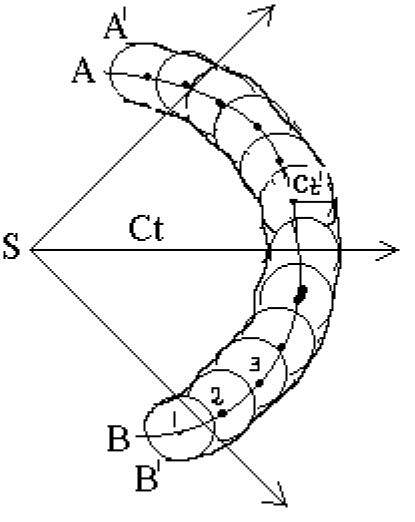
UNIT-V111

WAVE OPTICS

According to Huygen, light is propagated in the form of transverse waves. A source of light sends out waves in all directions through a hypothetical all pervading medium called 'ether'. Consider the light waves start from a source 'S" and travel in all direction with a velocity 'C'. After 't' seconds waves will propagate through a distance Ct and reach surface of an imaginary sphere with source 'S' as centre and Ct as radius. All the particles on the surface of this sphere will be in the same state of vibration or said to have identical phase. The surface of the sphere is called wave front. Wave front at any instant is defined as the locus of all particles, which are in the same phase

As the wave advances the wave front moves parallel to its initial position in a direction perpendicular to the wave front. Any line perpendicular to the wave front is called a ray of light. Depending upon the shape of the light source, its wave front is of different type:- plane wave front. (source at infinite distance), Cylindrical wave front (Slit source) and Spherical wave front (point source).



According to Huygen's principle every point on a wave front is a centre of disturbances. From these points (1,2,3etc) secondary wave propagate in all directions, which travel with same velocity 'C'. After a given interval (say t^1sec) of time an envelope of all these secondary waves gives rise to secondary wave front. Let AB be the primary wave front from a source "S" at an instant 't'. Every point (123) on AB is a source called secondary source. Wave coming from these acquires a radius Ct^1 after t^1 sec. The common surface A^1B^1 give the new wave front at that instant called secondary wave front. Secondary waves appear to move in the backward direction also. It can however be proved that this backward wave front has no physical existence.

Interference.

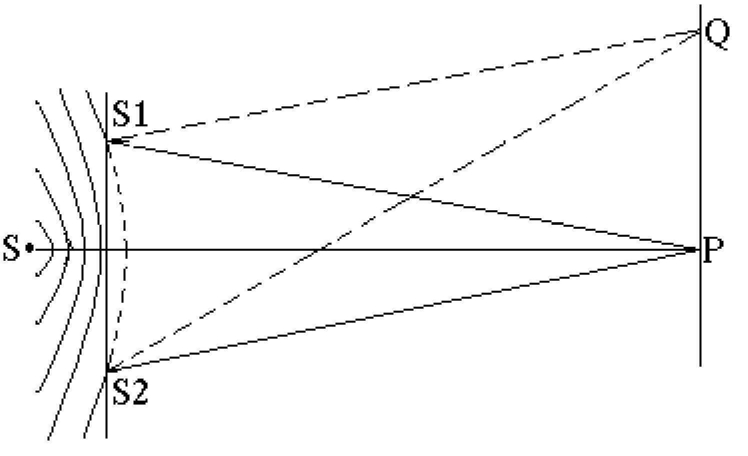
Light energy from an isolated source is uniformly distributed in the surrounding medium. But when light energy emitted from two or more sources, at certain parts where the resultant amplitude due to waves is maximum and at some other points amplitude is minimum, correspondingly intensities are also becomes maximum and minimum.

Thus when there is superposition of two or more waves in a medium there is modification in the distribution of light energy. This phenomenon is called interference.

Coherent sources.

Two sources of light, derived from the same source, which emit light waves of equal amplitude, wave length, and having the same phase (or constant phase difference) are called coherent sources.

'S' is a monochromatic source of light. The semi circles in the figure are wave fronts. S_1 and S_2 are two slits on a screen and act as two independent sources of light. Here source S_1 and S_2 can be considered as coherent sources.

