ENGINEERING PHYSICS
PHC 01

Odd Semester 2021-2022

NIT Durgapur

Section D

Syllabus

- **Harmonic Oscillations -** Linear superposition principle, Superposition of two perpendicular oscillations having same and different frequencies and phases, Free, Damped and forced vibrations, Equation of motion, Amplitude resonance, Velocity resonance, Quality factor, sharpness of resonance, etc. [8]
- **Wave Motion -** Wave equation, Longitudinal waves, Transverse waves, Electro-magnetic waves. [3]
- **Introductory Quantum Mechanics -** Inadequacy of classical mechanics, Blackbody radiation, Planck's quantum hypothesis, de Broglie's hypothesis, Heisenberg's uncertainty principle and applications, Schrodinger's wave equation and applications to simple problems: Particle in a one dimensional box, Simple harmonic oscillator, Tunnelling effect. [8]
- **Interference & Diffraction -** Huygens' principle, Young's experiment, Superposition of waves, Conditions of sustained Interference, Concepts of coherent sources, Interference by division of wavefront, Interference by division of amplitude with examples, The Michelson interferometer and some problems; Fraunhofer diffraction, Single slit, Multiple slits, Resolving power of grating. [13]
- **Polarisation -** Polarisation, Qualitative discussion on Plane, Circularly and elliptically polarized light, Malus law, Brewster's law, Double refraction (birefringence) - Ordinary and extra-ordinary rays, Optic axis etc.; Polaroid, Nicol prism, Retardation plates and analysis of polarized lights. [5]
- **Laser and Optical Fiber -** Spontaneous and stimulated emission of radiation, Population inversion, Einstein's A & B co-efficient, Optical resonator and pumping methods, He-Ne laser. Optical Fibre– Core and cladding, Total internal reflection, Calculation of numerical aperture and acceptance angle, Applications. [5]

Course Outcomes

- **To realize and apply the fundamental concepts of physics such as superposition principle, simple harmonic motion to real world problems.**
- **Learn about the quantum phenomenon of subatomic particles and its applications to the practical field.**
- **Gain an integrative overview and applications of fundamental optical phenomena such as interference, diffraction and polarization.**
- **Acquire basic knowledge related to the working mechanism of lasers and signal propagation through optical fibers.**

Topic will discuss by S. D.

Interference & Diffraction - Huygens' principle, Young's experiment, Superposition of waves, Conditions of sustained Interference, Concepts of coherent sources, Interference by division of wavefront, Interference by division of amplitude with examples, The Michelson interferometer and some problems; Fraunhofer diffraction, Single slit, Multiple slits, Resolving power of grating. [13]

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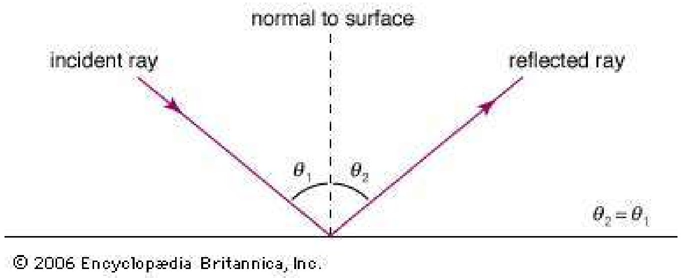
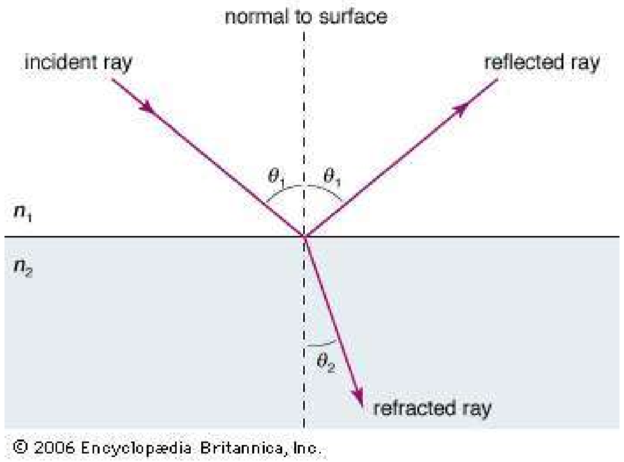
Reference and Suggested Books

