PHYSICAL OPTICS

THEORIES OF LIGHT :

1. **Nature of light :** Light is a form of energy. To explain the nature of light, different theories were proposed. Newton's Corpuscular theory, Huygen's Wave theory, Maxwell's electromagnetic theory and Max-Planck's Quantum theory.
2. **Newton's corpuscular theory :** According to Newton's corpuscular theory light consists of tiny invisible particles, moving with velocity of light. They are known as **corpuscles**. They are highly elastic and gravitational effects on them can be neglected. The colour of the light depends on the size of corpuscles.
   This theory suggests that velocity of light is more in denser medium. Rectilinear propagation of light is the strong basis of this theory. However this theory could not explain interference, diffraction and polarization of light.
3. **Huygen's wave theory :** According to Huygen's light propagates in the form of longitudinal mechanical waves. For the propagation of these mechanical waves, Huygen's proposed the existence of medium called ether which is present everywhere. The colour of the light depends upon the wavelength of these waves. According to Huygen's theory velocity of light is more in rarer medium. That is later verified by Focault's experiment. This theory could explain interference, diffraction and polarization. But the properties of polarization and photoelectric effect, Compton effect could not be explained on the basis of this theory.
4. **Electromagnetic theory :** Maxwell proposed that light is an electromagnetic wave but not mechanical. So it does not require a material medium. According to this theory electromagnetic wave is composed of electric and magnetic fields, varying at right angles. These variations propagate in vacuum perpendicular to the field. This theory could not explain photoelectric and Compton effects.
5. **Planck's quantum theory :** Max Planck proposed his quantum theory to explain the black body radiation. According to this theory light consists of photons which are quantized energy packets. The energy of a photon is known as **Quantum**. Photons have dual nature of light and particle.

Optical phenomena explained (√) or not explained (X) by the different theories of light.

Sr. No.	Phenomena	Theory				
		Corpu-scular	Wave	E.M. wave	Quan-tum	Dual
1.	Rectilinear Propagation	√	√	√	√	√
2.	Reflection	√	√	√	√	√
3.	Refraction	√	√	√	√	√
4.	Dispersion	X	√	√	X	√
5.	Interference	X	√	√	X	√
6.	Diffraction	X	√	√	X	√
7.	Polarisation	X	√	√	X	√
8.	Double refraction	X	√	√	X	√
9.	Doppler's effect	X	√	√	X	√
10.	Photoelec-tric effect	X	X	X	√	√
11.	Compton effect	X	X	X	√	√
12.	Raman effect	X	X	X	√	√

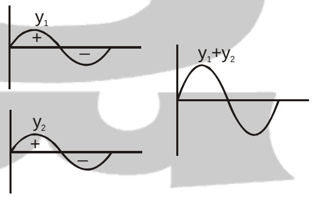
6. **Wavefront :** Wavefront is defined as the locus of the particles of the medium which are in the same state of vibration.
7. The line along which energy is propagated is called **a ray**. It is perpendicular to wavefront at any point.

<u>Types of wavefront :</u>

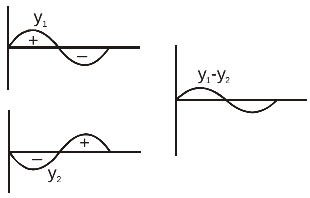
8. **Spherical wavefront :** A wavefront due to a point source in a three dimensional isotropic space is called spherical wavefront. In case of spherical wavefront intensity varies as $1/r^2$.
9. **Cylindrical wavefront :** If the source is a linear source of light, the wavefront is a cylindrical wavefront. In case of cylindrical wavefront intensity varies as 1/r.
10. **Plane wavefront :** When the source is at infinite distance, the radius of curvature of wavefront will be very large. A small portion of spherical wavefront with source at infinite distance is a plane wavefront. In case of plane wavefront intensity is constant.
11. **Huygen's principle :** Each point on the wavefront becomes a source of secondary disturbance and sends secondary wavelets which travels with the same speed as that of the original waves.
12. A surface tangential to all these secondary wavelets is the new wavefront. Huygen's theory explained satisfactorily phenomena like reflection, refraction, interference and diffraction of light.
13. Secondary wavelets spread out as spherical secondary wavefronts with the speed of light.
14. The tangential surface to all the secondary wavefronts gives the new wavefront.
15. The intensity of the secondary wavefront is given by $I=I_0(1+\cos\phi)$ where ϕ is the angle between the original direction of propagation and the direction of observation. This shows that the secondary wavefront has zero intensity in the backward direction.

Principle of superposition of light waves :

16. When two or more than two waves superimpose over each other at a common point of the medium then the resultant displacement (y) of the particle is equal to the vector sum of the displacements (y_1 and y_2) produced by individual waves i.e., $\vec{y}=\vec{y}_1+\vec{y}_2$.



17. When the displacement due to two wave are in the same direction (i.e., same phase) then resultant displacement is $y = y_1 + y_2$.
18. When the displacement due to two waves are mutually in opposite direction (i.e., opposite phase) then resultant displacement will be $y = y_1 - y_2$.



If two waves are represented by $y_1=a_1\sin(\omega t)$ and $y_2=a_2\sin(\omega t+\phi)$, the resultant wave equation is $y=y_1+y_2=A\sin(\omega t+\theta)$ where the resultant amplitude $A=\sqrt{a_1^2+a_2^2+2a_1a_2\cos\phi}$ and phase angle $\theta=\text{Tan}^{-1}\left(\frac{a_2\sin\phi}{a_1+a_2\cos\phi}\right)$

The resultant wave is also a harmonic wave of the same frequency. The resultant wave amplitude A will be maximum when $\cos\phi=1$ i.e., when $\phi=2n\pi$, n=0, 1, 2, …..

