Wave Optics

We can not see anything without **light** but we cannot even see how light travels from one end to other end in a dark room. Therefore, scientists found ***Wave Optics*** which primarily deals with the study of light as a wave phenomenon and explores various optical phenomena that cannot be explained by the geometric optics model, which treats light as straight-line rays.

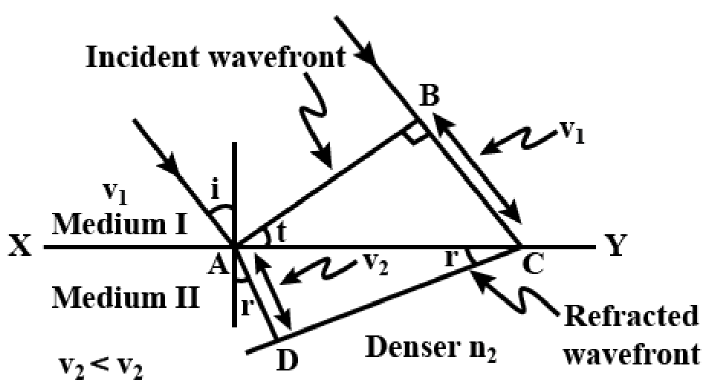
Formulae:

Huygens Principle: Huygens gave an idea about wave front, which states that each point on a wavefront can be considered as a source of secondary spherical wavelets. The principle helps in explaining the propagation of light waves.

Refraction and Reflection of Plane Waves using Huygens Principle:

- **Refraction of a plane wave:** When a light falls from one medium with speed v_1 to another medium with speed v_2 by making an incident angle i with normal to the plane P then it makes angle r by refraction of light wave through the plane. Hence,

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$



If $r < i$ then ray bends toward the normal and the speed of the light in second medium will be less than in first medium i.e., $v_2 < v_1$

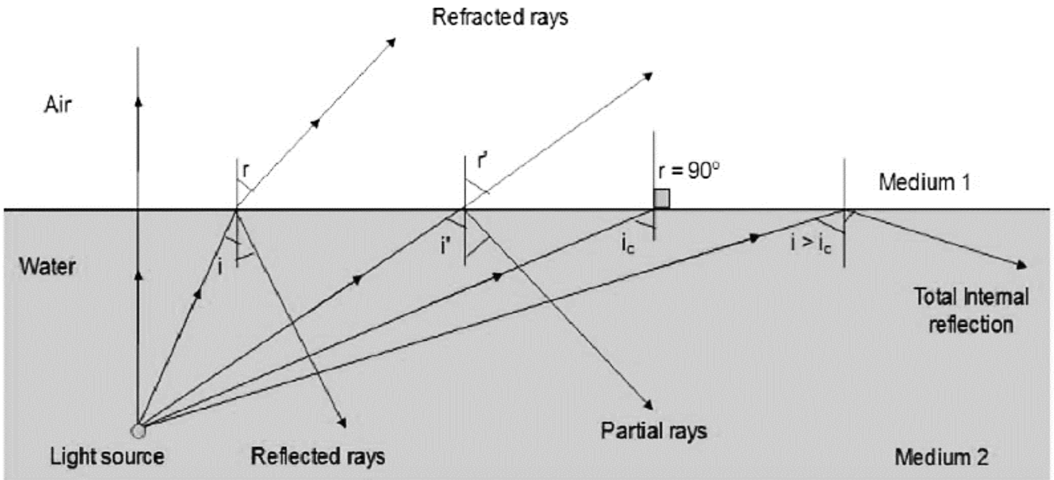
- **Snell's Law:** Ratio of refractive indices of medium 1 and medium 2 is equal to the ratio of sine of incident angle and sine of refraction angle,

$$\frac{n_1}{n_2} = \frac{\sin r}{\sin i}$$

- If λ_1 and λ_2 are wave lengths in different medium 1 and medium 2 respectively then

$$\frac{v_1}{\lambda_1} = \frac{v_2}{\lambda_2}$$

- **Refraction at a rarer medium:** In this case the angle of refraction will be greater than the angle of incident, $r > i$ Then, from Snell's law-

