PHY10SCI/PHY11ENG

WAVES

Lecture 10: Interference

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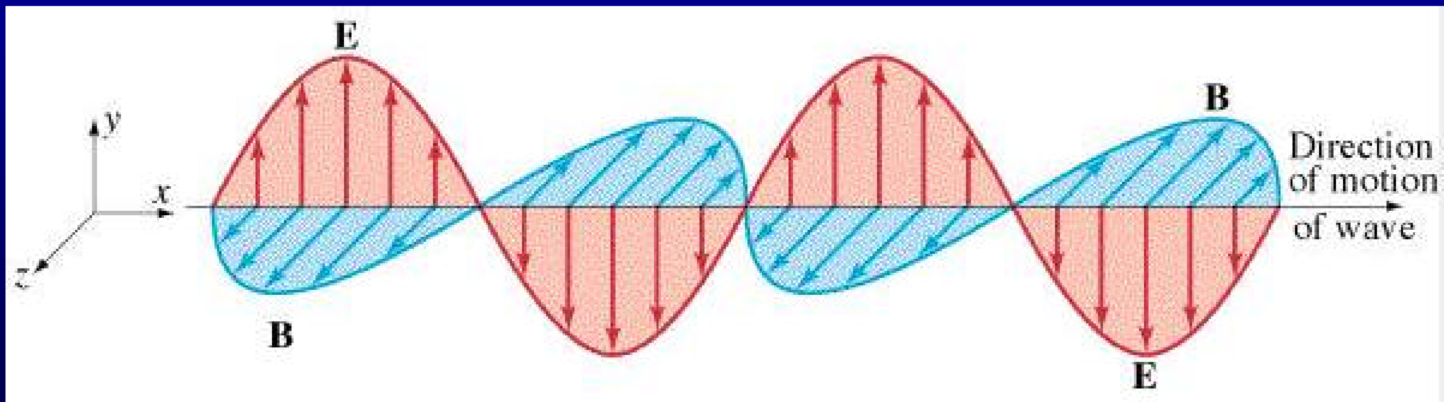
INTERFERENCE

We have already considered various examples of interference between waves which overlap in some region. We now want to look specifically at interference between light waves.

Light waves are tranverse electromagnetic waves. They have both an electric and magnetic component. What travels are electric and magnetic field oscillations which are mutually self-inducing, so electromagnetic waves travel without need of any medium. The transverse oscillations of the electric and magnetic fields are at right angles to each other.

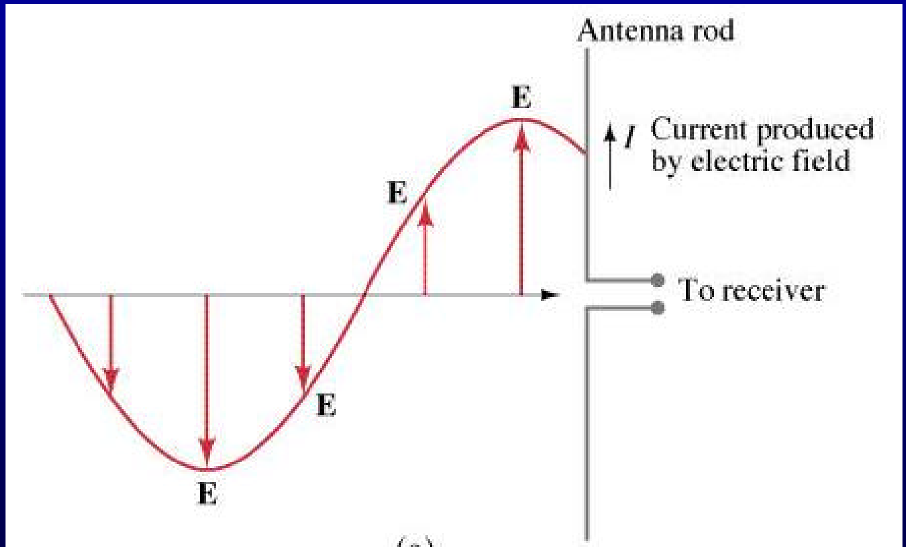


The components are both sinusoidal of the form:

$$E = E_o \sin(kx - \omega t) \quad \text{and} \quad B = B_o \sin(kx - \omega t)$$