$A_{max}=a_1+a_2$

The interference is then said to be **constructive**.

The resultant wave amplitude will be minimum when $\cos\phi=-1$, i.e., when $\phi=(2n+1)\pi$, n=0, 1, 2,..

$A_{min}=|a_1-a_2|$

The interference is then said to be **destructive**.

Non coherent and coherent sources of light :

19. Non coherent sources – Two sources of light, whose frequencies are not same and phase difference between the waves emitted by which does not remain constant with respect to time, are defined as non coherent sources.
20. The light emitted by two independent sources (candles, bulbs etc.) is non-coherent and interference phenomenon cannot be produced by such two sources.
21. The intensity of light or positions of fringes keep or changing in 10^{-8} second.
22. **Coherent sources –** The two sources of light, whose frequencies (or wavelength λ) are same and the phase difference between the waves emitted by which remains constant with respect to time are defined as coherent sources.
23. They are obtained from the same single source.
24. These can be apparent or real.
25. Laser light is highly coherent and monochromatic.
26. The distance between them is small.
27. Their state of polarization is the same.
28. These sources are of two types (i) Spatial coherent sources, (ii) Temporal coherent sources.
29. There are two methods of obtaining these sources (i) Division of wave front, (ii) Division of amplitude

Comparative study of two methods :

Division of wavefront	Division of amplitude
The light source is narrow.	Light source is extended.
The wavefront emitted by a narrow source is divided in two parts by reflection or refraction.	The amplitude of wave emitted by an extend source of light is divided in two parts by partial reflection and partial refraction.
The coherent sources obtained are imaginary. E.g., Fresnel's biprism, Llyod's mirror, Young's double slit etc.	The coherent sources obtained are real. E.g., Newton's rings, Michelson's interferometer colours in thin films.

30. In **Young's double slit** experiment two points of the same wavefront are used as two coherent sources where as in **Fresnel's biprism** two virtual images of same original source are used as two coherent sources.
31. In **Lloyd's** one original source and its image are used as coherent sources.

Interference of light :

32. When two light waves of nearly same amplitude, same frequency and traveling in the same direction of medium, superimpose over each other then there occurs variation of intensity of light with distance (maximum and minimum). This phenomenon is defined as interference of light.
33. The experiment on interference of light was first performed by Young in 1802.
34. The energy or intensity of light gets redistributed non uniformly as a result of superposition of the light waves.
35. Interference is observed in both longitudinal as well as transverse waves.
36. In interference phenomenon energy in neither created nor destroyed rather there occurs redistribution of energy in the form of maxima and minima.
37. The interference of light takes place in two waves. (1) Constructive interference.
    (2) Destructive interference.

Constructive interference :

38. The resultant amplitude of wave is equal to the sum of amplitudes of individual waves. $A=a_1+a_2$.
39. The amplitude of resultant wave is maximum.
40. The resultant intensity is more than the sum of intensities of individual waves. i.e., $I=I_1+I_2+2\sqrt{I_1 I_2}$
41. The intensity of resultant wave is maximum. I.e., $I_{max}=(\sqrt{I_1}+\sqrt{I_2})^2$.
42. The phase difference between two waves is an even multiple of π, i.e., $\phi = 2n\pi$ where n=0, 1, 2..
43. The path difference between two waves is an integral multiple of λ; i.e., $x=n\lambda$ where n=0, 1, 2,…
44. The time interval between two waves is an even multiple of T/2 i.e., $\tau = 2n\left(\frac{T}{2}\right)$ where n=0, 1, 2…

Destructive interference :

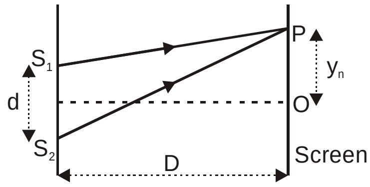
45. The resultant amplitude of wave is equal to the difference of amplitude of two waves. $A=a_1-a_2$
46. The amplitude of resultant wave is minimum.
47. The resultant intensity is less than the sum of intensities due individual waves. i.e., $I=I_1+I_2-2\sqrt{I_1 I_2}$.
48. The intensity of resultant waves is minimum. i.e., $I_{min}=(\sqrt{I_1}-\sqrt{I_2})^2$.
49. The phase difference between two waves is an odd multiple of π i.e., $\phi = (2n-1)\pi$ where n=1, 2, 3….
50. The path difference between two waves is an odd multiple of $\lambda/2$, i.e., $x = (2n-1)\frac{\lambda}{2}$ where n=1, 2, ..
51. The time interval between two waves is an odd multiple of T/2, i.e., $\tau = (2n-1)\frac{T}{2}$ where n=1, 2, 3..

Conditions for sustained interference pattern :

52. The source of light must be monochromatic.
53. Two sources of light must be coherent.
54. Frequencies (wavelength, time period) of two waves must be same.
55. The amplitudes of two waves must be nearly equal otherwise the contrast between two light sources and the screen must be large.
56. The distance between two light sources must be small and the distance between the source and the screen must be large.
57. The two coherent sources must be narrow.
58. If the two light waves are polarized then their states of polarization must be same.
59. The two light waves must travel in the same direction.
60. if the source of light is white, then the path difference between the waves emitted by it must be small.
61. The vibrations of two waves must be in the same direction.

Shape of the fringes :

62. The alternate bright and dark strips obtained on the screen as a result of interference are known as interference fringes.



