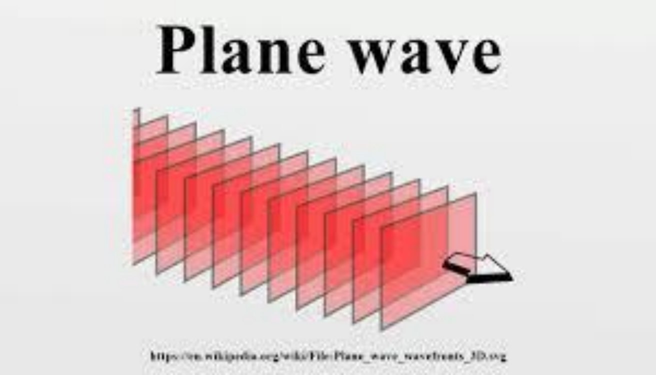
Lesson plan 22

Wave front: In physics the wave front of a time-varying field is the set of all points where the wave has the same phase.

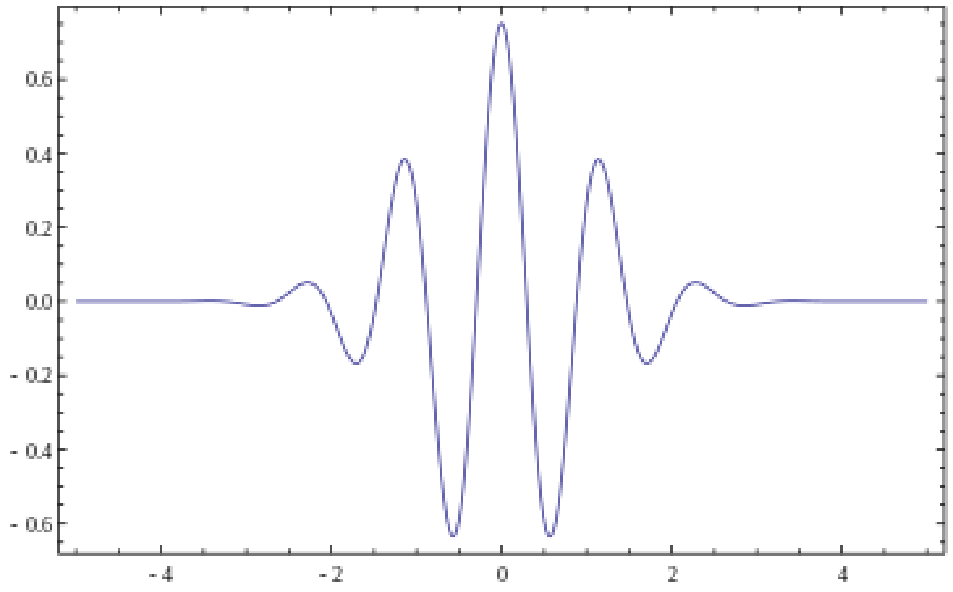
A plane wave is a constant-frequency wave whose wave fronts are infinite parallel planes of constant peak-to-peak amplitude normal to the phase velocity vector.



Circular wave on the water surface generated by a small ball oscillating in the vertical direction.

Wavelet :

A **wavelet** is a wave-like oscillation with an amplitude that begins at zero, increases, and then decreases back to zero.



Light as a Wave

Huygens' wave theory is based on a geometrical construction that allows us to tell where a given wavefront will be at any time in the future if we know its present position. **Huygens' principle** is:

All points on a wavefront serve as point sources of spherical secondary wavelets. After a time *t*, the new position of the wavefront will be that of a surface tangent to these secondary wavelets.