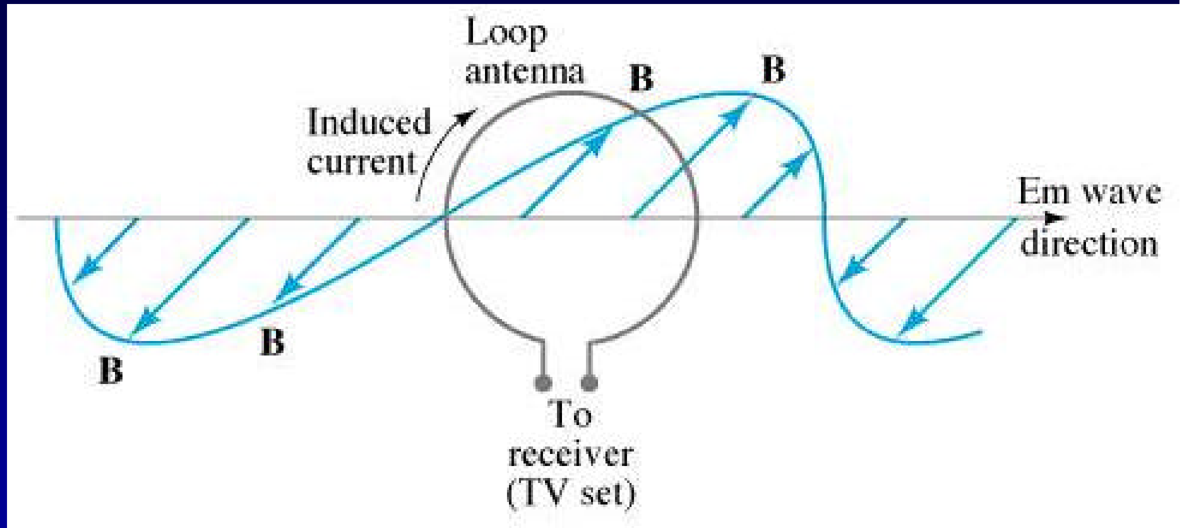
Because of their transverse character, EM waves can be transmitted in **polarised** form. That is, transmitted with the electric oscillations occurring in a particular direction, such as in the horizontal or vertical plane. They are then said to be "**plane polarised**".

TV signals are typically transmitted with the electric vector oscillating horizontally. That is why the conductors in a TV antenna array are horizontal, so that the electrons in the conductor can oscillate along the antenna elements in response to the electric field oscillations. Sometimes in regional areas or other countries you see TV antennas arranged vertically because there the signals have been transmitted with vertical polarisation.



(a)

Loop antennas respond to the magnetic vector oscillations. The oscillating magnetic flux through the plane of the loop induces an oscillating emf in the loop.



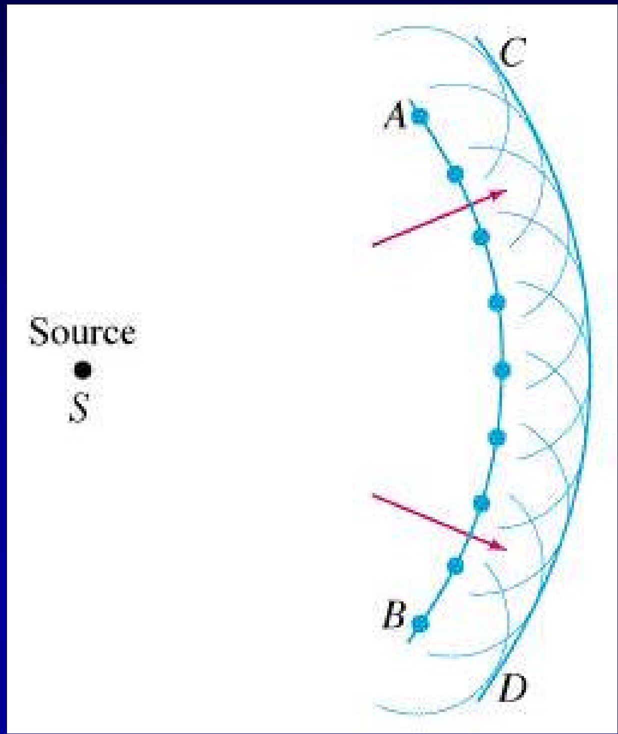
Light can be polarised by passing it through a polaroid material which preferentially transmits signals with a particular plane of polarisation.