63. The interference fringes are **hyperbolic** in shape, because the focus of path difference ($S_2P–S_1P$) for a given value of n is a hyperbola. The foci of this hyperbola are S_1 and S_2.
64. Fringes will be straight if D>>d.
65. **Fringe of zeroth order –** The fringe obtained at the centre of screen is known as zeroth order fringe. The distance of other fringes are measured from this central fringe.
66. The distance of n[th] bright fringe from central fringe $y_n = \frac{nD\lambda}{d}$ where n=0, 1, 2, …..
67. The distance of n[th] dark fringe from central fringe $y_n = (2n-1)\frac{D\lambda}{2d}$ where n=0, 1, 2, …..
68. The production of bright or dark fringes depends upon of path difference ($x=S_2P–S_1P$).
69. If $x=\frac{yd}{D} = n\lambda$, then bright fringes are produced on the screen.
70. If $x = \frac{yd}{D} = (2n-1)\frac{\lambda}{2}$, then dark fringes are produced on the screen.
71. The formation of fringes is in accordance with the law of conservation of energy.
72. The distance between two consecutive bright or consecutive dark fringes is known as **fringe width** β.
73. $\beta = y_{n+1} - y_n = \frac{D\lambda}{d}$.

    $A \propto \sqrt{w}$ where w is width of the slit.

Angular fringe width (ω) :

74. The ratio of fringe width to source screen distance is defined as angular fringe width (ω) i.e., $\omega = \frac{\beta}{D} = \frac{\lambda}{d}$.
75. It has no unit.

Dependence of fringe width :

76. β depends on the wavelength of light used. i.e., $\beta \alpha \lambda$.
77. β depends on the distance between two coherent sources i.e., $\beta \alpha \frac{1}{d}$.
78. β depends on the distance of screen from the source i.e., $\beta \alpha D$. If D is very large, then β will also be large and interference pattern will not be observed.

Fringe visibility (V) :

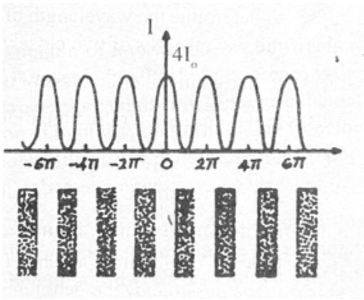
79. $V=\frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2}$.
80. If $I_{min}=0$, then V=1. In this state the fringe visibility will be maximum (best).
81. If $I_{max}=0$, then V=–1.
82. With the help of visibility, knowledge about coherence, fringe contrast and interference pattern is obtained.
83. If $I_{max}=I_{min}$, then V=0. In this condition interference pattern will not be visible.

Resultant intensity :

84. $I=I_1+I_2+2\sqrt{I_1 I_2}\cos\phi$ where ϕ is the phase difference between two waves.

85. $I = a_1^2 + a_2^2 + 2a_1a_2\cos\phi$

86. If $I_1 = I_2 = I_0$, $I = 2I_0[1 + \cos\phi] = 4I_0\cos^2\left(\frac{\phi}{2}\right)$.



Average intensity (I_{av}) :

87. $I_{av} = \frac{I_{max} + I_{min}}{2}$

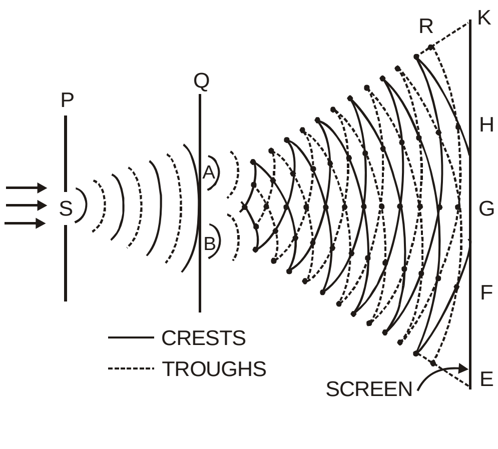
88. $I_{av} = a_1^2 + a_2^2 = I_1 + I_2 = 2I_0$

Difference between monochromatic light fringes and white light fringes :

Monochromatic light fringes	White light fringes
Central fringe is always bright.	Central fringe is always achromatic (white)
There are alternate bright and dark fringes on both sides of central fringe.	When path difference is small then some coloured fringes are obtained on two sides of the central fringe. The outer edge of the fringe is violet and inner edge is red.
The width of all fringes is the same.	The fringe width of different colours is different. $(\beta_R > \beta_V)$
Fringes of higher order are also obtained.	In the region of fringes of higher order uniform illumination is obtained.
The number of fringes obtained is more than that with white light source.	The number of fringes obtained is less than that with monochromatic light source.

Young's double slit experiment :

89. The interference of light was demonstrated for the first time with the help of this experiment.



90. In this experiment a single slit is exposed to two slits.

91. This experiment verifies the wave nature of light.

92. The slit S_1 and S_2 behave as coherent sources.
93. The bright and dark fringes are obtained alternately.
94. The bright fringes are the result of constructive interference whereas dark fringes are the result of destructive interference.
95. The central fringe is bright with monochromatic light whereas it is achromatic (white) with white light.
96. The formation of fringes is explained on the basis of the Huygen's wave theory of light.

