Theories of light and Interference

Important paints

Theories of Light

• Newton’s Corpuscular theory (1675)
• Christian Huygen’s Wave theory (1678)
• Maxwell’s Electromagnetic theory (1864)
• Max Planck’s Quantum theory (1901)

Huygen’s wave construction
Electromagnetic Wave

Blackbody Spectrum
Hertz Experiment

60 cm

Plate
Rod
Spark Gap
Wires to Spark Coil
Polished brass knobs

3 cm
Metal Ring
Interference of light

COHERENT SOURCES
Two sources of light are said to be ‘coherent’ if they emit waves of same frequency (or wavelength) and are either in phase or have a constant initial phase difference.

- Two real images of the same source. Ex: Young’s double slit experiment.
- One real and one virtual image (sources) Ex: Lloyd’s mirror.
- Two images from a parent source. Ex: sodium vapour lamps
- Two virtual images of a source Ex: Fresnel’s Biprism.

Method of Interference

- By division of wavefront
  Ex. Young’s double slit experiment
- By division of amplitude
  Ex. Newton’s rings, air wedge
Intensity Relations

Whenever constructive interference takes place, \( I \) is max, as \( I \propto |R^2| \)

\[
I_{\text{max}} = (\sqrt{I_a} + \sqrt{I_b})^2
\]

\( \text{Or} \)

\[
R_{\text{max}}^2 = (a + b)^2
\]

Whenever destructive interference takes place \( I \) is min, as \( I \propto |R^2| \)

\[
I_{\text{min}} = (\sqrt{I_a} - \sqrt{I_b})^2
\]

\( \text{Or} \)

\[
R_{\text{min}}^2 = (a - b)^2
\]

\[
\frac{I_{\text{max}}}{I_{\text{min}}} = \frac{(\sqrt{I_a} + \sqrt{I_b})^2}{(\sqrt{I_a} - \sqrt{I_b})^2} = \frac{(a + b)^2}{(a - b)^2}
\]

- If \( a = b \) then \( \sqrt{I_a} = \sqrt{I_b} \), \( \frac{I_{\text{max}}}{I_{\text{min}}} = \frac{(2\sqrt{I_a})^2}{0} = \frac{(2a)^2}{0} : \infty \)

- In general, \( I_{\text{max}} = 4a^2 = 4I_a \)
- \( I_{\text{min}} = 0 \)
- For better contrast \( a = b \), or \( I_a = I_b \)
Amplitude Ratio

\[ \frac{I_{\text{max}}}{I_{\text{min}}} = \frac{(\sqrt{I_a} + \sqrt{I_b})^2}{(\sqrt{I_a} - \sqrt{I_b})^2} = \frac{(a + b)^2}{(a - b)^2} = \left( \frac{a}{b} + 1 \right)^2 \left( \frac{a}{b} - 1 \right)^2 \]

\[ a/b = r, \text{ the amplitude ratio} \]

\[ \therefore \frac{I_{\text{max}}}{I_{\text{min}}} = \frac{(r + 1)^2}{(r - 1)^2} \]

Relation between the intensity of light source and the width of the source

If ‘w’ be the width of the source, then intensity \( I \propto W \)

\[ \therefore \frac{I_a}{I_b} = \frac{W_a}{W_b} \]

but \( I_a \propto a^2 \)

\[ I_b \propto b^2 \]

\[ \Rightarrow \frac{a^2}{b^2} = \frac{w_a}{w_b} \quad \text{OR} \quad \frac{a}{b} = \sqrt{\frac{w_a}{w_b}} \]
The average intensity of light on the screen in the absence of interference is

\[ I_{\text{avg}} = \frac{I_{\text{max}} + I_{\text{min}}}{2} = \frac{4I_0 + O}{2} \]

\[ I_{\text{avg}} = 2I_0 \]

Hence, the screen would be illuminated uniformly with uniform intensity of \(2I_0\)

Important observations of Young’s experiment

- If one of the two slits is closed, the interference pattern disappears.
- If white light is used as parent source, then fringes can be coloured and of unequal width.
- If two independent sources are used instead of coherent sources coming from single source, then interference pattern is not permanent and positions of bright and dark fringe do not remain fixed.
Whenever a transparent sheet of thickness ‘t’ and RI ‘n’ is placed in the path of one of the interfering beams, then

1. The fringe pattern shifts,
2. The fringe pattern shifts towards the same side as that of the plate,
3. The shift, \[ S = \frac{\beta}{\lambda} (n - 1)t \]
   \[ \text{or} \quad \frac{D}{d} (n - 1)t \]
4. The number of fringes shifts \[ m = \frac{(n - 1)t}{\lambda} \]
5. The fringe width remains same and if opaque plate is placed fringe pattern disappears.