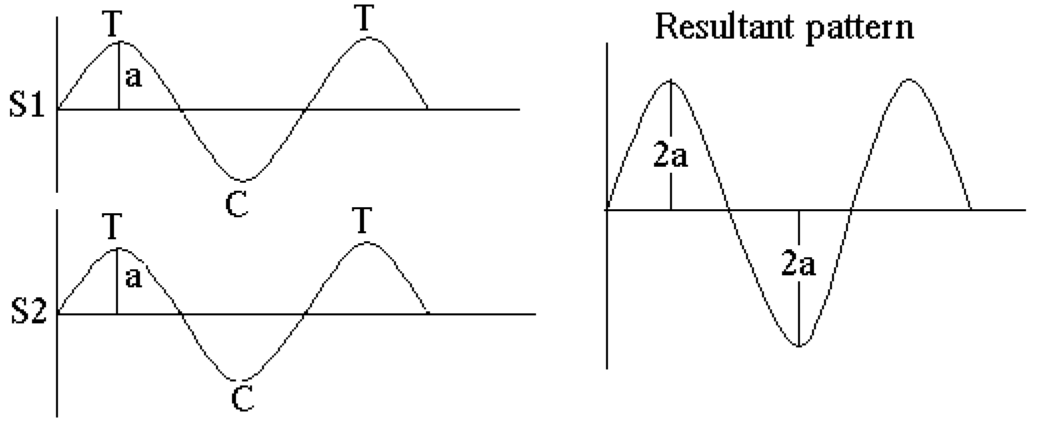


Explain interference based on the principle of superposition. M-00.

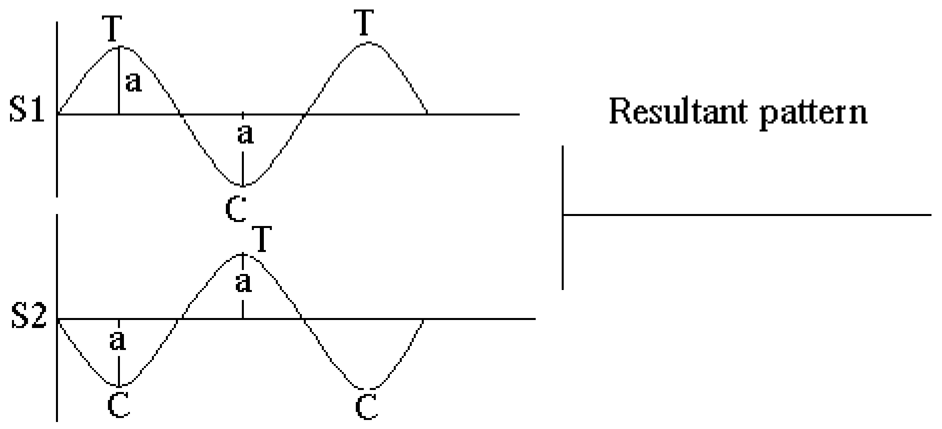
Principle of Superposition.

This principle states that, when two or more waves meet together in a medium, the resultant displacement at any point is the algebraic sum of the displacement of individual waves.

Constructive interference



When waves of same amplitude and wavelength interfere, at points where the crust of a wave falls over the crust of the other wave (trough over trough), the resultant displacement is a maximum. The resultant interference pattern will have double the amplitude (4times the intensities of individual wave) of individual waves. This is called constructive interference.



.Destructive interference.

In this case crust of a wave falls over the trough of other wave, the resultant displacement is zero and hence intensity is zero. This is called destructive interference.

Condition for constructive and destructive interference.

Consider a point 'P', equidistant from the sources. ie $S_1P = S_2P$. The path deference between waves arriving at point P will therefore be zero. Or $S_1P - S_2P = 0$. Hence at point P the two waves are in phase, and resultant amplitude become maximum (constructive interference). This happens when the path difference is λ, 2λ, 3λ and so on.

Therefore condition for maximum displacement (constructive interference) is, $\boldsymbol{\delta = n\lambda}$,

where n = 0, 1, 2, 3,- ---- ---.ie integral multiple of λ.

Now consider point Q, the waves arrive out of phase at Q, hence resultant displacement is zero. ie destructive interference. This is possible if there is path difference of $\lambda/2$, $3\lambda/2$, and so on. We can therefore put condition for destructive interference as path difference, $\boldsymbol{\delta = (2n + 1)\lambda/2}$,

where n = 0, 1, 2,------. ie odd multiple of $\lambda/2$.