Changes observed in the interference pattern obtained in Young's double slit experiment :

97. The fringe width β increases with increase of distance between the source and the screen and vice versa.
98. β decreases by increasing distance between two slits S_1 and S_2 and vice versa.
99. If the experiment is repeated in water instead of air, then λ decreases and consequently β decrease.
100. When S_1 and S_2 both are open, then $I=4a^2=(a_1+a_2)^2$.
101. When one of the slits of S_1 and S_2 is close, then $I=a^2=a_1^2=a_2^2$ in this state interference does not take place and uniform illumination is obtained on the screen.
102. When one slit is fully open and another one is partially open the contrast between the fringes decreases.
103. When the two slits are illuminated by two independent sources then interference fringes are not obtained.
104. If a transparent thin film of mica or glass is put in the path of one the slits (waves) then the whole of interference pattern gets shifted towards the side where film is placed. The distance through which the central fringe gets shifted is $\frac{D}{d}(\mu-1)t$.
105. When one of the slits is closed and width of another is made of the order of λ, then diffraction fringes are observed.
106. When one of the slits is covered with the blue and another one with red transparent papers, the interference pattern is not observed because the wavelengths of two are not same.
107. When slit is illuminated with different colours, then fringes are obtained of the same colour but their fringe width is different.
108. When the distance between the slits $d<\lambda$ then $\beta>D$ i.e., the fringe pattern will not be visible

$$\left[\beta=\frac{D\lambda}{d} \quad \therefore d<\lambda \quad \therefore \beta>D\right]$$

109. When D>>d and white light source is used, then the wavelength absent infront of one of the sources will be $\lambda=\frac{d^2}{D},\frac{d^2}{3D},\frac{d^2}{5D}$

Path difference=(D^2+d^2)–D=$\frac{d^2}{2D}$ of the point.

Path difference for dark fringe $\frac{d^2}{2D}=(2n-1)\frac{\lambda}{2}$

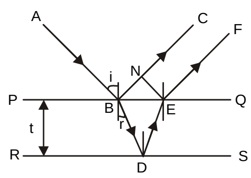
where on putting n=1, 2, 3… the missing wavelengths $\frac{d^2}{D}$, $\frac{d^2}{3D}$ are obtained.

110. If an additional phase difference of π is created in one of the waves then the central fringe becomes dark.

111. **Stoke's Law :** When a light wave is reflected from the surface of an optically denser medium, it suffers a phase change of π but it suffers no change in phase when reflected at the surface of optically rarer medium.

112. A soap film or a thin film of oil spread over water surface, when seen in white light, appears coloured due to interference of light reflected by them. Therefore, the effect path difference is $2\mu t\cos r - \frac{\lambda}{2}$.

113. Consider a thin film of thickness t and refractive index μ bounded by two plane surfaces PQ and RS. A ray of light AB incident on PQ is partly reflected along BC and partly reflected along BC and partly refracted along BD. At D it is again partly reflected along DE. The ray DE is again partly refracted along EF. The path difference between the rays BC and EF is μ(BD+DE)–BN and it is equal to $2\mu t\cos r$. Since the ray AB is reflected at a denser surface ($\mu>1$), it suffers a phase change of π.



For nearly-normal incidence cosr=1 and the conditions of maxima and minima become respectively.

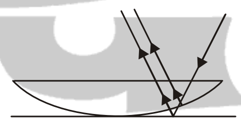
$2\mu t = (2n+1)\frac{\lambda}{2}$, n=0,1,2,… and $2\mu t = n\lambda$, n=0,1,2,….

For near-normal incidence, the intensity of reflected light depends only on thickness. If for a particular thickness the condition of minimum is satisfied, the film will appear dark and the condition of maximum is satisfied, the film will appear bright.

The conditions of maxima and minima in transmitted light are just reverse of the conditions for reflected light.

If white light is used, then the film will appear predominately of that colour for which the condition of maximum is satisfied.

114. **Newton's rings :** When a planoconvex lens of large radius of curvature is placed with its convex surface in contact with a plane glass plate, an air film is formed between the upper surface of the plate and the lower surface of lens.



The thickness of this film increases gradually from the point of contact towards the edge. If a monochromatic beam of light falls normally on this film, alternate dark and bright concentric rings are formed in the air film. These are called Newton's rings. These are formed as a result of interference between the light waves reflected from the upper and lower surface of air film. The center of the Newton's rings pattern is a dark spot when seen in the reflected light and it is a bright spot when seen in the transmitted light.

115. Applications of interference phenomenon :

Interference of light is used

i) to determine the wavelength of a monochromatic light and the difference between the wavelengths of two closely – spaced spectral lines.

ii) to determine the thickness of a thin transparent material.

iii) to determine the refractive index of a liquid or a gas.

iv) to test the flatness of surfaces

v) to test the reflectivity of the surfaces of lenses and prisms.

DIFFRACTION :

1. The phenomenon of bending of light waves around the sharp edges of opaque obstacles or aperture and their encroachment in the geometrical shadow of obstacle or aperture is defined as diffraction of light.
2. The phenomenon resulting from the superposition of secondary wavelets originating from different parts of the same wavefront is defined as diffraction of light.
3. Greater the wavelength of wave higher will be its degree of diffraction i.e., more deviation from its rectilinear path.
4. The phenomenon of diffraction of light waves takes place in the near vicinity of the edge geometrical shadow of the obstacle only whereas the diffraction of sound waves is observed in other parts of geometrical shadow also.
5. Due to low degree of diffraction of light waves, it appears to be propagating in straight lines where as due to high degree of diffraction, sound waves do not travel in straight lines.
6. The phenomenon of diffraction was first discovered by Grimaldi in the year 1665. Its experimental study was done by Newton and Young. But the systematic explanation was given by Fresnel on the basis of Huygen's wave theory of light.
7. Dependence of diffraction of waves – The phenomenon of diffraction depends on (a) the size of the obstacle (b) the wavelength of waves.
8. Necessary conditions of diffraction of waves – The size of the obstacle must be of the order of the wavelength of the waves i.e., $\frac{a}{\lambda} \le 1$.
9. The condition for observing the diffraction at an object (obstacle, narrow slit) on a screen is $D \approx \frac{d^2}{4\lambda}$ where D is the distance between screen and object, d is the size o the object and λ is wavelength of light.
10. The wavelength of sound waves is large (1.65 cm to 16.5 m). Hence the diffraction of sound can be observed in our daily life which occurs due to large obstacles like windows, doors, walls, stem, branches of tree etc.
11. The wavelength of audible sound waves is of order of one metre, hence these are diffracted by ordinary obstacles.
12. The wavelength of ultrasonic waves is of the order of 1 cm. Hence these are not diffracted by ordinary obstacles.
13. The wavelength of light (4800 Å – 8000 Å) is very small. Hence its diffraction is not observed in daily life. But diffraction of light waves can be observed in the laboratory under special circumstances.
14. The wavelength or radio waves is very large (2.5 m – 250 m), hence their diffraction can take place due to large building and small hills. The wavelength of telephone waves is comparatively very small
($\approx$0.3 m), hence their diffraction cannot occur due to large buildings and hills.
15. If the size of the obstacle as compared to the wavelength of the wave is
    a. very small (i.e., $a << \lambda$) then the waves will undergo reflection and not diffraction.
    b. very large (i.e., $a >> \lambda$) then its distinct geometrical shadow will be formed and the wave will not be diffracted.