Interference due to thin films

Reflected system: The path difference between two successive reflected rays is given by \[ x = 2nt \cos r \]
Reflection from the surface of denser medium involves an additional path difference \( \frac{\lambda}{2} \).
\[ \therefore \text{The exact path difference is} = 2nt \cos r - \frac{\lambda}{2} \]
For maxima,
\[ 2n \cdot t \cos r - \frac{\lambda}{2} = m\lambda \]
or \[ 2n \cdot t \cos r = m\lambda + \frac{\lambda}{2} = (2m + 1) \frac{\lambda}{2} \]
m = 0, 1, 2, 3, ……

For minima
\[ 2n \cdot t \cos r - \frac{\lambda}{2} = \frac{(2m + 1)\lambda}{2} \]
or \[ 2n \cdot t \cos r = \frac{(2m + 1)\lambda}{2} + \frac{\lambda}{2} = (m + 1)\lambda \]
as m is a whole number, m + 1 = m \text{ is an integer}
\[ \therefore 2n \cdot t \cos r = m^1 \lambda \]

TRANSMITTED SYSTEM

Here there is no additional path difference
For maxima, \( 2n \cdot t \cos r = m\lambda \)
m = 0, 1, 2, 3, …… an integer

for minima, \( 2n \cdot t \cos r = \)
\[ \frac{(2m + 1)\lambda}{2} \]
m = 0, 1, 2, 3, …… an integer
Newton’s rings due to reflected beam of light

• The radius of $m^{th}$ bright ring is,

$$ r = \sqrt{\frac{(2m+1)R\lambda}{2}} \quad (R \gg r) $$

• The difference in the radii between the $m^{th}$ bright ring and $(m+1)^{th}$ bright ring is

$$ r = \frac{1}{2} \sqrt{\frac{R\lambda}{m}} $$

• The area between the adjacent bright rings is given by

$$ A = \pi\lambda R $$
Theories of Light and Interference

Questions for practice

1. Wavefront originating from a point source is
   1) cylindrical  2) spherical  3) plane  4) cubical

2. Huygen’s wave theory of light could not explain
   1) diffraction  2) interference  3) polarization  4) photoelectric effect

3. The fact that light is transverse wave derives its evidence by the support from the observation that
   1) light travels as waves  2) light shows polarizing effects
   3) light can be diffracted  4) light waves undergo reflection

4. Velocity of light according to this theory, is greater in denser medium than in rarer medium:
   1) Corpuscular theory  2) Wave theory
   3) Electromagnetic theory  4) Quantum theory

5. The velocity of light in vacuum is
   1) \( \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \)  2) \( \sqrt{\frac{\mu_0}{\varepsilon_0}} \)
   3) \( \sqrt{\mu_0 \varepsilon_0} \)  4) \( \sqrt{\frac{\varepsilon_0}{\mu_0}} \)

6. According to the modern theory for nature of light, the light has
   1) Wave nature only  2) Particle nature only
   3) Both wave and particle (dual nature)  4) Neither particle nature nor wave nature

7. Which one among the following shows particle nature of light
   1) Photo electric effect  2) Interference  3) Refraction  4) Polarization

8. In Young’s double slit experiment, the distance between two slits is made three times then the fringe width will become---
   1) 9 times  2) \( \frac{1}{9} \) times  3) 3 times  4) \( \frac{1}{3} \) times

9. The intensity ratio of two waves is 9 : 1 these waves produce the event of interference. The ratio of maximum to minimum intensity will be
   1) 1 : 9  2) 9 : 1  3) 1 : 4  4) 4 : 1

10. The refractive index of air is 1.003. The thickness of air column which can accommodate one wave of wave length 6000 Å more than in vacuum will be
    1) 2 m  2) 2 cm  3) 2 mm  4) 0.2 m
11. In Young’s double slit experiment, if one of the slits is closed then what change in the pattern is observed?

1) Interference pattern will be obtained instead of diffraction pattern.
2) Diffraction pattern will be obtained instead of interference pattern.
3) Uniform illumination will be obtained.
4) Alternate bright and dark interference rings will be obtained.