Fundamental of Optics, Jankins and White, McGraw-Hill
Optics, A. K. Ghatak, Tata McGraw-Hill
Optics, E. Hecht, Pearson Publication
Lasers and Non-linear Optics, B. B. Laud , New Age International Pvt Lt
A Text Book of Optics, N. Subrahmanyam and Brij Lal, S. Chand & Company
Your choice

Light





Scientist were believed that light is made up of corpuscle (tiny particles).
This assumption was good enough to explain reflection, refraction of light
Does not explain Interference which occurs due to the superposition of two or more lights.

Light has dual nature – particle as well as wave

Wave nature of light

- The phenomena of interference, diffraction, polarization can be explained by the wave motion of light.
- This motion is periodic.
- This type of periodic movement of particles – Simple Harmonic Motion
- a wave is a disturbance that transfers energy through matter or space, with little or no associated mass transfer. Waves consist of oscillations or vibrations of a physical medium or a field, around relatively fixed locations. From the perspective of mathematics, waves, as functions of time and space, are a class of signals.

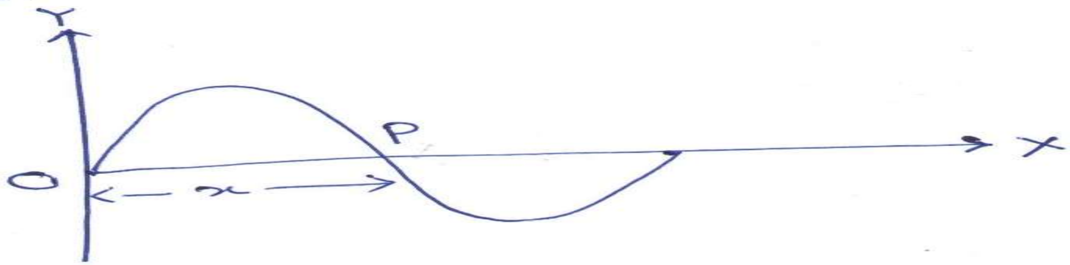
At any instant of time t the displacement of the particle in it is given by

$$y = a \sin \omega t$$
$$= a \sin \frac{2\pi t}{T}$$

where y is displacement, T is time period.

$$\omega = \frac{2\pi}{T}$$

A particle



If the particle has velocity v

Let The particle P at a distance x from the starting point O.

The particle starts vibrating some time later than O, given by $t_1 = \frac{x}{v}$

The displacement ~~at~~ any instant of time t would be same as that of Q is

$$y = a \sin \frac{2\pi}{T} (t - t_1)$$

$$= a \sin 2\pi \left(\frac{t}{T} - \frac{x}{vT} \right)$$

$$= a \sin (\omega t - \delta)$$

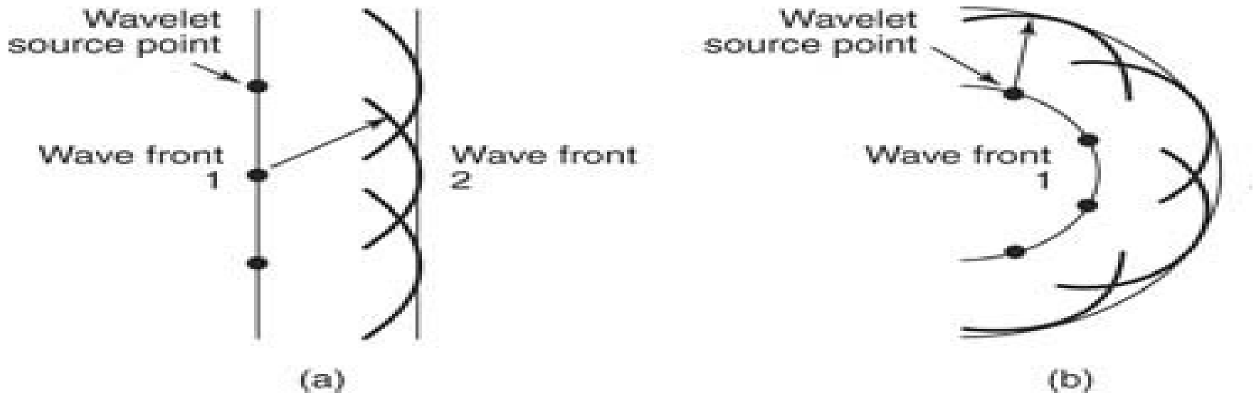
where $vT = \lambda$ is the wavelength

$2\pi \frac{x}{\lambda} = \delta$ is the phase difference

between the particles at O and P.