c. almost equal (i.e, $a \approx \lambda$) then the waves spread maximum in the geometrical shadow and hence undergo maximum diffraction.

16. Consequences of diffraction in daily life :
    a. Sound produced in one room can be heard in the nearby room.
    b. When an intense source of light is viewed with the partially opened eye, colours are observed in the light.
    c. Appearance of a shining circle around the section of sun just before sunrise.

Rectilinear propagation of light :

17. When the diffraction effect is negligible then the law of rectilinear propagation of light is quite valid. i.e., when $a >> \lambda$ then the law of rectilinear propagation is obeyed.
18. When the size of the obstacle or aperture is of the order of wavelength of light then the diffraction effect takes place and light encroaches in the region of geometrical shadow of obstacles thereby deviating from its straight path. Under this condition the rectilinear propagation of light is approximate.
19. The diffraction effect is observed near the edge of the obstacle or the aperture, hence rectilinear propagation is approximately obeyed in this region. Inside the region of geometrical shadow, diffraction effect is not observable and hence the law of rectilinear propagation is perfectly obeyed.
20. Diffraction can be explained by Huygen's –Fresnel principle. According to this principle each point on a wavefront, which is unobstructed, acts as a source of secondary waves. Diffraction is due to interference of secondary waves coming from same primary wavefront.
21. Condition for observing diffraction :

    a) If $\frac{d^2}{D\lambda} << 1$, Fraunhofer diffraction is observed.

    b) If $\frac{d^2}{D\lambda} \approx 1$, Fresnel diffraction is observed.

    c) If $\frac{d^2}{D\lambda} >> 1$, the approximation of geometrical optics is applicable.

Difference between interference and diffraction of light :

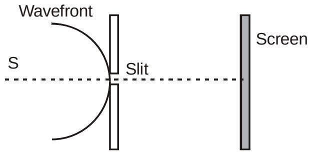
Interference	Diffraction
The phenomenon resulting from the superposition of secondary wavelets originating from two coherent sources is known as interference.	The phenomenon resulting from the superposition of secondary wavelets originating from various parts of a single coherent source is known as diffraction.
Interference fringes are of equal width in case of a monochromatic source whereas these are of unequal width in case of white light.	Diffraction fringes are never of equal width.
All bright fringes are of equal intensity.	The intensity of all bright fringes is not same.
The intensity of all dark fringes is zero, i.e., all dark fringes are perfectly black.	The intensity of dark fringes is not zero i.e., the dark fringes are not perfectly black.

Condition for maxima (a) Path difference $x = 2n\frac{\lambda}{2}$ b) time difference $\tau = 2n\frac{T}{2}$ c) phase difference $\phi = 2n\pi$ where n=0,1,2,3..	Condition for maxima a) $x = (2n-1)\frac{\lambda}{2}$ b) $\tau = (2n-1)\frac{T}{2}$ c) $\phi = (2n-1)\pi$
Condition for minima a) $x = (2n \pm 1)\frac{\lambda}{2}$ b) $\tau = (2n \pm 1)\frac{T}{2}$ c) $\phi = (2n \pm 1)\pi$	Condition for minima a) $x = 2n\frac{\lambda}{2}$ b) $\tau = 2n\frac{T}{2}$ c) $\phi = 2n\pi$

Two classes of diffraction and difference between them :

Fresnel diffraction	**Fraunhofer diffraction**
The diffracting device is at a finite distance from the source and the screen.	The diffracting device is at infinite distance from the source.
The wavefront is either spherical or cylindrical.	The wavefront is a plane one.
The centre of diffraction pattern is either bright or dark depending upon the number of half period zones.	The centre of diffraction pattern is always bright.
Lenses or mirrors are not used to observed diffraction effect.	Two convex lenses are used to observe diffraction effect.
The diffraction pattern is the image of the obstacle or aperture.	The diffraction pattern is the image of the source itself.
In this the distances are important.	In this the inclinations are important.
In this, there is diffraction effect of a single diffraction device i.e., the diffraction effects of devices are not added.	In this the effects of all diffracting devices are added.
The amplitudes at the point of observation due to various HPZ at different obliquities are different. e.g. circular obstacle or aperture etc.	The amplitudes at the point of observation due to various HPZ are the same due to same obliquity. e.g., singles lit, double slit, diffraction grating etc.