12. In Young’s double slit experiment the amplitudes of two sources are 3a and a respectively. The ratio of intensities of bright and dark fringes will be

1) 3 : 1  
2) 2 : 1  
3) 4 : 1  
4) 9 : 1

13. The two coherent light sources will produce constructive interference if they differ in phase by

1) 2\pi  
2) \pi/2  
3) 3\pi/2  
4) 5\pi/2

14. The ratio of maximum and minimum intensities obtained in the interference of waves emitted by two coherent sources is 121 : 81. The ratio of amplitudes of two coherent sources will be

1) 1 : 10  
2) 10 : 1  
3) 81 : 121  
4) 121 : 81

15. The two coherent sources of intensity ratio 2 : 8 produce an interference pattern. The values of maximum intensities will be respectively

1) I_1 and 9 I_1  
2) 9I_1 and I_1  
3) 2 I_1 and 8 I_1  
4) 8 I_1 and 2 I_1

16. The equations of two light waves are

\[ y_1 = 6 \cos \omega t, \quad y_2 = 8 \cos(\omega t + \phi) \]

The ratio of maximum to minimum intensities produced by the superposition of these wave will be

1) 49 : 1  
2) 1 : 49  
3) 1 : 7  
4) 7 : 1

17. In Young’s double slit experiment 10\textsuperscript{th} order maximum is obtained at the point of observation in the interference pattern for \( \lambda = 7000 \) Å. If the source is replaced by another one of wavelength 5000 Å then the order of maximum at the same point will be.

1) 12\textsuperscript{th}  
2) 14\textsuperscript{th}  
3) 16\textsuperscript{th}  
4) 18\textsuperscript{th}

18. When a mica sheet (\( \mu = 1.6 \)) of thickness 7 microns is placed in the path of one of interfering beams in the biprism experiment then the central fringe gets shifted at the position of seventh bright fringe. The wavelength of light used will be.

1) 4000 Å  
2) 5000 Å  
3) 6000 Å  
4) 7000 Å

19. In a double slit experiment the intensity of each wave producing interference is \( I_o \). Then the resultant intensity I will be.

1) \( 4 I_o \cos^2 \frac{\phi}{2} \)  
2) \( 4 I_o \sin^2 \frac{\phi}{2} \)  
3) \( 4 I_o \tan^2 \frac{\phi}{2} \)  
4) \( 2 I_o \cos^2 \frac{\phi}{2} \)

20. The equations of two interfering waves are

\[ y_1 = a \sin \omega t, \quad y_2 = a \sin(\omega t + \theta) \]

Constructive interference will take place at the point of observation if the value of \( \theta \) is

1) \( \pi \)  
2) \( 3 \pi \)  
3) \( 2 \pi \)  
4) \( 5 \pi \)
21. As shown in the figure Q, above point O is the position of the first bright fringe. On the other side of O, D is the position of 11th bright fringe with respect to Q. If the wavelength of light used is 6000 Å then the value of \( S_1B \) will be.

1) \( 6 \times 10^{-4} \) m
2) \( 6 \times 10^{-2} \) m
3) \( 6 \times 10^{-3} \) m
4) \( 6 \times 10^{-6} \) m

22. When a plastic thin film of refractive index 1.45 is placed in the path of one of the interfering waves then the central fringe is displaced through width of five fringes. The thickness of the film will be, if the wavelength of light is 5890Å.

1) \( 6.544 \times 10^{-4} \) cm
2) \( 6.544 \times 10^{-4} \) cm
3) \( 6.54 \times 10^{-4} \) cm
4) \( 6.5 \times 10^{-4} \) cm

23. The intensity variation in the interference pattern obtained with the help of two coherent sources is 5% of the average intensity. The ratio of intensities of two sources will be.

1) 1 : 1600
2) 1680 : 1
3) 1 : 400
4) 400 : 1

24. If the distance between two slits is halved then, the fringe width, as compared to its initial value, becomes

1) half
2) double
3) one fourth
4) four times

25. Interference event is observed in

1) only transverse waves
2) only longitudinal waves
3) both types of waves
4) not observed in both type of waves

26. In Young’s double slit experiment if the maximum intensity of light is \( I_{\text{max}} \) then the intensity at path difference \( \frac{\lambda}{2} \) will be---

1) \( I_{\text{max}} \)
2) \( \frac{I_{\text{max}}}{2} \)
3) \( \frac{I_{\text{max}}}{4} \)
4) zero

27. The correct curve between fringe width \( \beta \) and distance between the slits (d) is

28. If in Young’s double slit experiment, the distance between the slits is halved and the distance between slit and screen is doubled, then the fringe width will become

1) half
2) double
3) four times
4) unchanged
29. The fringe width for red colour as compared to that for violet colour is approximately

1) Three times  2) double  3) four times  4) eight times.