Huygen's principle

- In 1678 Christian Huygens wrote in ***Traite de la Lumiere*** on the wave theory of light that the wave front of a propagating wave of light at any instant conforms to the envelope of spherical wavelets emanating from every point on the wave front at the prior instant.
- Basically, each point on a wave front can be thought of as a new source of wavelets, and the development of the new wave front at a later time is determined by the propagation of these wavelets.



A

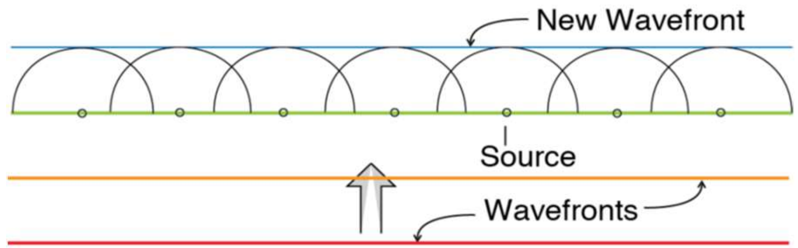
Every point on a wave front is a source of spherical secondary wavelets

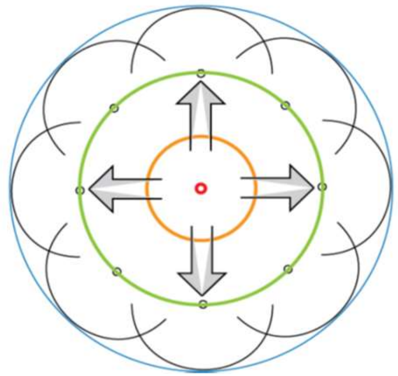
B

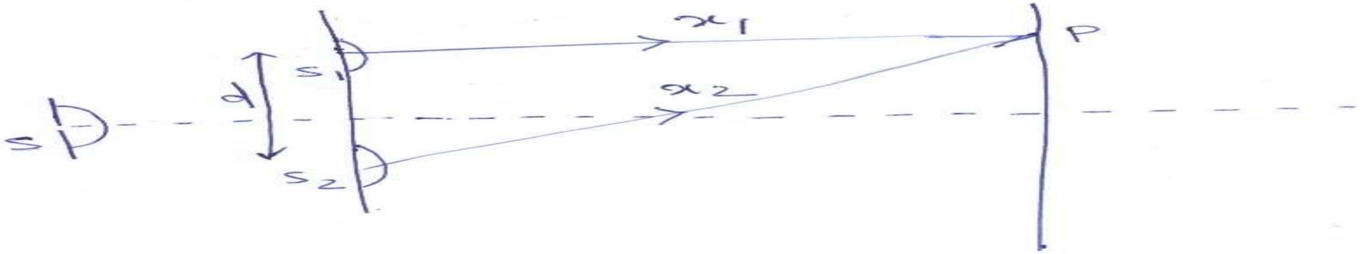
The new wave front is tangent to the secondary wavelet fronts

C

The points on a wavelet front are in phase







Let a_1 and a_2 be the amplitudes of the waves from S_1 and S_2 respectively.

Let S is a narrow slit illuminated by a source. S_1 and S_2 two similar slits which are equidistant from S.

Suppose the waves from S reach S_1 and S_2 in the same phase. Then, beyond S_1 and S_2, the waves proceed as if they started from S_1 and S_2.

