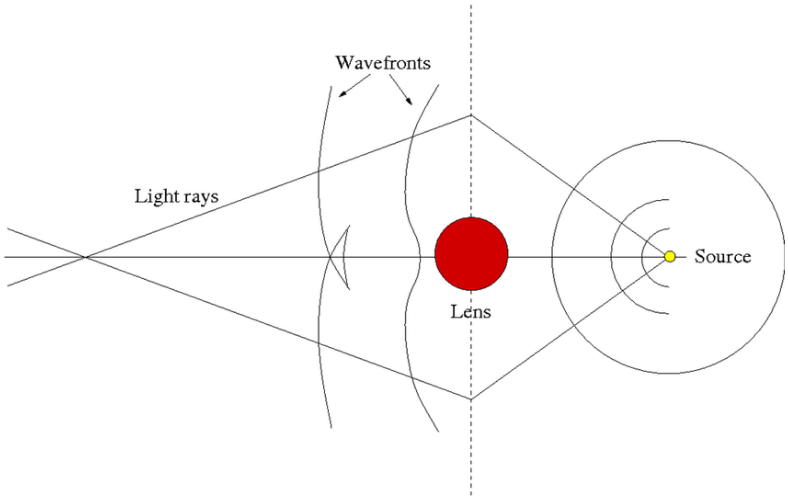
Wave optics.

The phenomenon like interference, diffraction and polarization establishes the wave nature of light. However, the phenomenon like black body radiation and photoelectric effect establishes the particle nature of light. De Broglie suggested that light has a dual nature i.e., it can behave as particles as well as waves.

Wavefront.

A wavefront is defined as the continuous locus of all such particles of the medium which are vibrating in the same phase at any instant. In case of waves travelling in all directions from a point source, the wavefronts are spherical in shape. When the source of light is linear in shape, the wavefronts are cylindrical. At very large distances from the source, a portion of spherical or cylindrical wavefront is plane wavefront.



Ray.

An arrow drawn perpendicular to a wavefront in the direction of propagation of a wave is called a ray.

Two general principles are valid for rays and wavefronts:

(i) Rays are normal to wavefronts.

(ii) The time taken to travel from one wavefront to another is the same along any ray.

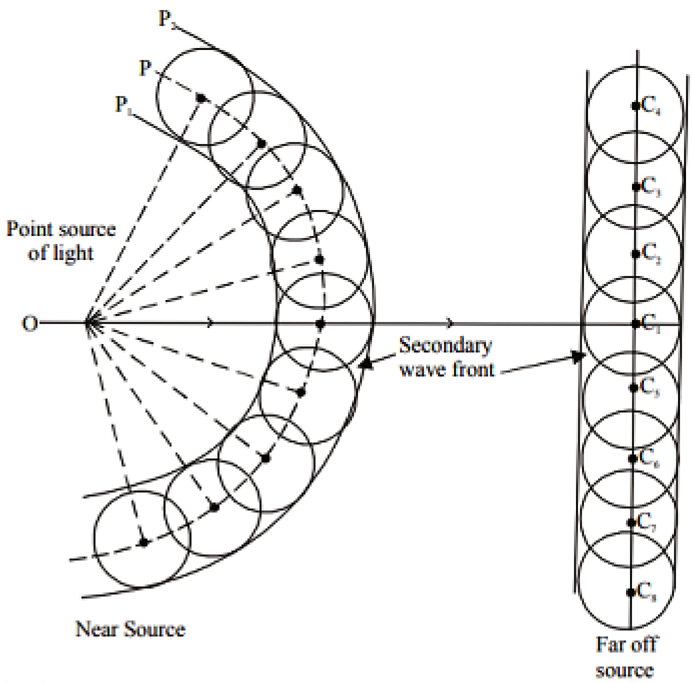
Huygens' principle of secondary wavelets.

Huygens' principle is the basis of the wave theory of light. It tells how a wavefront propagates through a medium. It is based on the following assumptions:

(i) Each point on a wavefront acts as a source of new disturbance called secondary waves of wavelets.

(ii) The secondary wavelets spread out in all directions with the speed of light in the given medium.

(iii) The wavefront at any later time is given by the forward envelope of the secondary wavelets at that time.