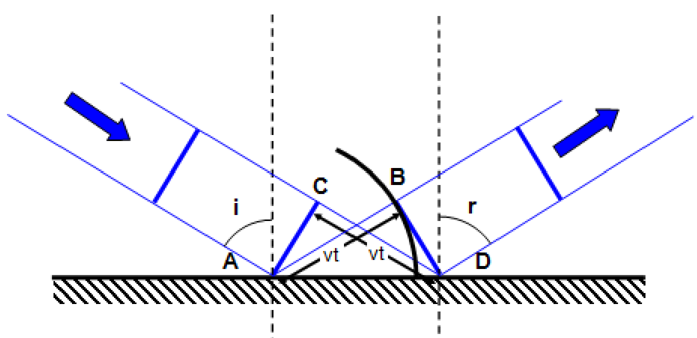


$$\sin i_c = \frac{n_2}{n_1}$$

Where, $i_c =$ critical angle

- **Condition for total internal reflection:** If $i = i_c$ then $\sin r = 1$ and $r = 90^o$ so there can not be any refracted wave and hence total wave will be reflected. In this case, all angles of incidence would be greater than critical angle.

- **Reflection of a plane wave by a plane surface:**



The doppler effect: The doppler shift can be expressed as $\frac{\Delta v}{v} = -\frac{v_{radial}}{c}$

Coherent and Incoherent Addition of Waves:

- If we have two coherent sources S_1 and S_2 vibrating in the same phase then for any point P, the path difference would be $S_1P - S_2P = n\lambda$ (n=0,1,2,3....)
- If path difference is $n\lambda$ then interference would be constructive and resultant intensity will be $4I_o$.
- For destructive interference, $S_1P - S_2P = (n + \frac{1}{2})\lambda$ (n=0,1,2,3....) where intensity will be zero.
- Displacement produced by source S_1 and source S_2 will be –

$$y_1 = a\cos\omega t$$

And, $$y_2 = a\cos(\omega t + \phi) \text{ where } \phi \text{ is path difference.}$$

Therefore, the resultant displacement will be- $y = y_1 + y_2$

$$y = 2a\cos(\frac{\phi}{2})\cos(\omega t + \frac{\phi}{2})$$

- The amplitude of the resultant displacement is $2a\cos(\frac{\phi}{2})$
- The intensity at a point will be: $I = 4I_o\cos^2(\frac{\phi}{2})$, if $\phi = 0, \pm 2\pi, \pm 4\pi....$ then interference will be constructive and if $\phi = \pm\pi, \pm 3\pi, \pm 5\pi....$ then interference will be destructive.

Young's Experiment:

- When two parallel and very close slits S_1 and S_2 behave like coherent sources and produce on a screen a pattern of dark and bright fringes. Then the path difference is-

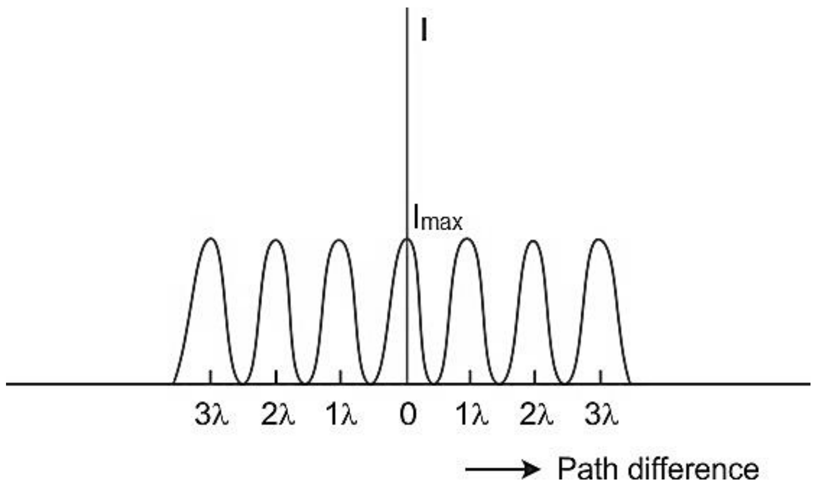
$$S_2P - S_1P = n\lambda$$

- Distance of the n[th] bright fringe from centre of the screen is

$$y_n = \frac{nD\lambda}{d} \text{ where } d = \text{ separation distance between two sources of light}$$

$$D = \text{ Distance between screen and slit}$$

- Angular position of n[th] bright fringe is: $\theta_n = \frac{y_n}{D} = \frac{n\lambda}{d}$
- Distance of the n[th] bright fringe from centre of the screen is: $y_n = \frac{(2n+1)D\lambda}{2d}$
- Angular position of n[th] dark fringe is: $\theta_n = \frac{y_n}{D} = \frac{(2n+1)\lambda}{2d}$



