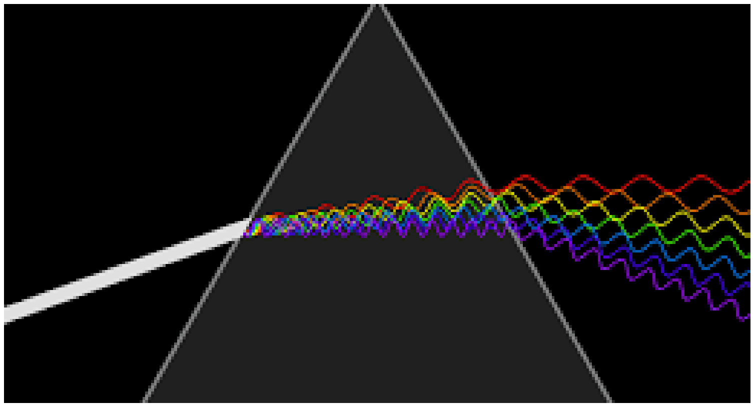

WAVE OPTICS

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INTRODUCTION

In 1637, Descartes gave the corpuscular model of light which explained the laws of reflection and refraction of light at an interface. But, since Newton made further improvements to this theory, so this model is also known as Newton's corpuscular model.

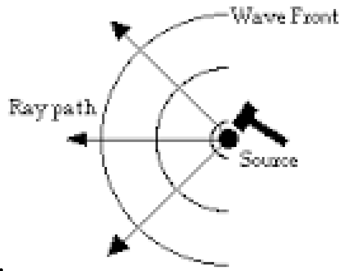
In 1678, Huygens put forward the wave theory of light, about which I will be teaching you in this chapter. The corpuscular model was the dominating model describing light until 1801, when Thomas Young presented his famous Double-slit experiment. After the interference experiment of Young , for the next 4 decades, many experiments were carried out involving the interference and diffraction of light waves; these experiments could only be explained by assuming a wave model of light.

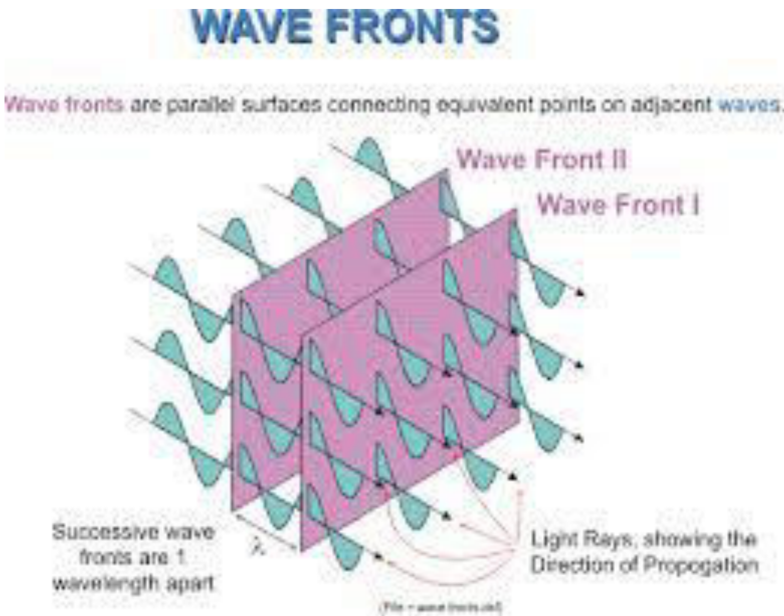
The only major difficulty was that since it was thought that a wave required a medium for its propagation, how could light waves propagate through vacuum. This was explained by Maxwell's electromagnetic theory of light.

So, we will first discuss about the Huygens principle and derive the laws of reflection and refraction.