Light is also partially polarised on reflection from non-metallic surfaces, in the plane parallel to the surface. The polaroid material in sunglasses is therefore oriented so as not to transmit the horizontally polarised components in the reflected glare off large surfaces of water.

Longitudinal waves cannot be polarised.

HUYGEN’S PRINCIPLE

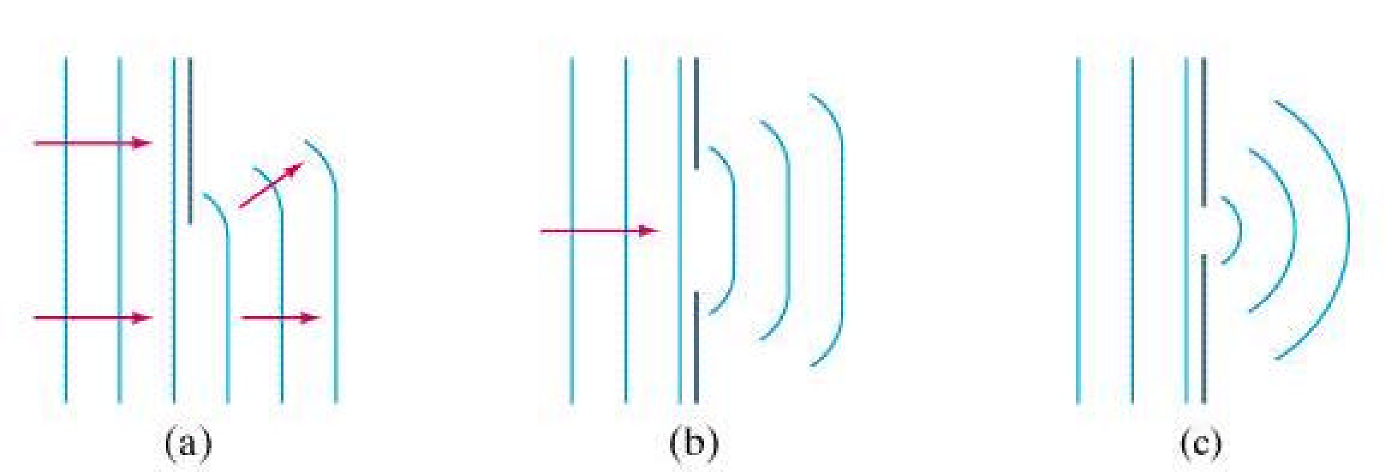
Huygen’s Principle can be used to explain the propagation of waves. It says that “every point on a wavefront can be considered as a source of secondary spherical wavelets which propagate at the speed of the wave. The new wavefront is tangent to all these secondary waves”.



This principle can be used to explain refraction, diffraction and interference.

Diffraction

When waves impinge on an obstacle and the wavefronts are partially interrupted, Huygen’s principle predicts that waves will bend around and behind an obstacle as shown.

