10.WAVE OPTICS

Single Page Simple Synopsis

Wave Optics (Physical Optics) is a branch of physics that studies light as a wave.
It introduces phenomena that ray optics cannot explain—specifically interference, diffraction, and polarization—by proving that light consists of oscillating electric and magnetic fields.

Key Concepts:

1. **Huygens' Principle**
   Instead of treating light as a straight ray, wave optics uses the concept of a wavefront (a surface where all points vibrate in the same phase). Huygens' Principle states that every point on an existing wavefront acts as a fresh source of secondary wavelets, which spread out and determine the new position of the wavefront.
2. **Interference:** When 2 light waves overlap, they combine to form region of brightness (constructive) and darkness (destructive).
   - **Constructive interference:** Waves meet "in-phase" (crests overlap with crests), resulting in a brighter spot.
   - **Destructive interference:** Waves meet "out-of-phase" (crests overlap with troughs), resulting in a darker spot.
   - **Young's Double-Slit Experiment (YDSE):** The classic proof of this phenomenon, which produces alternating bright and dark fringes on a screen.
3. **Diffraction**
   This is the bending of light waves around the edges of obstacles or through small apertures. When light passes through a single narrow slit, it spreads out and creates a broad, bright central maximum flanked by alternating dimmer bands on the screen.
4. **Polarization**
   Light is a transverse wave, meaning its electric and magnetic fields vibrate perpendicularly to the direction the wave travels. Unpolarized light vibrates in all directions perpendicular to the wave. Polarization is the process of filtering these vibrations so that the light waves only oscillate in a single plane.

Real Life Examples

- **Interference** - Rainbow colours soap bubbles, oil slicks, antiglare camera lenses;
  Diffraction - silver linings in clouds; **Polarisation-** polarised sun glasses, LCD Screens.

IMP. IPE POINTS

1. The locus of points having same phase is called **wavefront**.

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2. **Huygens Principle: Each** point on a wave front is a source of secondary waves, which adds up to give the wavefront at a later time.

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3. **Coherent waves:** If two waves are of same frequency and the phase difference between them does not change with time, such waves are called coherent waves.
Interference pattern produced by coherent waves can be seen by us on the screen

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Incoherent waves: If two waves are of same frequency and the phase difference between them changes rapidly with time, the waves are called incoherent waves.
Interference pattern produced by incoherent waves cannot be seen by us on the screen because of rapid changes in phase.

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4. Intensity of wave is directly proportional to square of its amplitude. $I = KA^2$

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5. $\frac{I_1}{I_2} = \frac{A_1^2}{A_2^2} = \frac{W_1}{W_2}$ where I_1, I_1 are intensities, A_1, A_2 are amplitudes, W_1, W_2 are slit widths.

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6. **Interference of Light** : When two or more coherent light waves superpose, the resultant light intensity in the region varies to form bright and dark fringes. This is called interference of light.

In interference, the intensity of light at any point on the screen is given by

$$I = 4\, I_0 \cos^2 (\phi/2)$$

where I_0 is the intensity of each wave and ϕ is the phase difference between the light waves producing interference.

- The **condition for maximum intensity** at the point is $\phi = 0, \pm 2\pi, \pm 4\pi \ldots$.
- The **maximum resultant intensity** is

$$I_{max} = 4\, I_0$$

The **condition for minimum intensity** at the point is $\phi = \pm \pi, \pm 3\pi, \pm 5\pi$.....
The **minimum resultant intensity** is

$$I_{mini} = 0$$

- Equation for n^{th} bright band distance on screen is $x_n = \frac{n\lambda D}{d}$

- Equation for n^{th} dark band distance is

$$x_n = \left(n + \frac{1}{2}\right)\frac{\lambda D}{d}$$

- **Fringe width** is given by $\beta = \frac{\lambda D}{d}$

where λ is wavelength, D is the distance between slits and screen and d is the distance between the coherent slits S_1, S_2.

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7. **Diffraction :** The phenomenon of bending of light round the sharp corners of an obstacle placed in the path of light is called diffraction of light.

- The diffraction pattern of single slit has central maximum. The other maxima become weaker and weaker in intensity.

- The condition for minima in single-slit diffraction is $a\sin\theta = n\lambda$
for $n = \pm 1, \pm 2, \pm 3 \ldots$.

- The condition for maxima other than central maximum in single-slit diffraction is $a\sin\theta = (n + ½)\lambda$. for $n = \pm 1, \pm 2, \pm 3$ .....

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8. **Polarisation:** Restricting the transverse vibrations of light waves to one plane is called polarization.

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9. **Malus Law :** $I = I_0 \cos^2 \theta$

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10. **Brewster's law :** $n = \tan i_B$

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11. **Fresnel distance :** $z_F = \frac{a^2}{\lambda}$