Chapter -10: Wave Optics

1. BASIC WAVE RELATIONS

Wave velocity:

$$v = f\lambda$$

Frequency

$$f = \frac{1}{T}$$

Time period

$$T = \frac{1}{f}$$

Angular frequency

$$\omega = 2\pi f$$

Wave number

$$k = \frac{2\pi}{\lambda}$$

Relation between velocity, angular frequency and wave number

$$v = \frac{\omega}{k}$$

2. EQUATION OF A PROGRESSIVE WAVE

A sinusoidal progressive wave can be represented as:

$$y = A\sin(kx - \omega t + \varphi)$$

3. PHASE DIFFERENCE

Phase difference corresponding to path difference Δ:

$$\varphi = \frac{2\pi\Delta}{\lambda}$$

4. SNELL'S LAW

For refraction from medium 1 to medium 2:

$$\mu_1 \sin i = \mu_2 \sin r$$

Therefore:

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$$

5. RELATIVE REFRACTIVE INDEX

Relative refractive index of medium 2 with respect to medium 1:

$$\mu_{21} = \frac{\mu_2}{\mu_1}$$

Also:

$$\mu_{21} = \frac{v_1}{v_2}$$

and:

$$\mu_{21} = \frac{\lambda_1}{\lambda_2}$$

6. WAVELENGTH IN A MEDIUM

For light entering a medium of refractive index μ:

$$\lambda_m = \frac{\lambda_0}{\mu}$$

7. PRINCIPLE OF SUPERPOSITION

For two waves:

$$y = y_1 + y_2$$

For n waves:

$$y = y_1 + y_2 + y_3 + \ldots + y_n$$

8. INTENSITY AND AMPLITUDE RELATION

$$I \propto A^2$$

9. RESULTANT AMPLITUDE

For two waves of amplitudes a_1 and a_2 with phase difference φ:

$$A = \sqrt{{a_1}^2 + {a_2}^2 + 2a_1a_2\cos\varphi}$$

10. RESULTANT INTENSITY

For two coherent waves:

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\varphi$$

11. MAXIMUM INTENSITY

For constructive interference: $\varphi = 2n\pi$

$$I_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$$

12. MINIMUM INTENSITY

For destructive interference: $\varphi = (2n - 1)\pi$

$$I_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$$

13. EQUAL-INTENSITY INTERFERENCE

If: $I_1 = I_2 = I_0$

Then:

$$I_r = 4I_0 cos^2\left(\frac{\varphi}{2}\right)$$

Maximum intensity

$$I_{max} = 4I_0$$

Minimum intensity

$$I_{min} = 0$$

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14. CONDITIONS OF INTERFERENCE

Constructive Interference

Phase condition:

$$\varphi = 2n\pi$$

Path condition:

$$\Delta = n\lambda$$

Where, n = 0, $\pm 1;\ \pm 2;\ \pm 3;\ ----$

Result: **Bright fringe**

Destructive Interference

Phase condition:

$$\varphi = (2n-1)\pi$$

Path condition:

$$\Delta = (2n-1)\frac{\lambda}{2}$$

Result: **Dark fringe**

Where: n = $\pm 1;\ \pm 2;\ \pm 3;\ -----$

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15. VISIBILITY OF FRINGES

Visibility:

$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

For two interfering waves:

$$V = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2}$$

For equal intensities:

$$V = I$$

Thus, maximum visibility occurs when:

$$I_1 = I_2$$

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16. PATH DIFFERENCE IN YDSE

Exact geometrical relation:

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

For small angle: $\sin\theta \approx \tan\theta$ and:

$\tan\theta = y/D$

Therefore:

$$\Delta = \frac{yd}{D}$$

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17. BRIGHT FRINGE IN YDSE

Condition: $\Delta = n\lambda$

$$(y_n)_{bright} = \frac{nD\lambda}{d}$$

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18. DARK FRINGE IN YDSE

Condition: $\Delta = (2n - 1)\lambda/2$

$$(y_n)_{dark} = \frac{(2n-1)D\lambda}{2d}$$

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19. FRINGE WIDTH

Fringe width is the distance between two successive bright fringes or two successive dark fringes.

$$\beta = \frac{D\lambda}{d}$$

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20. ANGULAR FRINGE WIDTH

Angular fringe width:

$$\Delta\theta = \frac{\lambda}{d}$$

Relation between linear and angular fringe width:

$$\beta = D\Delta\theta$$

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21. YDSE IN A MEDIUM

If refractive index of medium is μ:

$$\mu_m = \frac{\lambda_0}{\mu}$$

Therefore:

$$\beta_m = \frac{\beta_0}{\mu}$$

Thus: $\beta_m < \beta_0$ for $\mu > 1$.

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22. YDSE RATIO FORMULA

For two different situations:

$\beta_1 = \lambda_1 D_1/d_1$

$\beta_2 = \lambda_2 D_2/d_2$

Therefore:

$$\frac{\beta_2}{\beta_1} = \frac{D_2\lambda_2 d_1}{D_1\lambda_1 d_2}$$

This is particularly useful for NEET/JEE numerical problems.

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23. DIFFRACTION OF LIGHT

Diffraction is the bending or spreading of light waves around obstacles or through narrow apertures.

Diffraction becomes appreciable when:

$$a \approx \lambda$$

Where: a = slit width

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24. SINGLE-SLIT DIFFRACTION

For a single slit of width a:

Path difference:

$$\Delta = a \sin\theta$$

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25. ANGULAR WIDTH OF CENTRAL MAXIMUM

First minimum occurs at approximately:

$\theta_1 \approx \lambda/a$

Therefore, central maximum extends from $-\theta_1$ to $+\theta_1$.

$$\Delta\theta \approx \frac{2\lambda}{a}$$

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26. LINEAR WIDTH OF CENTRAL MAXIMUM

For a screen at distance D:

$$W = \frac{2D\lambda}{a}$$

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27. INTERFERENCE vs DIFFRACTION

Interference

$\beta = \lambda D/d$

Diffraction

$W = 2\lambda D/a$

Remember:

d → YDSE slit separation

a → Diffraction slit width

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28. Position of nth Secondary Minima in Diffraction Pattern

$$y_n = \frac{nD\lambda}{a}$$

29. Position of nth Secondary Maxima in Diffraction Pattern

$$y_n = \frac{(2n-1)D\lambda}{2a}$$

30. MALUS' LAW

If plane-polarised light of intensity I_0 falls on an analyser at angle θ:

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

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31. UNPOLARISED LIGHT THROUGH A POLARISER

For ideal polariser: **$I = I_0/2$**

Where I_0 is the intensity of incident unpolarised light.

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32. POLARISER + ANALYSER

For unpolarised light of intensity I_0:

After polariser: $I_1 = I_0/2$

After analyser: **$I = (I_0/2)\cos^2\theta$**

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33. CROSSED POLAROIDS

If: $\theta = 90°$ then: $I = (I_0/2)\cos^2 90°$

Therefore: **$I = 0$**

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34. THREE-POLAROID ARRANGEMENT

If first and third Polaroids are crossed and the middle Polaroid makes angle θ with the first:

$I = (I_0/8)\sin^2 2\theta$

Maximum transmission occurs at: **$\theta = 45°$**

Maximum intensity: **$I_{max} = I_0/8$**

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35. BREWSTER'S LAW

At the polarising angle i_p: **$\mu = \tan i_p$**

For light travelling from medium 1 to medium 2: **$n_2/n_1 = \tan i_p$**

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36. BREWSTER ANGLE CONDITION

At Brewster angle: **$i_p + r = 90°$**

Therefore: **Reflected ray ⊥ Refracted ray**