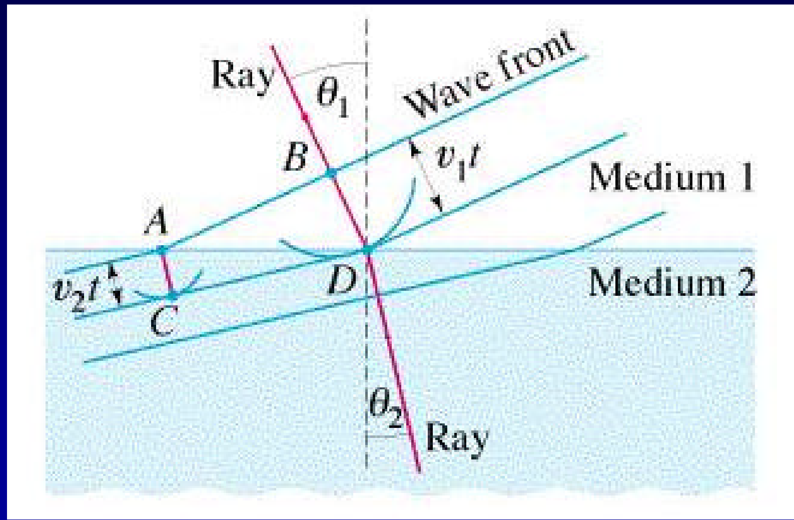


This bending of waves around objects and through apertures into “shadow regions” is called diffraction as we have previously seen.

Refraction

We have previously deduced a relationship between the directions of the incident and refracted waves and the wave velocity in the two media:

$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$$



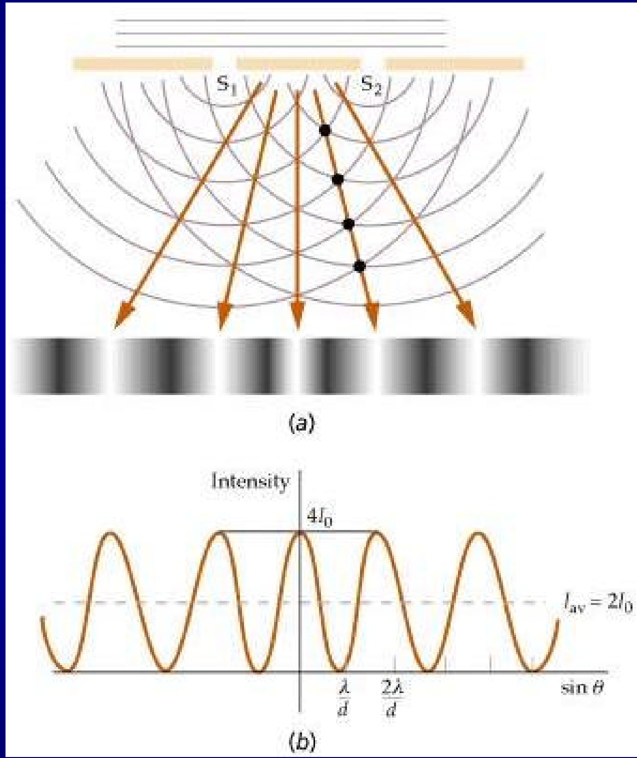
In the world of light, the optical parameter called the **refractive index (n)** of a material is defined as the ratio of the speed of light in vacuum (c) to the speed of light in the medium (v). Thus **n = c/v**, and the law of refraction can be written in terms of the refractive indices of the two materials as:

$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1} = \frac{c/n_2}{c/n_1} = \frac{n_1}{n_2} \quad \text{OR} \quad n_1 \sin\theta_1 = n_2 \sin\theta_2$$