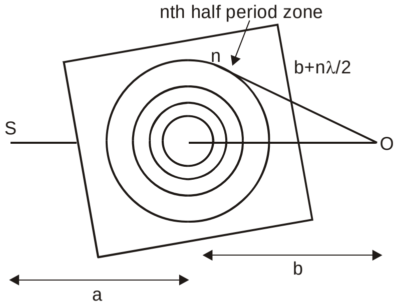
22. **Huygens-Fresnel half period zone theory of diffraction**.



a. The wavefront originating from the source and striking the aperture or obstacle is divided into a number of circular and concentric half period zones.

b. Zone : A small area on a plane wavefront with reference to a point of observation, so that all the waves from the area reach the point without any path difference is called a zone. As the paths of light rays from successive zones differ by $\lambda/2$ these zones are called half period zones.

c. The center of half period zones lies at the point of intersection of the wavefront and the line joining the source and the observer.



d. The outer boundary of n^{th} half period zone is at a distance $b+n\frac{\lambda}{2}$ from the observation point. Here b is the distance of the screen from the slit.

e. The boundaries of the circles bounding n^{th} half period zone lies at distance $b+n\frac{\lambda}{2}$ and $b+(n-1)\frac{\lambda}{2}$ from O.

f. In case of circular half period zones, the area of half period zone $\pi b\lambda$. The areas of all zones are approximately same. The annular region between the $(n-1)^{th}$ and n^{th} circle is known as n^{th} zone.

g. Resultant disturbance produced by the n^{th} zone will be π out of phase with the disturbance produced by $(n-1)^{th}$ (or the $(n+1)^{th}$ zone) zone.

h. The amplitude produced by a particular zone is proportional to the area of the zone and inversely proportional to the distance of the zone from the observation point 'O' (r) and also depends on an obliquity factor which is proportional to $\left(\frac{1+\cos\theta}{2}\right)$ where θ is angle that the normal to the zone makes with 'r'. The net amplitude produced by the secondary wavelets emanating from the n^{th} zone is $A_n = K\frac{a_n}{r}\left(\frac{1+\cos\theta}{2}\right)$

where a_n represents the area of the n^{th} zone.

i. The radius of n^{th} half period zone is $r_n = \sqrt{nb\lambda}$.

j. The light waves originating from the consecutive half period ozone reach O with a path difference of $\lambda/2$ or phase difference 180^o.

k. The amplitude of the light reaching O goes on decreasing as the serial number of half period zones increases.

l. The secondary wavelets from the consecutive half period zones meet at O in the opposite phase.

m. If A_1, A_2, A_3 ….. A_n be the amplitudes of the light waves reaching O from $1^{st}, 2^{nd}, 3^{rd}$…. nth half period zone, then resultant amplitude of the wave at O will be $A=A_1-A_2+A_3-A_4+$……

Here $A_1>A_2>A_3>$……

We can write : $A_2=\frac{A_1+A_3}{2}$, $A_3=\frac{A_2+A_4}{2}$ and so on Hence $A=\frac{A_1}{2}+\frac{A_n}{2}$ when n is odd

And $A=\frac{A_1}{2}+\frac{A_{n-1}}{2}-A_n$ when n is even.

n. Therefore O will be maximum if the total number of half period zones is odd and it will be a minimum when the total number of half period zones is even.

o. In Fraunhoffer diffraction width of central maximum $\beta_0 = \frac{2D\lambda}{d}$.

Applications of diffraction :

i) The wavelengths of either monochromatic or composite radiations can be measured accurately by diffraction technique using diffraction grating.

ii) The wavelength of x-rays are determined by x-ray diffraction.

iii) Structures of crystalline solids are determined by x-ray, electron and neutron diffraction measurements.

iv) Velocity of sound in liquids (organic or inorganic) can be estimated with the help of ultrasonic diffraction techniques.

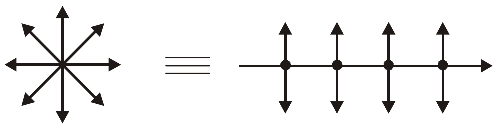
v) Ultrasound scanning used the principle of diffraction to assess the size and shape of ulcers, tumours etc in human body.

Limit of resolution and revolving power of optical instruments :

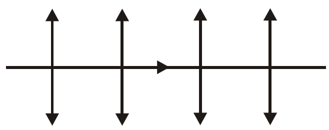
21. Resolving power :
    a. The ability of an optical instrument to produce separate diffraction pattern of two nearby objects is known as resolving power.
    b. The ability of an optical instrument to show two closely lying objects or spectral lines as separate, is known as its resolving power.
22. Limit of resolution – The reciprocal of resolving power is defined as the limit of resolution.
23. Rayleigh's limit of resolution – The distance between two object points, when the central maximum of diffraction pattern of one coincides with the first minimum of diffraction pattern of another, is defined as the Rayleigh's limit of resolution.
24. Limit of resolution $d\theta = \frac{1.22\lambda}{d}$.

POLARIZATION :

1. Light waves :
   Light propagates as transverse electromagnetic waves.
2. Description of light waves :
   The magnitude of electric field vector is much larger as compared to the magnetic field vector. (E=cB where c=speed of light).
   Also, the eye is mainly affected by electric vector, Therefore, we generally prefer to describe light as electric field oscillations.
3. Representation of polarized light :
   Unpolarized light consists of a very large number of vibrations in all planes with equal probability at right angles to the direction of propagation. Hence unpolarized light is represented by star.
4. Unpolarized light :



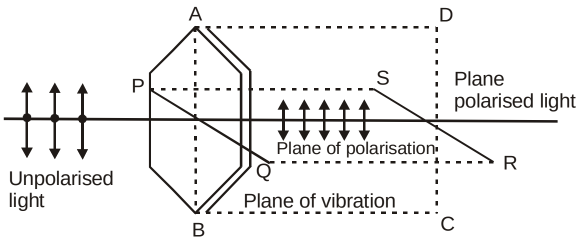
   a) In polarized light the vibrations of electric vector are confined to only one direction perpendicular to the direction of wave propagation.
5. Polarized light :
   a) The light having oscillations only in one plane is called polarized or plane polarized.
   b) If the vibration of electric vector are parallel to the plane of paper then polarized light is represented by arrow lines. They are referred as π components.



   c) If the vibrations of electric vector are perpendicular to the plane of paper, then polarized light is represented by dots. They are referred as σ components.