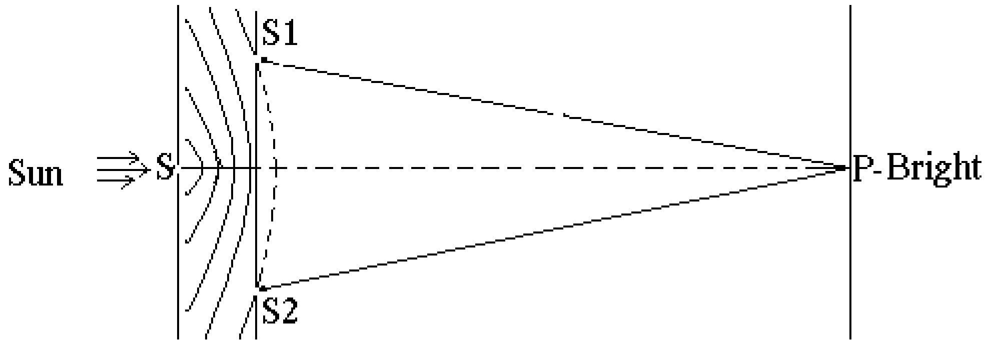
What are the conditions for obtaining good interference pattern? M-96, M-99, S-00

Condition for obtaining good interference pattern.

1) The two sources of light must be coherent (same amplitude, phase, wavelength).
2) The two sources must be monochromatic (same frequency or same colour).
3) The sources should continuously emit light.
4) The sources should be narrow.

5) The distance between the sources should be small.
6) The distance between sources and screen should be large.

Young's double slit experiment.



A pin- hole S is illuminated from the sun. The emergent light is allowed to fall on two more pin- holes S_1 and S_2 close to each other. These two pin- holes act as two coherent sources and give rise to secondary spherical wave fronts. The light emerging from S_1 and S_2 produces a steady interference pattern on the screen. The interference pattern consists of alternative dark and bright bands.

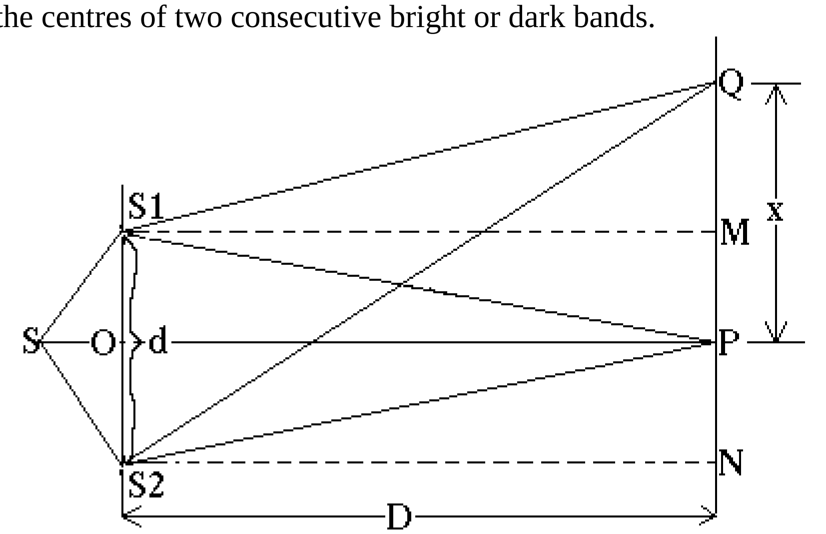
Importance of Young's experiment .

(1) It was the first experiment in which interference of light was observed.
(2) It proved conclusively that light is propagated in the form of waves.

Describe Young's double slit experiment to demonstrate the interference of light waves and deduce an expression for the width of interference bands formed on the screen.S96,97,M99

Expression for bandwidth.

Bandwidth β :- It is the distance between the centres of two consecutive bright or dark bands.



Consider two coherent monochromatic sources S_1 and S_2 separated by a distance 'd'. Let λ be the wavelength of light. 'D' is the distance between screen and sources of light. Perpendicular bisector of S_1S_2 meet the screen at point P. S_1M and S_2N are the perpendiculars drawn from S_1 and S_2 respectively.