WAVEFRONT

A wavefront is a surface over which the wave has a constant phase. For example, a wavefront could be the surface over which the wave has a maximum (the crest of a water wave, for example) or a minimum (the trough of the same wave) value. The shape of a wavefront is usually determined by the geometry of the source. A point source has wavefronts that are spheres whose centers are at the point source. A fluorescent tube would have wavefronts that are cylinders concentric with the tube itself. A very large sheet of material that is uniformly illuminated would generate wavefronts that are plane waves parallel to the sheet.



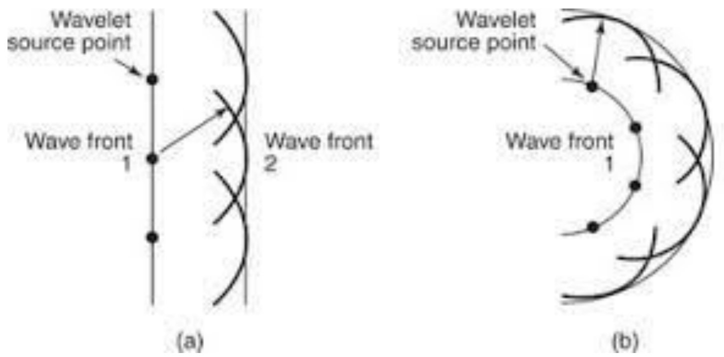


The speed with which the wavefront moves outwards from the source is called the speed of the wave. The energy of the wave travels in a direction perpendicular to the wavefront.

HUYGEN'S PRINCIPLE

According to Huygens principle, **'Each point of the wavefront is the source of a secondary disturbance and the wavelets emanating from these points spread out in all directions with the speed of the wave. These wavelets emanating from the wavefront**

are usually referred to as the secondary wavelets and if we draw a common tangent to all these spheres, we obtain the new position of the wavefront at a later time t'.



Shown above are the geometric constructions of secondary plane waveform and spherical wavefronts respectively using Huygen's principle.

REFLECTION AND REFRACTION USING HUYGEN'S PRINCIPLE

The laws of reflection and refraction of waves, which you have been taught in earlier classes, can also be verified using Huygen's Principle. The derivations are shown in the video part. You can also find it in NCERT section 10.3.1 --- 10.3.3

ADDITION AND SUPERPOSITION OF WAVES

In this section we will discuss the interference pattern produced by the superposition of two waves. The entire field of interference is based on the superposition principle according to which **'At a particular point in the medium, the resultant displacement produced by a number of waves is the vector sum of the displacements produced by each of the waves**.'

Consider two sources S1 and S2 producing two waves(any type of wave, eg water wave, sound wave etc), and at a particular point, the phase difference between the displacements produced by each of the waves does not change with time; when this happens, the two sources are said to be coherent

If the displacement produced by S1 is given by

$y_1 = a \cos \omega t$

And the displacement produced by S2 is given by

$y_2 = a \cos (\omega t + \varphi)$

Then the resultant displacement will be given by

$y = y_1 + y_2$

$= a [\cos \omega t + \cos (\omega t + \varphi)]$

$= 2 a \cos (\varphi/2) \cos (\omega t + \varphi/2)$

The amplitude of the resultant displacement is $2a \cos (\varphi/2)$ and therefore the intensity at that point will be

$I = 4 I_0 \cos^2 (\varphi/2)$.

For eg, If $\varphi = 0, \pm 2\pi, \pm 4\pi,\ldots$ we will have constructive interference leading to maximum intensity. On the other hand, if $\varphi = \pm \pi, \pm 3\pi, \pm 5\pi \ldots$we will have destructive interference leading to zero intensity.