6. If unpolarized light is incident on a Polaroid, the transmitted light is plane polarized as shown below.

   Here, the vertical oscillations are transmitted because the transmission axis is also vertical. The horizontal oscillations are not transmitted. That is why, on the right hand side there are no dots at the intersection of lines.



7. Plane of vibration – The imaginary plane in a crystal containing the vibrations of electric vector in polarized light as well as the direction of propagation of light wave, is defined as the plane of vibration.
8. Plane of polarization – The imaginary plane in a crystal containing the direction of propagation of light wave and which is perpendicular to the plane of vibration is defined as the plane of polarization.
9. Optic axis – The imaginary axis in a crystal (polarizer), parallel to which the vibrations of electric vector in unpolarized light pass through it, is defined as the optic axis of the crystal.
10. Light can be polarized by transmitting through certain crystals such as tourmaline or polaroids.
11. Polaroids are thin films of ultramicroscopic crystals of quinine idosulphate with their optic axes parallel to each other.
12. Quinine idosulphate is also called herpathite.
13. Polaroids allow the light oscillations parallel to the transmission axis pass through them.
14. The intensity of the transmitted light should be 50% of the incident light. However, in actual practice it is found to be about 35% of the incident light.
15. The crystal or Polaroid on which unpolarized light is incident is called polarizer.
16. Crystal or Polaroid on which polarized light is incident is called analyzer.
17. If the transmission axes of the polarizer and analyzer are parallel, then whole of the polarized light passes through the analyzer.
18. If the transmission axis of the analyzer is perpendicular to that of polarizer, then no light passes through the analyzer.

    Such polarizer and analyzer are said to be crossed.
19. Malus Law :

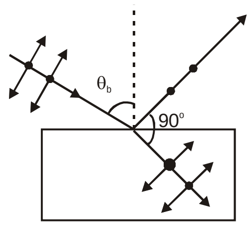
    If I_0 be the intensity of the polarized light incident on the analyzer and θ be the angle between the transmission axes of the polarizer and analyzer, then the intensity of the light transmitted through the analyzer is given by : $I=I_0\cos^2\theta$
20. If A be the amplitude of the light transmitted through the analyzer and A_0 be the amplitude of the polarized light incident on it, then

    $A^2=A_0^2\cos^2\theta$ or $A=A_0\cos\theta$
21. If Ii be the intensity of the unpolarized light incident on the polarizer and I be the intensity of the light transmitted through the analyzer, then

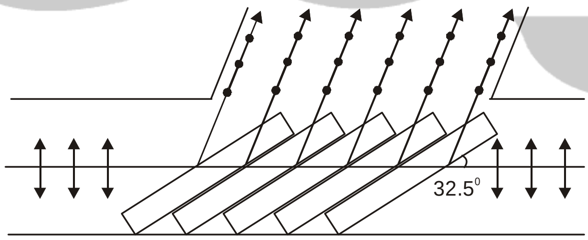
$I_i = \frac{I_i}{2}\cos^2\theta$

Here $I_0 = I_i/2$

22. In the above expressions θ is also angle between the plane of oscillation of the polarized light and the transmission axes of the analyzer.
23. For the crossed polarizer and analyzer, $\theta = 90^o$ hence : $I = I_0 \cos^2 90^o = 0$.
24. Polarization confirms the transverse nature of the light waves.
25. Light can be polarized by the following methods
(i) reflection, (ii) refraction, (iii) double refraction, (iv) dichorism, (v) scattering.
26. Polarization by reflection :



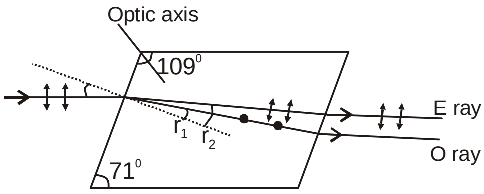
   a) If the light is incident on a surface at a certain angle known at Brewster's angle (θ_b), then the reflected light is completely polarized having oscillations perpendicular to the plane of incidence. The Brewster's angle is also called polarizing angle.
   b) The refracted ray is partially polarized.
   c) When the reflected ray is completely polarized, the angle between the reflected ray and refracted ray is 90^o. Also, the refractive index of the material on which the light is incident is given by $\mu = \tan\theta_b$. Because
   $\mu = \frac{\sin i}{\sin r} = \frac{\sin\theta_b}{\sin(90 - \theta_b)} = \tan\theta_b$ This equation is called Brewster's law.
   d) The polarizing angle θ_b depends on nature of material and wavelength of incident light.
27. Polarization by refraction :
By using a pile of plates a large amount of polarized light can be obtained. Because the refracted light is only partially polarized. So, when it is incident on the next plate, we obtain more polarized light. Every subsequent plate contributes polarized light giving a strong beam of polarized light.



Also, larger the number of plates greater will be the polarization of the refracted beam. This is called polarization by refraction.

Note : The Malus law is not applicable to the pile of plates.