Consider a point Q situated at a distance 'x' from point P. join S_1q and S_2Q.

The path difference between the light waves reaching Q is $S_2Q – S_1Q$.

From figure,

$S_2Q^2 = S_2N^2 + NQ^2 = D^2 + (x + d/2)^2$ ----------(1).

$S_1Q^2 = S_1M^2 + MQ^2 = D^2 + (x-d/2)^2$ -----------(2).

(1)–(2) gives, $S_2Q^2 – S_1Q^2 = [D^2 + (x+ d/2)^2] – [D^2 + (x- d/2)^2]$. After simplification we have.

$S_2Q^2 – S_1Q^2 = 2xd$ --------(3).

In practice 'x' and 'd' are very small as compared to D. Hence eqn (3) can be written as

$(S_2Q – S_1Q) (S_2Q + S_1Q) = 2xd$. Therefore path difference = $S_2Q – S_1Q = 2xd/(S_2Q + S_1Q)$.

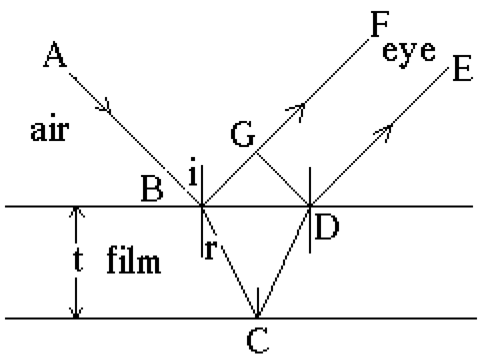
ie Path difference,$\delta = 2xd/(D + D) = 2xd/2D$. Or $\boxed{\delta = xd/D}$ ---------(4).

The point Q will be bright if, $xd/D = n\lambda$, it will be dark if, $xd/D = (2n + 1)\lambda/2$.

The point P is bright since $S_1P – S_2P = 0$. There will be alternate dark and bright bands on either sides of P. Let us consider bright bands. Let Xn be the distance of the n^{th} bright band and (Xn – 1) be the distance of the $(n-1)^{th}$ bright band from point P. Then we can put $Xd/D = n\lambda$.

Or $X_n d/D = n\lambda$. Or $X_n = n\lambda D/d$, and $X_{n-1} = (n-1)\lambda D/d$.
$\therefore$ $X_n - X_{n-1} = n\lambda D/d - (n-1)\lambda D/d$. Or $X_n - X_{n-1} = \lambda D/d$.
But $[X_n - X_{n-1}]$ is the distance between two successive bright bands. This is called bandwidth or fringe width, ie $[X_n - X_{n-1}] = \beta = \lambda D/d$. Or band width, **$\beta = \lambda D/d$**