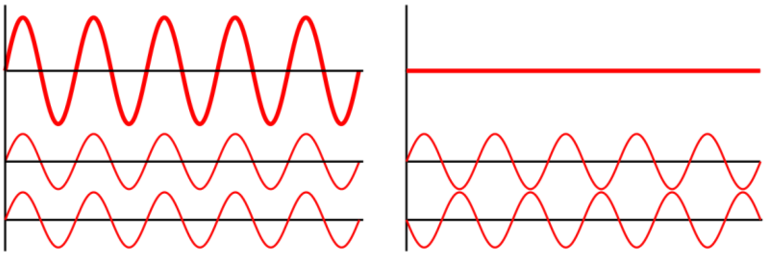


Effect on frequency, wavelength and speed during refraction.

When a light wave travels from one medium to another medium, its frequency remains unchanged but both its wavelength and speed gets changed, depending on the refractive index of the refracting medium.

Interference of light waves.

When light waves from two coherent sources travelling in the same direction superpose each other, the intensity in the region of superposition gets redistributed, becoming maximum at some points and minimum at others. This phenomenon is called interference of light.



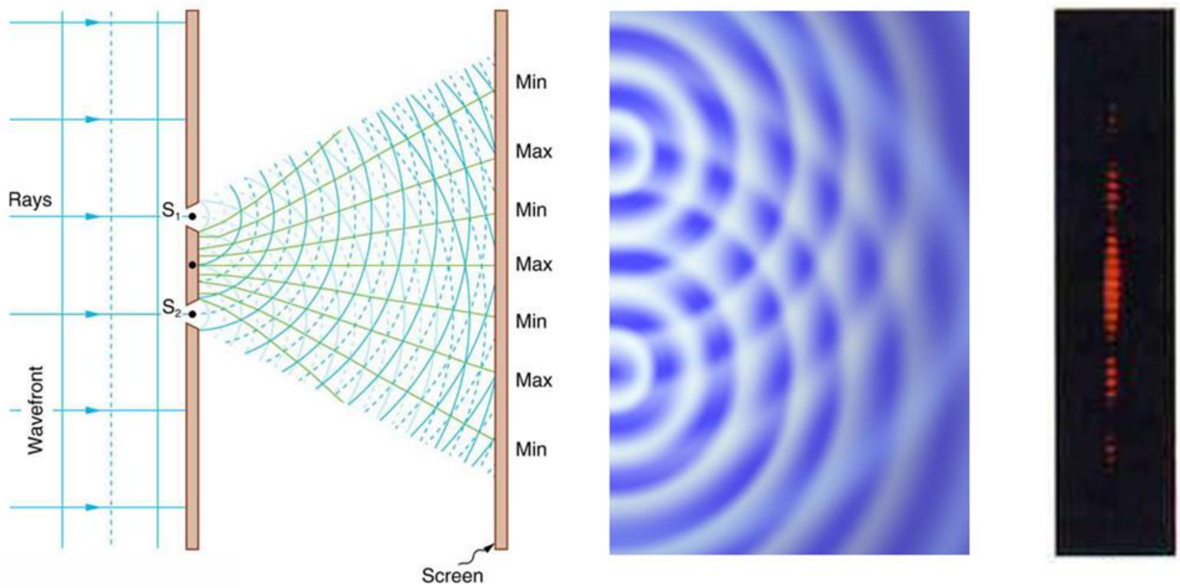
Constructive and destructive interference.

If path difference $p = n\lambda$ or phase difference $\phi = 2n\pi$, the two waves are in same phase and so add up to give maximum of intensity. This is called constructive interference.

If $p = (2n-1)\lambda/2$ or $\phi = (2n-1)\pi$, the two superposing waves are out of phase, the resultant amplitude is equal to difference between their individual amplitudes and hence intensity is minimum. This is called destructive interference.

Young's double slit experiment.

In Young's double slit experiment, two identical narrow slits S_1 and S_2 are placed symmetrically with respect to narrow slit S illuminated with monochromatic light. The interference pattern is obtained on an observation screen placed at large distance D from S_1 and S_2. The distance between S_1 *and* S_2 is d.