The waves arrive at P, having traversed different paths S_1P and S_2P. Hence they are superposed at P with a phase difference δ

Let the instantaneous displacements y_1 and y_2 at P which is at a distance x_1 and x_2 from S_1 and S_2 respectively.

$$y_1 = a_1 \sin 2\pi \left(\frac{t}{T} - \frac{x_1}{\lambda}\right)$$

$$y_2 = a_2 \sin 2\pi \left(\frac{t}{T} - \frac{x_2}{\lambda}\right)$$

$$\delta = \frac{2\pi}{\lambda} \times \text{path difference}$$

$$= \frac{2\pi}{\lambda} (x_2 \sim x_1)$$

By the ~~superposition~~ principle of superposition of waves when two or more waves reach a particle simultaneously, the resultant displacement is equal to the sum of the displacements of all the waves,

$$y = y_1 + y_2$$

$$= a_1 \sin 2\pi\left(\frac{t}{T} - \frac{x_1}{\lambda}\right) + a_2 \sin 2\pi\left(\frac{t}{T} - \frac{x_2}{\lambda}\right)$$

$$= a_1 \sin\frac{2\pi t}{T}\cos\frac{2\pi x_1}{\lambda} - a_1 \cos\frac{2\pi t}{T}\sin\frac{2\pi x_1}{\lambda}$$

$$+ a_2 \sin\frac{2\pi t}{T}\cos\frac{2\pi x_2}{\lambda} - a_2 \cos\frac{2\pi t}{T}\sin\frac{2\pi x_1}{\lambda}$$

$$= \sin\frac{2\pi t}{T}\left(a_1 \cos\frac{2\pi x_1}{\lambda} + a_2 \cos\frac{2\pi x_2}{\lambda}\right)$$

$$- \cos\frac{2\pi t}{T}\left(a_1 \sin\frac{2\pi x_1}{\lambda} + a_2 \sin\frac{2\pi x_2}{\lambda}\right)$$

Let

$$a_1 \cos\frac{2\pi x_1}{\lambda} + a_2 \cos\frac{2\pi x_2}{\lambda} = R\cos\theta \quad \text{—(1)}$$

$$a_1 \sin\frac{2\pi x_1}{\lambda} + a_2 \sin\frac{2\pi x_2}{\lambda} = R\sin\theta \quad \text{—(2)}$$

So

$$y = \sin\frac{2\pi t}{T} R\cos\theta - \cos\frac{2\pi t}{T} R\sin\theta$$

$$= R\sin\left(\frac{2\pi t}{T} - \theta\right)$$

Hence the resultant displacement at P is simple harmonic and of amplitude R.

Squaring equations (1) and (2) and adding

$$R^2\cos^2\theta = a_1^2\cos^2\frac{2\pi x_1}{\lambda} + a_2^2\cos^2\frac{2\pi x_2}{\lambda} + 2a_1a_2\cos()\cos()$$

$$R^2\sin^2\theta = a_1^2\sin^2\frac{2\pi x_1}{\lambda} + a_2^2\sin^2\frac{2\pi x_2}{\lambda} + 2a_1a_2\sin()\sin()$$

$$R^2 = a_1^2 + a_2^2 + 2a_1a_2\left(\cos\frac{2\pi x_1}{\lambda}\cos\frac{2\pi x_2}{\lambda} + \sin\frac{2\pi x_1}{\lambda}\sin\frac{2\pi x_2}{\lambda}\right)$$

$$= a_1^2 + a_2^2 + 2a_1a_2\cos\frac{2\pi}{\lambda}(x_2 - x_1)$$

$$= a_1^2 + a_2^2 + 2a_1a_2\cos\delta$$

The resultant intensity (I) at P

$$I \propto R^2$$

If we take constant of proportionality is 1,

$$I = a_1^2 + a_2^2 + 2a_1a_2 \cos\delta$$

Conditions for maxima

The intensity I is a maximum when $\cos\delta = +1$

phase difference $\delta = 2n\pi$ $\quad n = 0, 1, 2, \ldots$

path difference $= x_2 \sim x_1 = n\lambda$

$$I_{max} = a_1^2 + a_2^2 + 2a_1a_2 = (a_1 + a_2)^2$$

The maximum intensity is greater than the sum of two separate intensities.