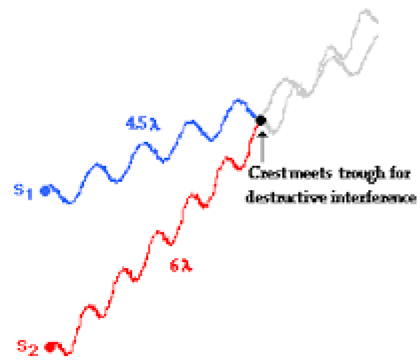
If we have two coherent sources S_1 and S_2 vibrating in phase, then for an arbitrary point P whenever the path difference,

$S_1P \sim S_2P = n\lambda \quad (n = 0, 1, 2, 3,...)$

we will have constructive interference and the resultant intensity will be $4I_0$; the sign ~ between S_1P and S_2P represents the difference between S_1P and S_2P. On the other hand, if the point P is such that the path difference,

$S_1P \sim S_2P = (n+1/2)\lambda \quad (n = 0, 1, 2, 3, ...)$

we will have destructive interference and the resultant intensity will be zero.



For the given alongside figure,

$S_1P \sim S_2P = 1.5\ \lambda$.

Hence, they interfere destructively.

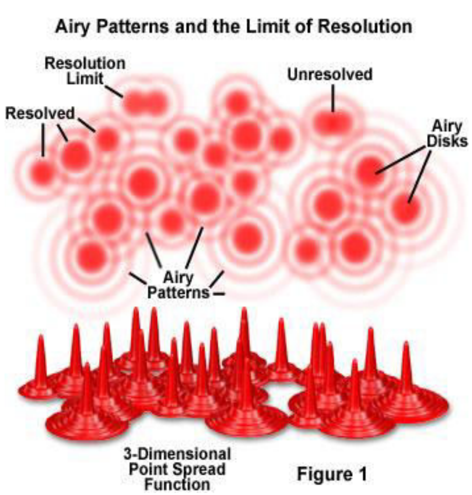
YOUNG'S DOUBLE SLIT EXPERIMENT

I will explain in detail about this expt in the video part. You can find it in NCERT in section 10.5 .

The effect of the fringe pattern can be seen in this short video:-

https://www.youtube.com/watch?v=9UkkKM1IkKg

DIFFRACTION



If we look clearly at the shadow cast by an opaque object, close to the region of geometrical shadow, there are alternate dark and bright regions just like in interference.This happens due to the phenomenon of diffraction.

Since the wavelength of light is much smaller than the dimensions of most obstacles; we do not encounter diffraction effects of light in everyday observations. But, the limited resolution of our eyes, microscopes, etc can be attributed to diffraction effects.

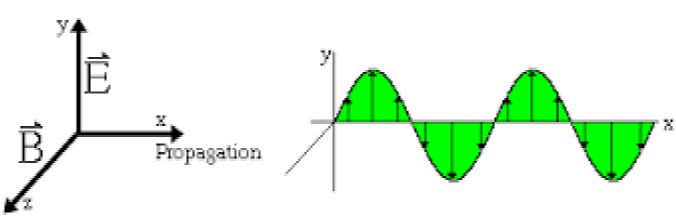
THE SINGLE SLIT

When the double slit in Young's experiment is replaced by a single narrow slit, a broad pattern with a central bright region is seen. On both sides, there are alternate dark and bright regions, the intensity becoming weaker away from the centre.

You can find the derivation of diffraction by a single slit explained in the video part. The corresponding NCERT part which you may refer is section 10.6.1. Through the link given below, you can relate the diffraction effects to the slit width.

https://www.youtube.com/watch?v=uPQMI2q_vPQ

POLARISATION



Consider a wave propagating in the +x direction. Such type of wave can be generated by moving the end of the string up and down in a periodic manner.