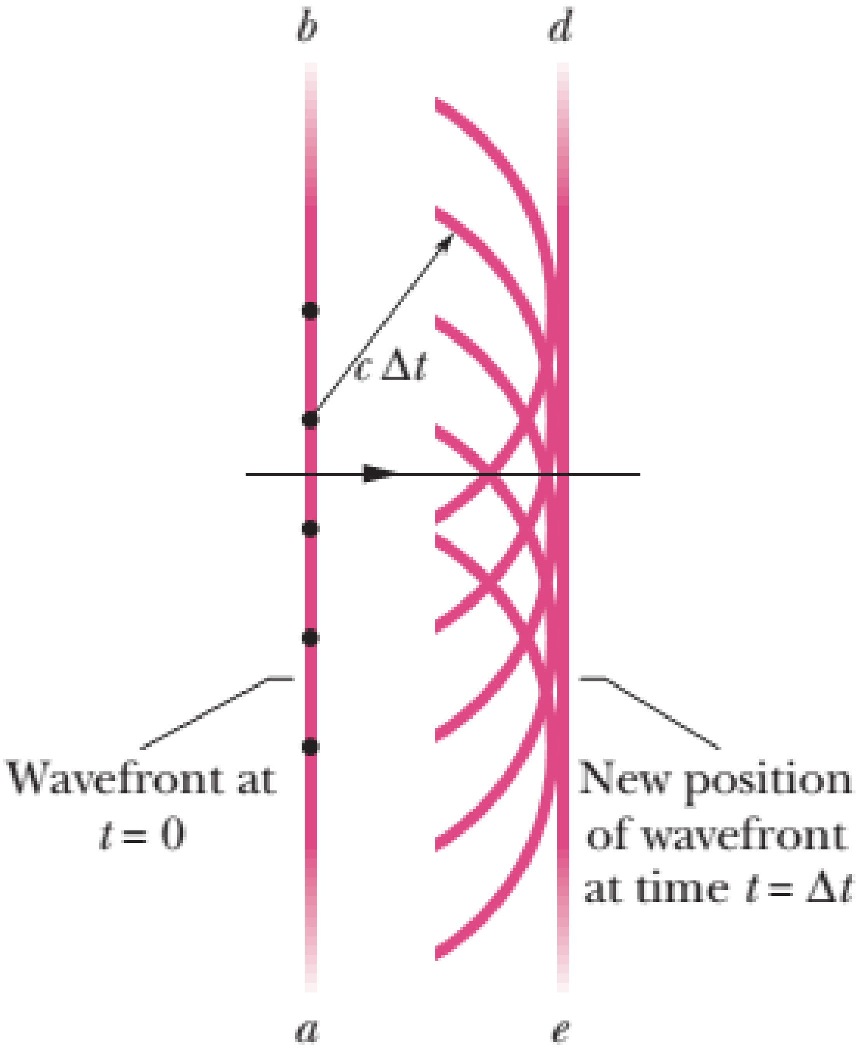
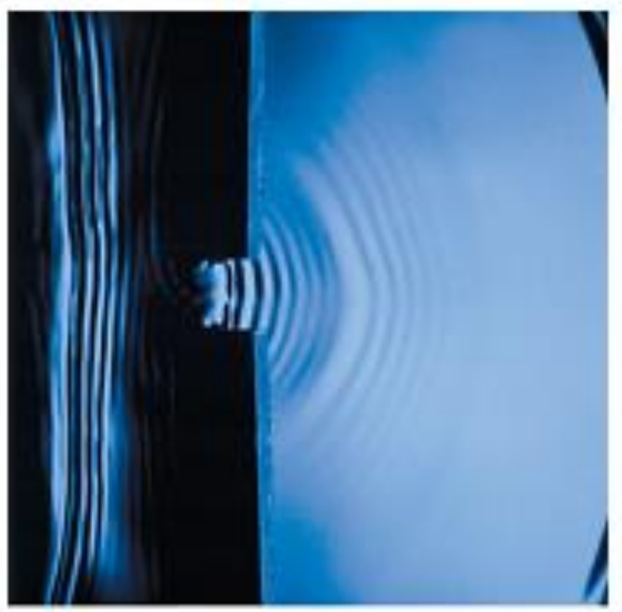


Figure 35-2 The propagation of a plane wave in vacuum, as portrayed by Huygens' principle.

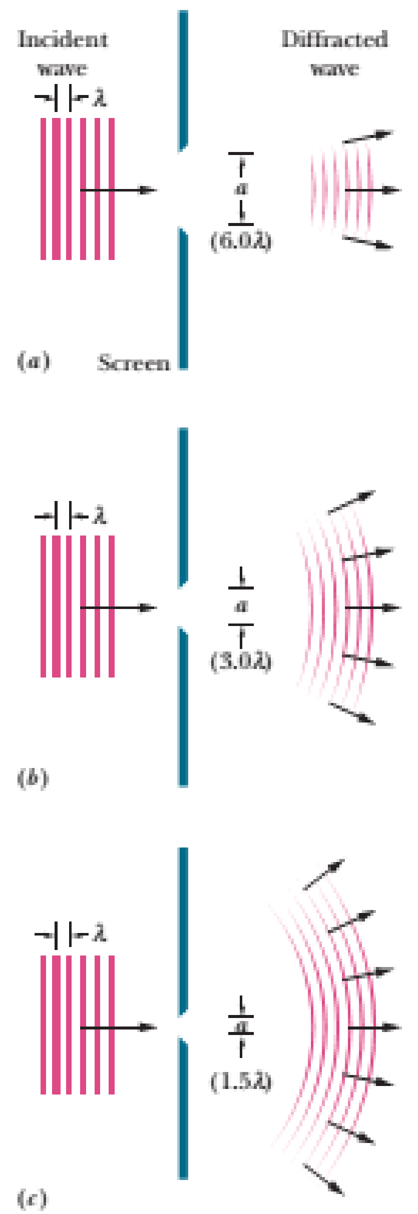
Diffraction

If a wave encounters a barrier that has an opening of dimensions similar to the wavelength, the part of the wave that passes through the opening will flare (spread) out—will *diffract*—into the region beyond the barrier. The flaring is consistent with the spreading of wavelets in the Huygens construction of Fig. 35-2. Diffraction occurs for waves of all types, not just light waves; Fig. 35-6 shows the diffraction of water waves traveling across the surface of water in a shallow tank.