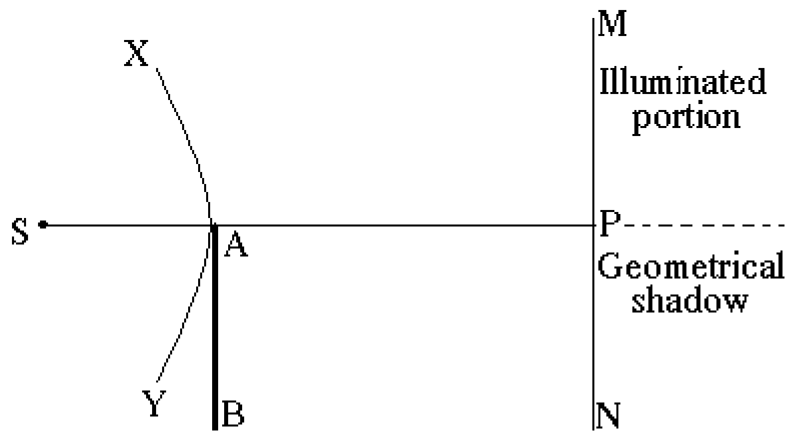
Interference due to thin films



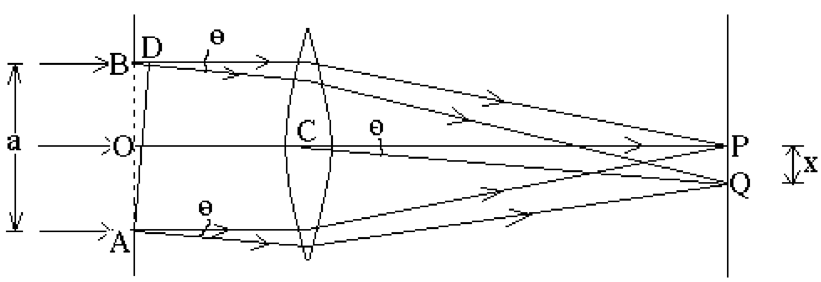
When a soap film or a thin film of oil is viewed in sunlight, they are found to exhibit different colours. These colours are due to the phenomenon of interference.
The rays BF and DE interfere at the focal plane of the observer's eye. Here the path difference,
$\delta = 2nt \cos r$, where 'r' is the angle of refraction-thickness of film, n- refractive index of the material of film. Hence colour depends on thickness of the film and angle of incidence.

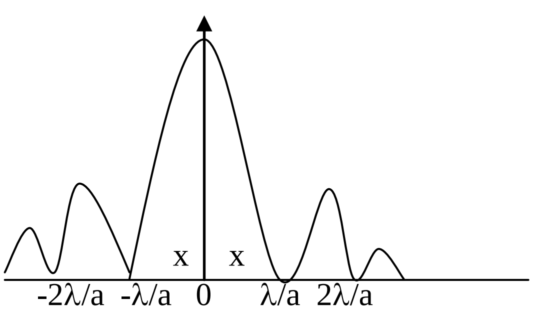
Diffraction.

When light falls on obstacles and if the dimensions of the obstacles are comparable with the wavelength of light, it deviates from its rectilinear path and bends around the corners of the obstacle. The bending of light waves around the corners of the obstacles is called diffraction of light. Diffraction makes light wave spread below the geometrical shadow of the obstacles.



Diffraction due to a single slit.





Consider a plane wave front of monochromatic light incident normally on a narrow slit of width 'a'. The diffracted light is focused on a screen by means of a convex lens.
According to geometrical optics we expect only a sharp image of the slit. But we observe a central bright image and a series of alternative dark and bright bands of decreasing intensity symmetrically on either side of bright image.

According to Huygen's principle, each and every point of the incident wave front acts as an independent source of light. The secondary wave lets coming from different parts of the slit interfere in such a way that maxima and minima are produced in different directions. The condition for minimum intensity is, $a\theta = n\lambda$ Or $\theta = n\lambda/a$, where θ is the diffraction angle corresponding to the n^{th} minimum. For secondary maxima, the condition is $a\theta = (2n + 1)\lambda/2$.

Width of central maximum.

If the lens is very close to the slit (See figure), then $\sin\theta = x/f$, where f is the focal length of the lens.

But, $\sin\theta = \lambda/a$

$\therefore x/f = \lambda/a$ or $x = f\lambda/a$. Since x is the distance of the secondary minima from point P, the width of the central maximum, $\boxed{2x = 2f\lambda/a}$.

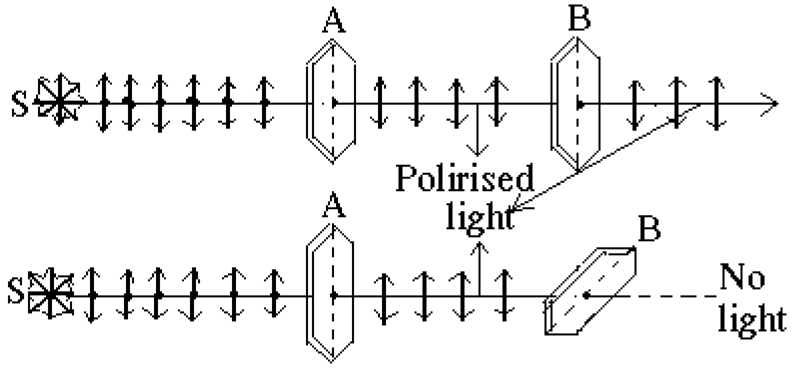
Distinction between interference and diffraction

Interference	Diffraction
Bands are produced by superposition of primary waves. Bandwidths are same. Bands are of uniform dark and bright. Large numbers of fringes are seen.	Bands are produced by superposition of secondary waves after diffraction. Bandwidths are not same. Both dark and bright bands are not uniform. Few numbers of fringes are seen.