Condition for minima

The intensity I is a minimum when $\cos\delta = -1$

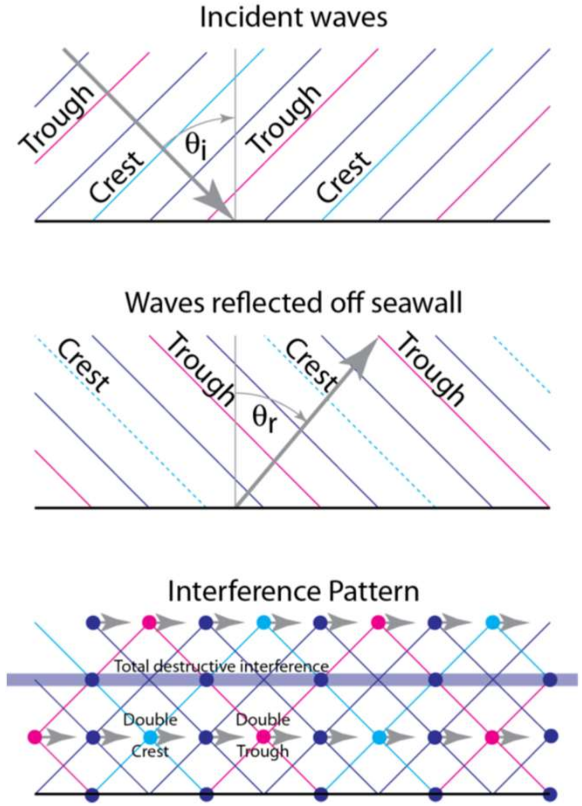
phase difference $\delta = (2n+1)\pi$ $\quad n = 1, 2, 3, \ldots$