SNELL'S LAW OF REFRACTION

Interference – Young’s Double Slit Experiment

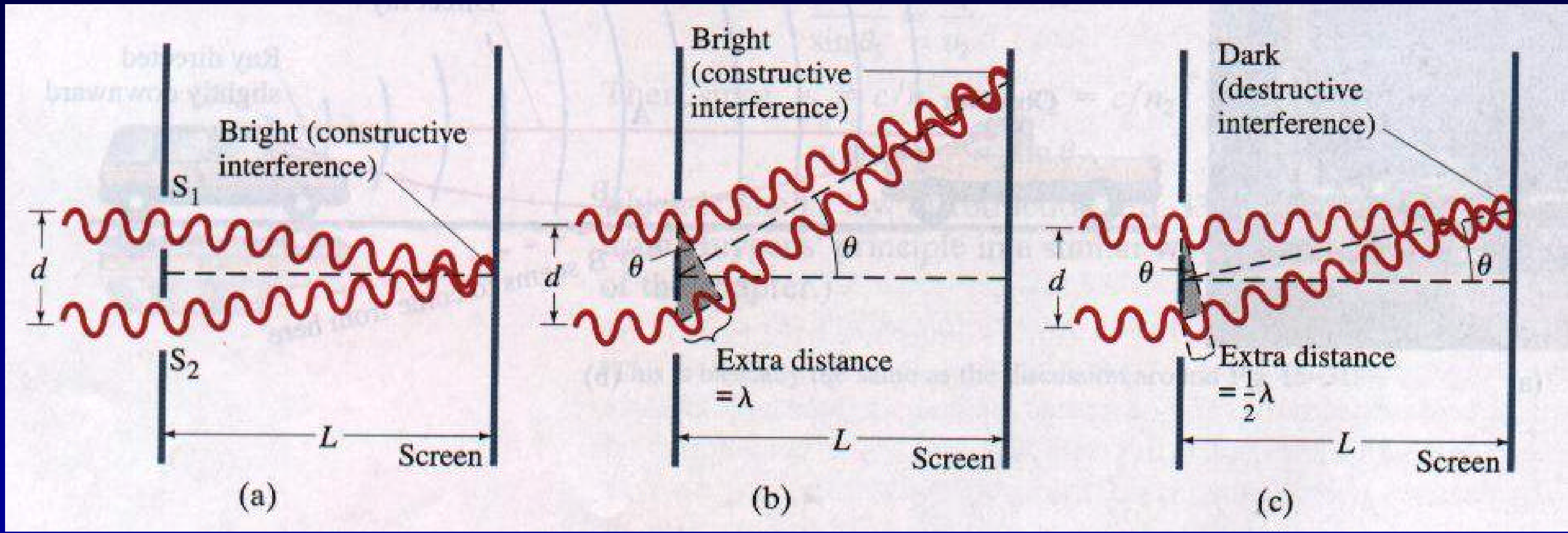
This is a classic example of the interference of two light waves. Light from a single source falls on a screen containing two closely spaced slits. Diffraction causes two spherical waves emerging from the slits as shown.



Young observed a series of parallel dark and bright lines on the screen.

He explained them as regions of destructive and constructive interference between the waves emerging from the two slits.

Waves which emerge from the two slits in phase, travel different distances to points on the screen and therefore are no longer in phase there. Depending on the path difference, at some points crests and troughs coincide causing destructive interference (dark lines) and at others, crests coincide causing constructive interference (bright lines).



In (a) the waves, having travelled the same distance, reach the centre of the screen still in phase, producing a bright line.

In (b), the lower wave has travelled an extra distance of one wavelength, so the waves are in phase at the screen again, producing a bright line there.

In (c), the lower wave has travelled an extra distance of half a wavelength, so the waves are exactly out of phase at the screen, producing a dark line.

To determine where the bright and dark lines fall, note that the previous diagrams are greatly exaggerated. In practice, the distance d is very small compared with the distance L to the screen. The rays from each slit are therefore nearly parallel, and if θ is the angle they make with the centre line, **the extra distance travelled by the lower ray is dsinq**.

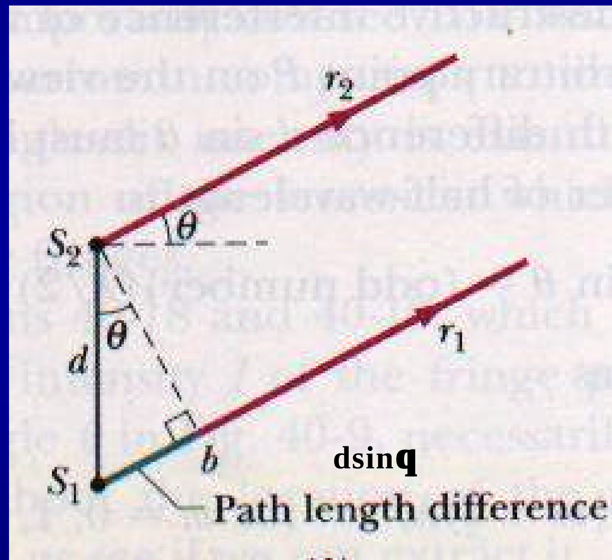
Constructive interference and a bright line will occur on the screen where:

$$d\sin\theta = m\lambda \qquad m = 0,1,2,\ldots$$

m is the order of the interference fringe.