(a) (b) (c)

The position of nth bright fringe from the centre of screen is

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

The position of nth dark fringe from the centre of the screen is

$$x'_n = (2n-1)\frac{D\lambda}{2d}$$

Fringe width is the separation between two successive bright or dark fringes and is given by

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

Resultant amplitude and intensity of interfering.

if a_1 and a_2 are the amplitudes and I_1 and I_2 are the intensities of two coherent waves having phase difference ϕ, then their resultant amplitude and intensity at the point of superposition are given by

$$a = \sqrt{a_1^2 + a_2^2 + 2a_1a_2cos\phi}$$

$$and \qquad I = I_1 + I_2 + 2.\sqrt{I_1I_2}\cos\phi$$

If amplitude of each wave is a_0 and intensity I_0, then

$$I = 2ka_0^2(1+cos\ \phi) = 2I_0(1+cos\ \phi)$$

$$= 4I_0\ cos^2\ \frac{\phi}{2}$$

The term $2.\sqrt{I_1I_2}\cos\phi$ is called interference term.

(i) When $\cos\phi$ remains constant with time, the two sources are coherent. The intensity will be maximum at points for which $cos\ \phi = +1$ and minimum at points for which $cos\ \phi = -1$.

(ii) When $cos\ \phi$ varies continuously with time so that its average value is zero over the time interval of measurement, the resultant intensity at all points will be $I_1 + I_2$. No interference fringes are observed. The sources are incoherent.

Ratio of intensity at maxima and minima of an interference pattern.

If a_1 and a_2 are the amplitudes of two interfering waves, then the ratio between the intensities at maxima and minima will be

$$\frac{I_{max}}{I_{min}} = \frac{(a_1+a_2)^2}{(a_1-a_2)^2} = \left(\frac{r+1}{r-1}\right)^2$$

Where $r = \frac{a_1}{a_2} = \sqrt{\frac{I_1}{I_2}}$, is the amplitude ratio of two waves. If w_1 and w_2 are the widths of the two slits, then

$$\frac{w_1}{w_2} = \frac{I_1}{I_2} = \frac{a_1^2}{a_2^2}$$

Coherent sources.

Two sources of light which continuously emit light waves of same frequency (or wavelength) with a zero or constant phase difference between them, are called coherent sources. Two independent sources of light cannot act as coherent sources, they have to be derived from the same parent source.

Conditions for sustained interference.

(i) The two sources should continuously emit waves of same frequency or wavelength.

(ii) The two sources of light should be coherent.

(iii) The amplitudes of the interfering waves should be equal.

(iv) The two sources should be narrow.

(v) The interfering waves must travel nearly along the same direction.

(vi) The sources should be monochromatic.

(vii) The interfering waves should be in the same state of polarization.

(viii) The distance between the two coherent sources should be small and the distance between the two sources and the screen should be large.

Displacement of interference fringes.

When a thin transparent sheet of thickness t and refractive index μ is inserted in the path of one of the interfering beams, the extra path difference introduced is

$$\Delta p = Length\ t\ in\ transparent\ sheet - Length\ t\ in\ air$$

$$or \qquad \Delta p = \mu t - t = (\mu - 1)t$$

Net path difference for any point on the screen

$$= \frac{xd}{D} - (\mu - 1)t$$

For the central point of the screen,

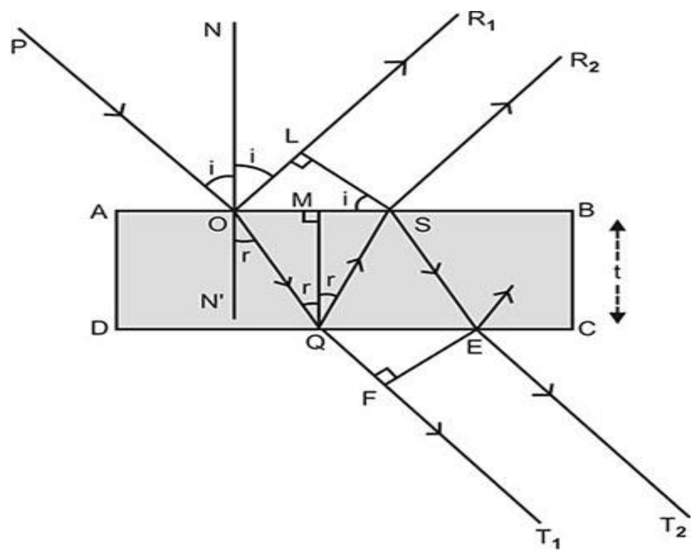
$$\frac{xd}{D} - (\mu - 1)t = 0 \qquad or \qquad x = \frac{D}{d}(\mu - 1)t$$

Thus, the shift in the central bright fringe and hence shift of any other fringe is

$$\Delta x = \frac{D}{d}(\mu - 1)t = \frac{\beta}{\lambda}(\mu - 1)t$$

Interference in thin films.