path difference $= x_2 \sim x_1 = (2n+1)\frac{\lambda}{2}$

$$I_{min} = a_1^2 + a_2^2 - 2a_1a_2 = (a_1 - a_2)^2$$

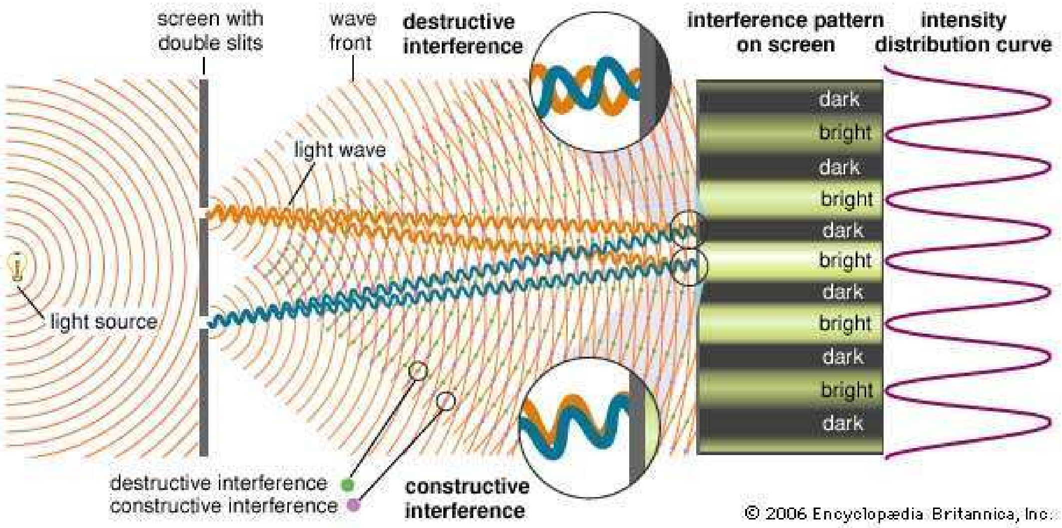
Interference

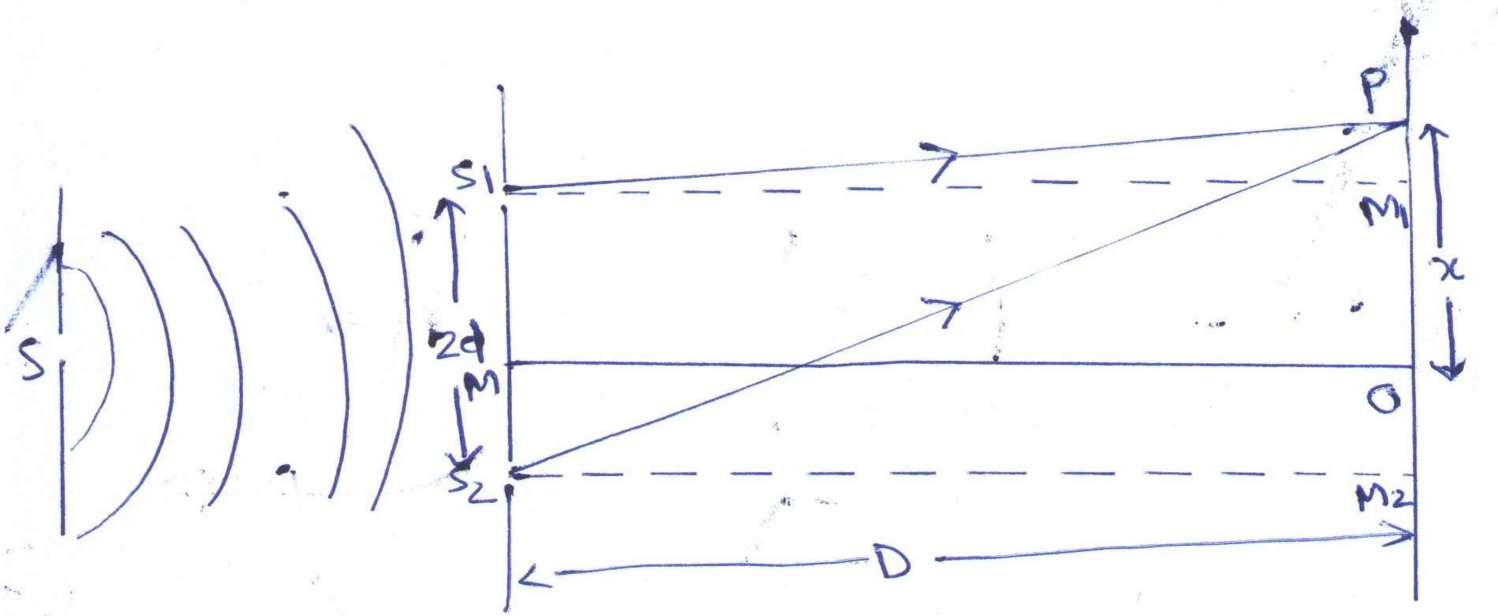
- Light waves from two coherent sources mix up and cross each other's path
- Modification of intensity of light occur in region of crossing
- Interference occurs due to superposition of two or more waves
- The total amplitude of superposed waves at a point will be sum of the amplitudes of the individual waves



Young's experiment

- Thomas Young in 1801 demonstrated the phenomenon of interference of light
- He used sunlight to pass through a pin hole S
- There were two pin holes S1 and S2 placed a considerable distance away from S
- The light from two pin holes was received at screen





P
S1
M1
x
2d
S
M
O
S2
M2
D

Let us join S_1 and S_2 and bisect the line S_1S_2 at M. From M, let us draw a perpendicular MO on the screen. Let P be any point on the screen and let

$$S_1S_2 = 2d$$
$$MO = D$$
$$OP = x$$

To find intensity at P, let us join S_1P and S_2P. The two waves are at P, having traversed different paths S_1P and S_2P. Let us calculate this path difference $S_2P \sim S_1P$.

Let S_1M_1 and S_2M_2 be perpendicular on the screen.