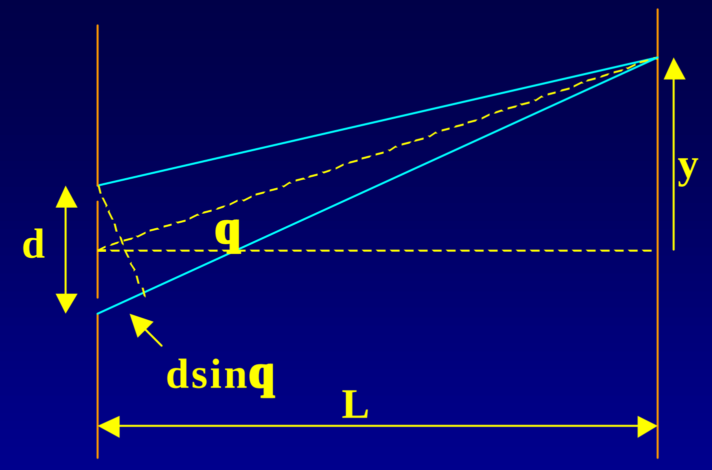
Destructive interference and a dark line will occur on the screen where:

$$d\sin\theta = (m + ½)\lambda \qquad m = 0,1,2,\ldots$$



These equations give the values of θ, measured from the centre line, at which maxima and minima occur.

If we want instead to know the distance
y, measured up or down the screen from
the central maximum, at which maxima
and minima occur, we use y = Ltanθ.



The distance between adjacent maxima
for small θ can be determined using
sinθ ≈ tanθ ≈ θ in radians.

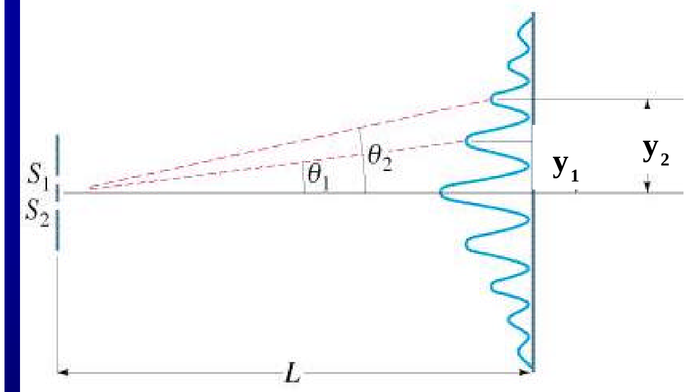
Then $d \sin \theta = m\lambda \quad \rightarrow \quad \therefore \theta = \frac{m\lambda}{d}$

and $y = L \tan \theta \quad \rightarrow \quad \therefore y = L\theta$

$$\therefore y = \frac{m\lambda L}{d}$$

For adjacent maxima : $y_1 = \frac{m\lambda L}{d}$ and $y_2 = \frac{(m+1)\lambda L}{d}$

Therefore $y_2 - y_1 = \Delta y = \frac{\lambda L}{d}$



EXAMPLE

(a) Monochromatic light falling on a Young's double slit with separation 0.026 mm, produces the fourth order fringe at $\theta = 6.4^o$. What is the wavelength of the light ?

$$d \sin\theta = m\lambda \quad \rightarrow \quad \lambda = \frac{d \sin\theta}{m}$$

$$= \frac{(2.6\,x10^{-5}) \sin 6.4^o}{4}$$

$$\therefore \quad \lambda = 7.26\,x10^{-7}\ \mathrm{m} = 726\ \mathrm{nm}$$

(b) What is the distance between adjacent maxima if d = 0.100 mm, L = 1.2 m and λ = 500 nm ?

$$\Delta y = \frac{\lambda L}{d} = \frac{(5x10^{-7}m)(1.2m)}{(1x10^{-4}m)} = 6.0\ \mathrm{mm}$$