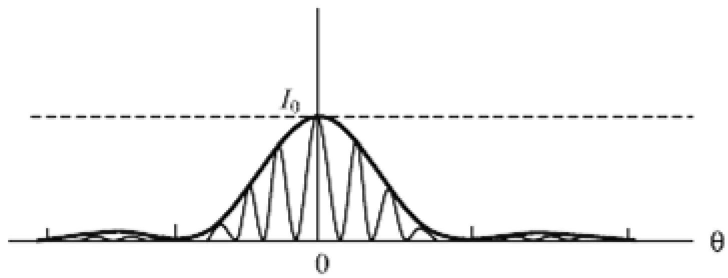
Intensity graphs for YDSE

Cases and Variations of the YDSE experiment:

1. **Using White Light:**
    - When white light is used instead of monochromatic light, the interference pattern appears as a series of colored fringes due to the different wavelengths of light being spread out (dispersed).
    - This dispersion results in a spectrum of colors on the screen, with each color corresponding to a different wavelength and thus a different fringe spacing.
2. **YDSE in a Fluid Medium:**
    - Conducting the YDSE experiment in a medium other than air, such as a liquid introduces changes to the refractive index. This affects the wavelength of light and, consequently, the interference pattern.
    - The interference fringes will be shifted due to the change in wavelength in the medium, leading to alterations in the pattern.
3. **YDSE with Different Slit Separations:**
    - Changing the separation between the two slits alters the spacing of the interference pattern. A smaller slit separation results in wider fringes, while a larger separation leads to narrower fringes.
    - This variation can be used to study the relationship between slit separation and the resulting interference pattern.
4. **YDSE with Coherent and Incoherent Light Sources:**
    - Using a coherent light source, such as a laser, produces a clear and stable interference pattern. In contrast, using an incoherent light source, such as an ordinary light bulb, produces a less-defined pattern due to the lack of coherence between the light waves.
5. **YDSE with Different Wavelengths:**
    - Experimenting with light of different wavelengths, such as using laser light with different colors, can produce interference patterns with varying fringe spacings.
    - This can be used to illustrate the relationship between wavelength and interference pattern characteristics.

Diffraction due to single slit:

- Angular width of the central maxima= $\frac{2\lambda}{a}$
- Linear Width of central maxima: $y = \frac{2\lambda D}{a}$, where D= distance of slit from the screen and a is slit width.
- Condition for the minima on the both side of Central maxima is
  $a \sin(\theta) = n\lambda,\ n = 1,\ 2,\ 3$



Polarization:

- If wave equation is $y(x,t) = a\sin(kx - \omega t)$, where *a* and ω represent the amplitude and the angular frequency of wave with wavelength $\lambda = \frac{2\pi}{k}$ then for polarization maximum intensity would be $I = I_o \cos^2\theta$
  Where, I= intensity of light after polarization
  I_o= Original Intensity
  θ = Angle between the axis of analyser and the polarizer.
- This concept was first given by Malus and thus this law is known as Malus' Law.

Brewster's Law: Brewster's Law, in the context of polarization, describes the relationship between the angle of incidence of light on a dielectric surface and the polarization of the reflected light. It specifically addresses the angle at which light with a certain polarization state (perpendicular or parallel to the plane of incidence) experiences no reflection, only transmission. This angle is known as Brewster's angle (i_B).

So, from Snell's law: $\mu = \frac{\sin i_B}{\sin r} = \frac{\sin i_B}{\sin\left(\frac{\pi}{2} - i_B\right)} = \frac{\sin i_B}{\cos i_B} = \tan i_B$

And, $\tan i_B = \frac{n_1}{n_2}$ Where, n_1 is the refractive index of the first medium (from which the light is coming, often air) and n_2 is the refractive index of the second medium (into which the light is entering, often a dielectric material).