Such a wave can be represented by a wave function-

$y(x,t) = a \sin(kx - \omega t)$

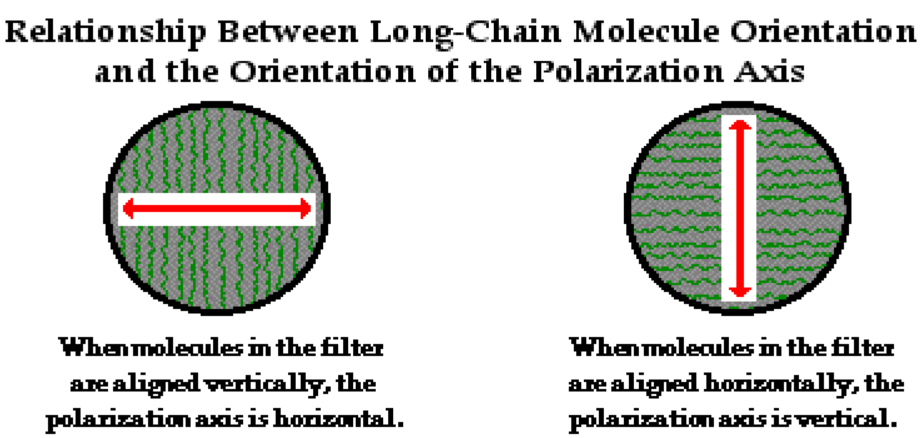
where a and ω (= 2πν) represent the amplitude and the angular frequency of the wave, and

λ=2π/k represents the wavelength of the wave.

Since the displacement, along the y direction is at right angles to the direction of propagation of the wave, it is known as a transverse wave. And as the displacement is in the y direction, it is called a y-polarised wave.

If the plane of vibration of the string is changed randomly with respect to time, then we get an unpolarised wave. Here, the displacement will be randomly changing with time though it will always be perpendicular to the direction of propagation.

Light waves are transverse in nature; i.e., the electric field associated with a propagating light wave is always at right angles to the direction of propagation of the wave. This can be verified using a polaroid. A polaroid consists of long chain molecules aligned in a particular direction. The electric vectors (associated with the propagating light wave) along the direction of the aligned molecules get absorbed. Thus, if an unpolarised light wave is incident on such a polaroid then the light wave will get linearly polarised with the electric vector oscillating along a direction perpendicular to the aligned molecules; this direction is known as the pass-axis of the polaroid.



Thus, if the light from an ordinary source (like a sodium lamp) passes through a polaroid sheet P1, it is observed that its intensity is reduced by half. Rotating P1 has no effect on the transmitted beam and transmitted intensity remains constant. Now, let an identical piece of polaroid P2 be placed before P1. As expected, the light from the lamp is reduced in intensity on passing through P2 alone. But now rotating P1 has a dramatic effect on the light coming from P2. In one position, the intensity transmitted by P2 followed by P1 is nearly zero. When turned by 90º from this position,

In general, it obeys MALU'S LAW, i.e. as we rotate the polaroid P1 (or P2), the intensity will vary as:

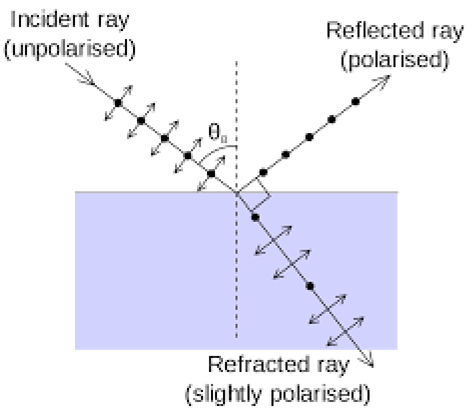
$I = I_0 \cos^2\theta$,

Where pass-axis of P2 makes an angle θ with the pass-axis of P1.

Polaroids can be used to control the intensity, in sunglasses, windowpanes, etc. Polaroids are also used in photographic cameras and 3D movie cameras.

BREWESTER'S LAW

When unpolarised light is incident on the boundary between two transparent media, the reflected light is polarised with its electric vector perpendicular to the plane of incidence when the refracted and reflected rays make a right angle with each other. This is called Brewester's law.



Since we have $i_B + r = \pi/2$, we get

from Snell's law,

$\mu = \tan i_B$,

Where i_B is the Brewester's angle.