Now $(S_2P)^2 = (S_2M_2)^2 + (PM_2)^2$ for ΔS_2M_2P

$$= D^2 + (x+d)^2$$

$$= D^2\left[1 + \frac{(x+d)^2}{D^2}\right]$$

$$\therefore S_2P = D\left[1 + \frac{(x+d)^2}{D^2}\right]^{1/2}$$

since $D \gg (x+d)$
For expansion

$$= D\left[1 + \frac{1}{2}\frac{(x+d)^2}{D^2}\right]$$

$$= D + \frac{1}{2}\frac{(x+d)^2}{D}$$

Similarly $S_1P = D + \frac{1}{2}\frac{(x-d)^2}{D}$

$$\therefore S_2P \sim S_1P = \frac{1}{2}\left[\frac{(x+d)^2}{D} - \frac{(x-d)^2}{D}\right]$$

$$= \frac{2xd}{D}$$

The intensity at point P is a maximum or minimum depending on path difference as

For maxima $S_2P \sim S_1P = \frac{2xd}{D} = n\lambda$ where $n = 0, 1, 2, \ldots$

$$\text{so, } x = \frac{D}{2d} n\lambda$$

For minima $S_2P \sim S_1P = \frac{2xd}{D} = (2n+1)\frac{\lambda}{2}$ where $n = 0, 1, 2, \ldots$

$$\text{so, } x = \frac{D}{2d}(2n+1)\frac{\lambda}{2}$$

Let x_n and x_{n+1} denote the distances of nth and (n+1)th bright fringes. Then

$$x_n = \frac{D}{2d} n\lambda$$

$$x_{n+1} = \frac{D}{2d}(n+1)\lambda$$

$\therefore$ Spacing between nth and (n+1)th bright fringes is

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

$$= \frac{D}{2d}\lambda$$

Which is independent of n. So, the spacing between any two consecutive bright fringes is the same.

Similarly, spacing between dark fringes is also $\frac{D}{2d}\lambda$.

The spacing between any two consecutive bright or dark fringes is called the fringe width

$$W = \frac{D}{2d} \lambda .$$

Shape of the interference fringes :

Let S_1 and S_2 be two sources which have constant phase difference. At the point P, there is maximum or minimum intensity

$$S_2P - S_1P = n\lambda$$

and $$S_2P - S_1P = (2n+1)\frac{\lambda}{2}$$

Thus for a given value of n, the locus of points of maximum or minimum intensity is a constant.

$$S_2P \sim S_1P = \text{constant}.$$

Condition for sustained interference

- The interfering waves should be coherent, i. e. the phase difference between them must remain constant with time
- The interfering waves should have same frequency
- If the interfering waves are polarized, they must be in the same state of polarization
- The separation between the light sources should be as small as possible
- The distance of the screen from the sources should be large
- The amplitudes of the interfering waves should be equal or comparable
- The sources must be narrow
- The sources should be monochromatic

- The non-uniform distribution of the light intensity due to the superposition of coherent waves is called interference.
- When light sources produce waves having sharply defined phase difference that remains constant with time, are said to be coherent.

Let I_1 and I_2 be the intensities, and a_1 and a_2 the amplitudes of the disturbances from the two coherent sources

$$\frac{a_1}{a_2} = \frac{\sqrt{I_1}}{\sqrt{I_2}} = \sqrt{\alpha} \quad \text{(say)}$$

The maximum and minimum intensities in the interference pattern are given by

$$I_{max} = (a_1 + a_2)^2 \quad \text{and} \quad I_{min} = (a_1 \sim a_2)^2$$

$$I = a_1^2 + a_2^2 + 2a_1a_2\cos\delta$$

average intensity between range $\delta = 0$ to $\delta = 2\pi$ is

$$I_{ave} = \frac{\int_0^{2\pi} I \, d\delta}{\int_0^{2\pi} d\delta}$$

$$= \frac{\int_0^{2\pi} (a_1^2 + a_2^2 + 2a_1a_2\cos\delta)\, d\delta}{\int_0^{2\pi} d\delta}$$

$$= \frac{\left[a_1^2\delta + a_2^2\delta + 2a_1a_2\sin\delta\right]_0^{2\pi}}{[\delta]_0^{2\pi}}$$

$$= (a_1^2 + a_2^2)$$

Concept of coherence

- Coherence is a measure of the correlation between the phases measured at different points on a wave.
- It is of two types - temporal and spatial
- Temporal Coherence is a measure of the correlation of light wave's phase at different points along the direction of propagation – it tells us how monochromatic a source is.
- Spatial Coherence is a measure of the correlation of a light wave's phase at different points transverse to the direction of propagation - it tells us how uniform the phase of a wavefront is.
- No interference is produced by independent sources: Such as two bulbs which have no steady phase difference between light waves emitted from them.
- Obtaining coherence sources of light: If two sources are derived from a single source by some device, then any phase change in one is simultaneously accompanied by same phase change in the other. – the phase difference between two sources remains constant
- Young's double slit, Llyod mirror, Fresnel's double mirror, Fresnel biprism, Michelson's interferometer are examples of some devices for creating coherent sources of light