28. Double refraction or Birefringence :
   a) When a ray of unpolarized light is incident on calcite or quartz crystal, it splits into two refracted rays. One of the refracted rays is called ordinary (O-ray) as it obeys the laws of refraction. The other refracted ray is called extraordinary ray (E-ray) because it does not obey the laws of refraction. Double refraction discovered by *bartholinus* in 1669.



b) The E-ray propagates through the crystal with different speeds in different directions. That is, it has different refractive indices in different directions.

c) Along the optic axis of the crystal both O-ray as well as E-ray travel with the same speed and have the same refractive index.

d) Both the O-ray as well as E-ray are plane polarized in mutually perpendicular directions.

e) If v_0 and v_e represent the speed of O-ray and E-ray respectively, and μ_0 and μ_e represent the corresponding refractive indices, then along the optic axis of the crystal $v_e = v_0$ and $\mu_0 = \mu_e$

f) Crystal having only one optic axis is called uniaxial. Calcite, quartz, ice, tourmaline sodium nitrate are the examples of uniaxial crystals.

g) Crystal having two optic axes are called biaxial. Mica, topaz, borax etc. are the examples of biaxial crystals.

h) If a double refracting crystal is placed on a dot and rotated in its own plane, then E-ray image rotates about the O-ray image.

i) For calcite crystal $v_e \geq v_0$ and $\mu_0 \leq \mu_e$

Such crystals are called negative.

j) For quartz crystal $v_e \leq v_0$ and $\mu_0 \geq \mu_e$

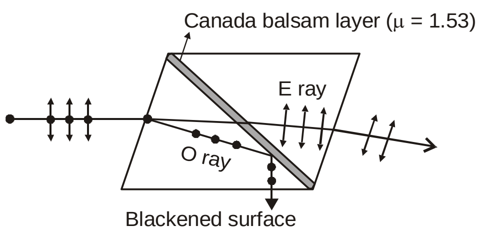
Such crystals are called positive.

k) Polaroids also exhibit double refraction but they absorb one of the two rays. This phenomenon of absorbing either O-ray or E-ray is called dichorism.

l) Nicol prism is a device for producing or analyzing the polarized light. It is made from calcite crystal. It is a doubly refracting crystal.

m) In the Nicol prism the E-ray has oscillations in the principal section of the crystal and the O-ray has oscillation perpendicular to the principal section.

n) By suitable cutting, the transmission of one of the rays is stopped in the nicol prism. Therefore, the light transmitted through it is plane polarized



o) Nicol prism was devised in 1828 by Willam Nicol

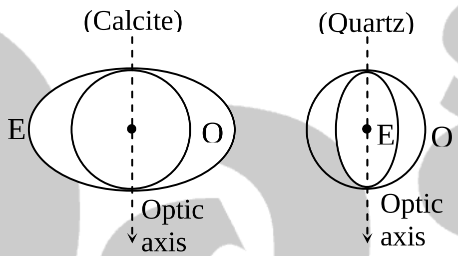
p) In some homogenious transparent media such as glass the speed of light is same in all directions. These media are called optically isotropic media. For these secondary wavelets are spherical.

q) Substances in which speed of light is not same in all directions are called as optically an isotropic media. E.g.: Quartz, Calcite (μ = 1.66), Topaz

29. HUYGEN'S THEORY OF DOUBLE REFRACTION

According to Huygen's theory each point on a wavefront acts as a fresh source of disturbance and sends secondary wavelets. The envelope of all the secondary wavelets at any instant represents a wavefront which is the locus of the particles vibrating in the same phase. Huygen;s theory as such could not explain the phenomenon of double refraction. To explain the phenomenon of double refraction in uniaxial crystals, he extended his thory of secondary wavelets. According to his theory :

1) When any wavefront strikes a doubly refracting crystal, every point of the crystal becomes a source of two wavefronts:
   a) Ordinary wavefront corresponding to ordinary rays. Since ordinary rays have same velocity in all directions, the secondary wavefront is spherical.
   b) Extra-ordinary wavefront corresponding to extra-ordinary rays. Since extra-ordinary rays have different velocities in different directions, the extra-ordinary wavefront is ellipsoid of revolution, with optic axis as the axis of revolution.
2) The sphere and ellipsoid touch each other at points which lie on the optic axis of the crystal, because the velocity of ordinary and extra-ordinary ray is same along the optic axis.



Negative Crystal (a)   Positive Crystal (b)

3) In certain crystals (like calcite and tourmaline) called the negative crystals, the ellipsoid lies outside the sphere as shown in figure (a) This shows that in negative crystals, the extra-ordinary wavefront travels faster than ordinary wavefront except along optic axis.
4) In certain crystals (like those of ice, quartz and rutile) called the positive crystals, the sphere lies outside the ellipsoid as shown in figure (b). This shows that velocity of ordinary wavefront is greater than extraordinary wavefront (in positive crystals) except along optic axis.

30. Polarisation by scattering :

Suppose, a ray of unpolarised light is incident on a microscopic particle from which it is scattered. Then the scattered light is plane polarized.

31. Polaroids :

i) The tourmaline crystal is a natural polarizer.
ii) Man made polarizing materials are called as polaroids.
iii) Polaroid is a thin transparent film containing tiny synthetic dichroic crystals with their optic axes are lined up parallel.
iv) A modern Polaroid is a molecular polarizer containing long chains of molecules of poly vinyle alcohol oriented in a preferred direction and stained with an ink containing iodine.
v) Polaroids are used as polarizers and analyzers.

32. Uses of polaroids :
    1. There are used widely as polarizing sun-glasses.
    2. Polaroid films are used in 3-D films or pictures.
    3. Polaroid sheets are used as polarizers and analysers.
33. Applications of polarization and polarized light:
    1. Polarizing light is used to test and measure the optical activity of crystal and liquids.
    2. Polarized light can be used to study the helical structure of nucleic acids.
    3. Studies of light-scattering estimate depolarization of transversely scattered light and help to study size and shape of the molecules.
    4. Polarizing glasses reduce the intensity of sun light falling on the eye and prevent the damage of retina