A soap film or thin film of oil spread over water shows beautiful colors, when seen in the reflected light. This is due to interference between light waves reflected by the upper and lower surfaces of thin films. The ray reflected from the upper denser surface of thin film suffers a phase change of π or path difference of $\lambda/2$



Reflected system. **The path difference between the two consecutive rays reflected from the upper and the lower surfaces of a thin film of refractive index μ and thickness t is given by**

$$p = 2\mu t \cos r - \frac{\lambda}{2}$$

$$For\ maximum\ intensity. \quad 2\mu t \cos r = (2n + 1)\frac{\lambda}{2}$$

$$For\ minimum\ intensity. \quad 2\mu t \cos r = n\lambda$$

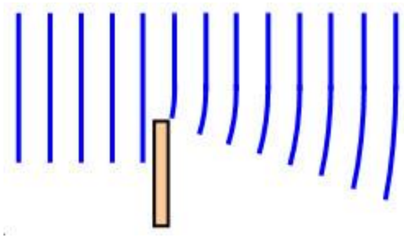
Transmitted system.

$$For\ maximum\ intensity. \quad 2\mu t\cos r = n\lambda$$

$$For\ minimum\ intensity. \quad 2\mu t\cos r = (2n+1)\frac{\lambda}{2}, \quad where\ n = 0, 1, 2, \ldots$$

Diffraction of light.

The phenomenon of bending of light around the corners of small obstacles or apertures and their consequent spreading into the regions of geometrical shadow is called diffraction of light.



Diffraction at a single slit.

A plane wave of wavelength λ on passing through a narrow slit of width a suffers diffraction producing a central fringe ($\theta = 0$), flanked on both sides by minima and maxima. The intensity of secondary maxima decreases with the increase in distance from the centre.

For nth minimum:

$$a\sin\theta_n = n\lambda, \quad n = 1, 2, 3, \ldots$$

For nth secondary maximum:

$$a\sin\theta_n = (2n+1)\lambda/2, \quad n = 1, 2, 3, \ldots$$

Angular position of nth minimum,

$$\theta_n = \frac{n\lambda}{a}$$

Distance of nth minimum from the centre of the screen,

$$x_n = n\frac{D\lambda}{a}$$

Angular position of nth secondary maximum,

$$\theta'_n = (2n+1)\frac{\lambda}{2a}$$

Distance of nth secondary maximum from the centre of the screen,

$$x'_n = (2n+1)\frac{D\lambda}{2a}$$

Width of a secondary maximum,

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

Width of central maximum

$$\beta_0 = 2\beta = \frac{2D\lambda}{a}$$

Angular spread of central maximum on either side of the centre of the screen is

$$\theta = \pm\frac{\lambda}{a}$$

Total angular spread of the central maximum is

$$2\theta = \frac{2\lambda}{a}$$

For diffraction to be more pronounced, the size of the slit should be comparable to the wavelength of light used.

Fresnel's distance.

It is the distance at which the diffraction spread of a beam becomes equal to the size of the aperture. If a is the width of the aperture, then

$$D_F = \frac{a^2}{\lambda}$$

The ray optics is valid for a distance $D < D_F$

Diffraction grating.

It is an arrangement of a very large number of very narrow, equidistant and parallel slits. The diffraction pattern has the central principal maximum of maximum intensity and a number of high order intensity maxima whose intensity decreases with the increase of n, the order of the spectrum. The direction of nth principal maximum is given by

$$(a+b)\sin\theta_n = n\lambda, \quad where\ n = 0, 1, 2, \ldots$$

This equation is known as grating law. Here (a + b) is called grating element, where a is width of each slit and b is the width of opaque space between two consecutive slits.

Resolving power of a microscope.

