 9:1$