Temporal coherence

- Temporal coherence - Time interval in which the light resembles a sinusoidal wave. (~10 ns for natural light)
- The amplitude is constant and the phase varies linearly with time.
- The prediction of phase and amplitude is possible over any length of time
- Light sources emit light of short pulses called wave trains
- Different atoms of a source emit radiation in a random fashion there will be no phase relationship between the pulses
- At a given space point, the prediction of phase and amplitude is possible at two different instants of time provided that the same wavepulse is still passing through the point
- Longitudinal coherence length of the wavepulse or coherence length $\Delta l_c = c\Delta t_c$ *c is speed of light*
- *The light is said to be coherent for the time Δt_c which is called coherent time*
- Δt_c is the longest time interval over which prediction of phase and amplitude in a given space is possible

...

- In an interference experiment, we consider two wave fields arriving at a particular space point from a point sources via two different optical paths.
- If the path difference between interfering beams greater than Δl_c - no interference
- Temporal coherence can be related to the line width as $\Delta\nu = \frac{1}{\Delta t_c}$ $\Delta\nu$ is frequency spread or line bandwidth i. e. the width of the spectrum
- Sunlight is temporally very incoherent because its bandwidth is very large (the entire visible spectrum).
- The correlation of the phase of a light wave between different locations – spatial coherence. It is basically concerned with phase correlation between two points in space
- The spatial coherence length is the distance over which the beam wave-fronts remain flat
- The spatial coherence depends on the emitter size and its distance away
- The lateral dimension of the source over which the radiation remains coherent determines the spatial coherence defined as the length in space over which the light has a predictable phase. A laser, for example, has a long coherence length. Although there are random fluctuations in phase over time they occur after the waves have traveled some meters in distance. A incandescent bulb on the other hand, has tremendously fast variations so the phase is predictable over only a very short period of space. Consider the double slit experiment: The interference arises from the difference in path lengths between the two mutually coherence sources of light. For high angles, the path difference can be come very large (multiple wavelengths). For a laser, which has a long coherence length, the two beams will still retain a fixed phase difference between them. For a normal light source, there will be so much difference in distance between the two waves that there will have been time for random phase jumps to occur. So the two sources are essentially mutually incoherent.
- The path difference must be within the coherence length for interference to occur. For a laser, the coherence length is on the order of meters. For an incandescent light bulb, the coherence length is only a few micrometers. For the sun, the coherence length is on the order of millimeters. For some lasers, the coherence length can be many kilometers.

Different type of interference

- Interference by division of wavefront
- Interference by division of amplitude
- Optical devices which divide the incident wavefront into two parts by reflection, refraction or diffraction and thereby give rise to two coherent interfering beams – division of wavefront
- Formation of fringes by biprism, llyod mirror are examples of interference by division of wavefront
- Optical devices which divide the amplitude of incident light wave into two or more parts by partial reflection and refraction and thereby give rise to two or more coherent interfering beams – division of amplitude
- Formation of fringes by thin films, Newton's ring, Michelson's interferometer, Fabre-Perot interferometer are examples of interference by division of amplitude

Interference by thin film

- Newton and Hooke observed and developed an interference phenomenon due to multiple reflections from the surface of thin transparent materials.
- Colors produced by thin film of a soap bubble and mica
- Colors produced by thin film of oil on the surface of water
- Constructive and destructive interference of light waves occurs due to

1. the light from the air reflecting off the top surface
2. Transmitted light from the top and bottom surface of the thin film. The light traveling from the air, through the oil, reflecting off the bottom surface, traveling back through the oil and out into the air again.

- An important consideration in determining whether these waves interfere constructively or destructively is the fact that whenever light reflects off a surface of higher index of refraction, a 180° phase shift in the wave is introduced.