30. The oil layer on the surface of water appears coloured due to interference. For this effect to be visible the thickness of oil layer will be

1) 1 mm  2) 1 cm  3) 100 Å  4) 10000 Å

31. What will be the distance between two slits which when illuminated by light of wavelength 5000Å produce fringes of width 0.5 mm on a screen distant 1 m from the slits?

1) $10^{-2}$ m  2) $10^{-3}$ m  3) $10^{-4}$ m  4) $10^{-6}$ m

32. The equations of waves emitted by $s_1$, $s_2$, $s_3$ and $s_4$ are respectively $y_1 = 20 \sin(100 \pi t)$, $y_2 = 20 \cos(200 \pi t)$, $y_3 = 20 \cos(100 \pi t)$ and $y_4 = 20 \cos(200 \pi t)$. The phenomenon of interference will be produced by—

1) $y_1$ and $y_2$  2) $y_2$ and $y_3$  3) $y_1$ and $y_3$  4) Interference is not possible

33. The Young's double slit experiment is performed in succession using blue light of wavelength 4360 Å and green light of wavelength 5460 Å. If the distance of fourth maximum from central maximum is $x$, then

1) $X_{\text{blue}} > X_{\text{green}}$  2) $X_{\text{blue}} < X_{\text{green}}$  3) $X_{\text{blue}} = X_{\text{green}}$  4) $\frac{X_{\text{blue}}}{X_{\text{green}}} = \frac{5460}{4360}$

34. In Young's double slit experiment the slits are illuminated by white light. The distance between two slits is $b$ and screen is $d$ distance apart from the slits. Some wavelengths are missing on the screen in front of one of the slits. These wavelengths are—

1) $\lambda = \frac{b^2}{d}, \frac{b^2}{3d}$  2) $\lambda = \frac{2b^2}{d}$  3) $\lambda = \frac{2b^2}{2d}$  4) $\lambda = \frac{b^2}{d}, \frac{b^2}{2d}$

35. Two independent monochromatic sodium lamps can not produce interference because

1) The frequencies of two sources are different
2) The phase difference between two sources changes with respect to time
3) The two sources become coherent
4) The amplitudes of two sources are different.

36. In Young's slit experiment one slit is covered with red filter and another slit is covered by green filter, then the interference pattern will be

1) red  2) green  3) yellow  4) invisible

37. In double slit experiment the distance between two slits is 0.6 mm and these are illuminated with light of wavelength 4800Å. The angular width of dark fringe on the screen distant 1.20 m from slits will be

1) $8 \times 10^{-4}$ Radian  2) $6 \times 10^{-4}$ Radian
3) $4 \times 10^{-4}$ Radian  4) $16 \times 10^{-4}$ Radian
38. In Young’s experiment the distance between two slits is \( \frac{d}{3} \) and the distance between the screen and the slits is 3D. The number of fringes in \( \frac{1}{3} \) m on the screen, formed by monochromatic light of wave length \( 3\lambda \), will be—

\[
1) \frac{d}{9D\lambda} \quad 2) \frac{d}{27D\lambda} \quad 3) \frac{d}{81D\lambda} \quad 4) \frac{d}{D\lambda}
\]

39. The experimental arrangement of Young’s double slit experiment is shown in the following figure. If \( \lambda \) is the wavelength of light used, the fringe width will be—

\[
1) \frac{\lambda\theta}{\theta} \quad 2) \frac{2\lambda}{\theta} \quad 3) \frac{\lambda}{2\theta} \quad 4) \frac{\lambda}{\theta}
\]

40. White light is incident normally on a thin film of refractive index 1.5. The minimum thickness of the film so that the wavelength 6000Å is absent in the reflected light, will be—

\[
1) 2000 \text{ Å} \quad 2) 4000 \text{ Å} \quad 3) 8000 \text{ Å} \quad 4) 16000 \text{ Å}
\]