Polarisation.

According to electromagnetic theory of light, light is propagation of mutually perpendicular vibrating electric and magnetic vectors. When light passes through certain crystals like tourmaline, or Calcite the vibration of electric vectors is restricted.

The phenomenon due to which the vibrations of light are restricted in a particular or one direction is called polarization of light. Only transverse waves can exhibit polarisation. Therefore, polarisation is the property of light, which revels that, light is a transverse wave.



P (Polarizer) and A (Analyser) are two thin tourmaline crystals, which are cut with their surfaces parallel to the crystallographic (optical) axis. They are placed with their axes parallel to each other and their planes are at right angles to the direction of propagation of light. When ordinary light is passed through this pair, the light intensity is maximum. But as the crystal P is rotated the emergent light shows variation of intensity. When the axes of A are perpendicular to that of P the intensity of light becomes zero and no light is observed.

This experiment shows that light emerging out of first crystal has only unidirectional vibration, hence called plane-polarised light. The plane in which the vibrations of electric vector are confined is called plane of vibration, and the plane perpendicular to the plane of vibration is known as plane of polarisation.

Malus' law

In the above experiment, the intensity of light coming out from the crystal B varies as $I = I_o \cos^2 \theta$, where I_o is the intensity of light coming from A and θ is the angle between the orientation of crystals A and B. This is known as Malus' law.

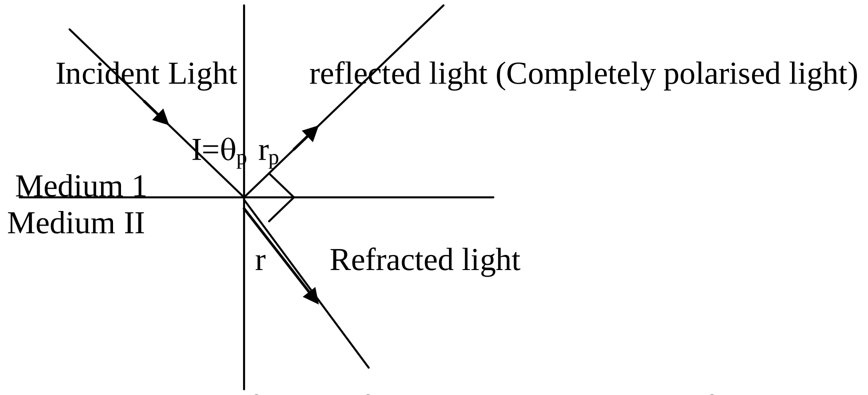
Types of polarisation

1. Linear Polarisation: - Light in the form of a plane wave.
2. Circular Polarisation:- equal amplitude and 90^0 phase difference
3. Elliptical polarisation:- Unequal amplitude and 90^0 or other than 90^0 phase difference

Brewster's angle:-

One of the methods for the production of Polarised light is Reflection (other is scattering).
When ordinary light reflected from a transparent surface the reflected ray is partially plane polarised. Degree of polarization depends on angle of incidence. At particular angle of incidence the reflected ray is completely plane polarised. This particular angle of incidence is called angle of polarization or Brewster's angle. At the polarizing angle reflected ray and refracted ray are perpendicular to each other.

Brewster's law



The law state that tangent of angle of polarization is equal to refractive index of the medium.
According to laws of reflection I = r Or $\theta_p = r_p$-----------(1)

Snell's law gives $\frac{\sin i}{\sin r} = \frac{\sin\theta_p}{\sin r} = n$

From figure, $r_p + 90 + r = 180$

Or $r = 90 - r_p$

Or $\frac{\sin \theta_p}{\sin(90-r_p)} = \frac{\sin\theta_p}{\cos\theta_p} = \mathbf{\tan\theta_p = n}$

Polaroid's:-

Polaroid's are artificially made large sheets capable of producing strong beam of polarized light.

Uses of Polaroid's

1. Used in sunglasses to cut off the glare of sunlight.
2. Used to see three-dimensional motion pictures.
3. Used in headlight and windscreen of cars.
4. Used for producing and analysing plane polarized light.

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