The resolving power of a microscope is defined as the reciprocal of the smallest distance d between two point objects at which they can be just resolved when seen in the microscope.

$$R.P\ of\ a\ microscope = \frac{1}{d} = \frac{2\mu \sin\theta}{\lambda}$$

Where θ is half the angle of cone of light from each point object and μ is the refractive index of the medium between the object and the objective.

The factor $\mu \sin\theta$ is called numerical aperture (N.A).

Resolving power of a telescope.

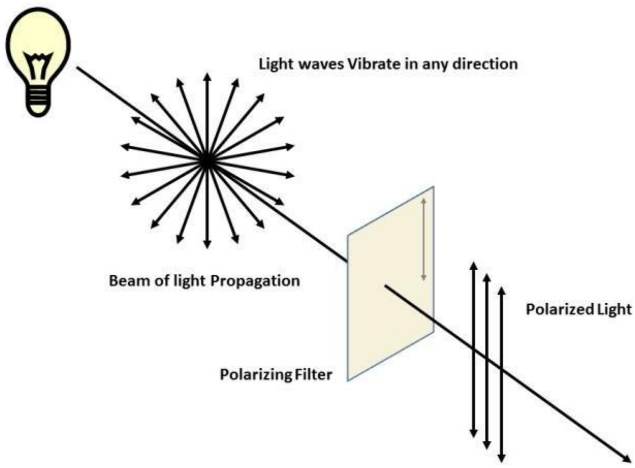
The resolving power of a telescope is defined as the reciprocal of the smallest angular separation $'d\theta'$ between two distant objects whose images can be just resolved by it.

$$R.P\ of\ a\ telescope = \frac{1}{d\theta} = \frac{D}{1.22\lambda}$$

Where D is the diameter of the telescope objective and λ is the wavelength of light used.

Polarization of wave.

A transverse wave in which vibrations are present in all possible directions, in a plane perpendicular to the direction of propagation, is said to be unpolarized. If the vibrations of a wave are present in just one direction in a plane perpendicular to the direction of propagation, the wave is said to be polarized or plane polarized. The phenomenon of restricting the oscillations of a wave to just one direction in the transverse plane is called polarization.



Law of malus.

This law states that when a beam of completely plane polarized light is passed through an analyzer, the intensity $'I'$ of the transmitted light varies directly as the square of the angle $'\theta'$ between the transmission directions of polarizer and analyzer.

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

Where I_0 is the maximum intensity of transmitted light.

Plane of polarization.

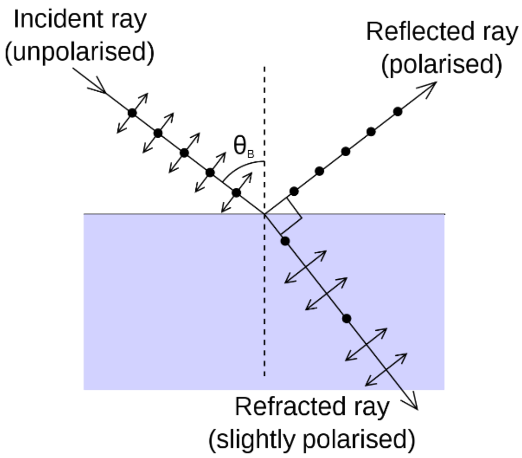
The plane of passing through the direction of wave propagation and perpendicular to the plane of vibration is called the plane of polarization.

Plane of vibration.

The plane containing the direction of vibration and the direction of wave propagation is called the plane of vibration.

Brewster angle

The angle of incidence at which a beam of unpolarized light falling on a transparent surface is reflected as a beam of completely plane polarized light is called polarizing or Brewster angle.



Brewster law.

This law states that the tangent of the polarizing angle of incidence of a transparent medium is equal to its refractive index.

$$\mu = \tan \theta_B$$

Doppler effect.

It is the phenomenon of the apparent change in the frequency of light due to the relative motion between the source and observer. The apparent frequency ν' is given by

$$\nu' = \nu\left(1 \pm \frac{v}{c}\right)$$

When source moves towards the observer, velocity v is taken +ve and when it moves away from the observer then it is taken -ve.

Doppler shift.

The apparent change in the frequency of light due to Doppler effect is called Doppler shift.

(i) $\Delta\nu = \pm\frac{v}{c}\nu$

(ii) $\Delta\lambda = \pm\frac{v}{c}\lambda$