George Resch/Fundamental Photographs

A wave passing through a slit flares (diffracts).



Monocromatic Light : Monochromatic describes **light** that has the same wavelength so it is one color.

Coherent Sources : Two sources are said to be coherent if the emit light of same wavelength having no phase difference or if there is any phase difference it is maintained all along during propagation.

If there is phase difference then they are called Incoherent sources.

Diffraction : The process by which a beam of light or other system of waves is spread out as a result of passing through a narrow slit or across an edge, typically accompanied by interference between the wave forms produced.

Conditions for Intereference :

!. The light sources should be coherent ,

2. The amplitudes of the two waves producing interference should be equal or almost equal.

3. The sources should be close to each other.

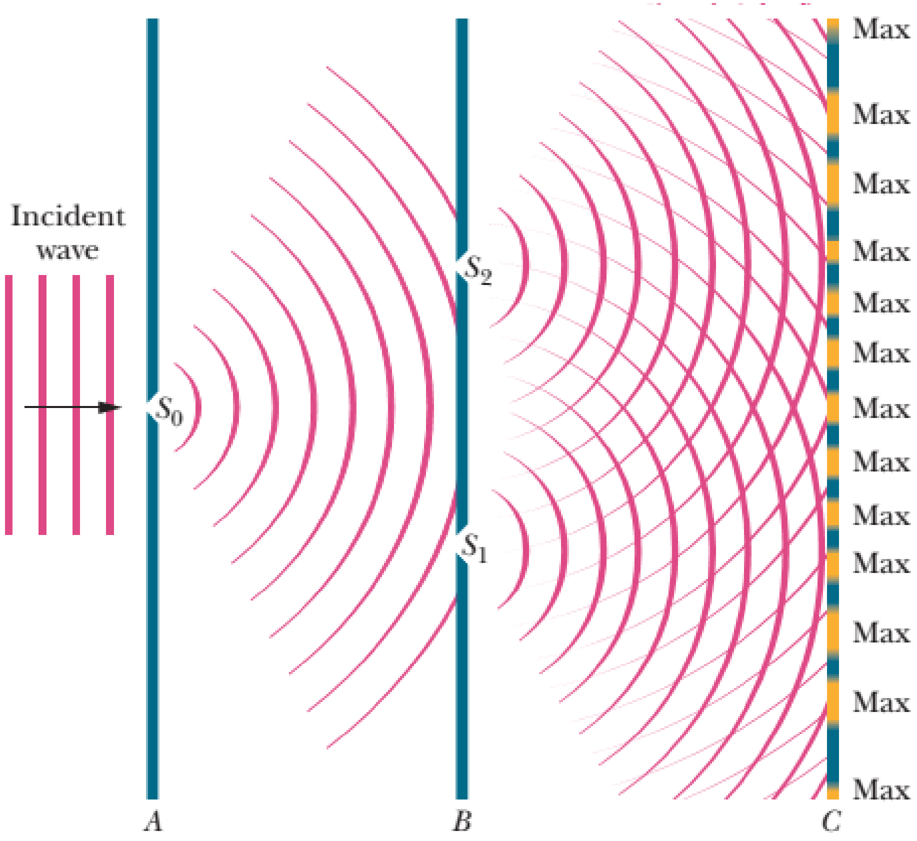
4. The sources should be narrow.

35-2 YOUNG'S INTERFERENCE EXPERIMENT:

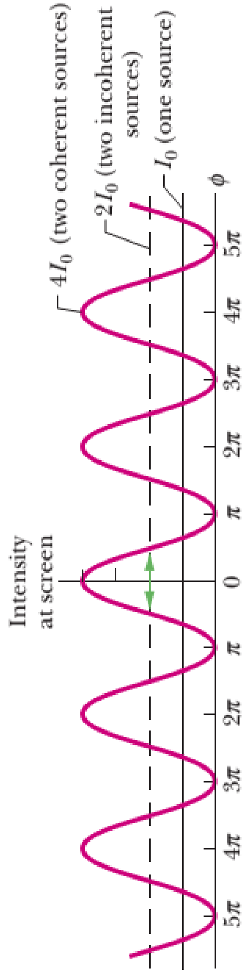
To form Interference, the incident light satisfy two conditions:

(1) Monochromatic source: Light consists of one colour or one wavelength.

(2) Coherent source: Plane waves from the monochromatic source maintain a constant phase relation. If two waves are out of phase, this phase difference must not change with time.



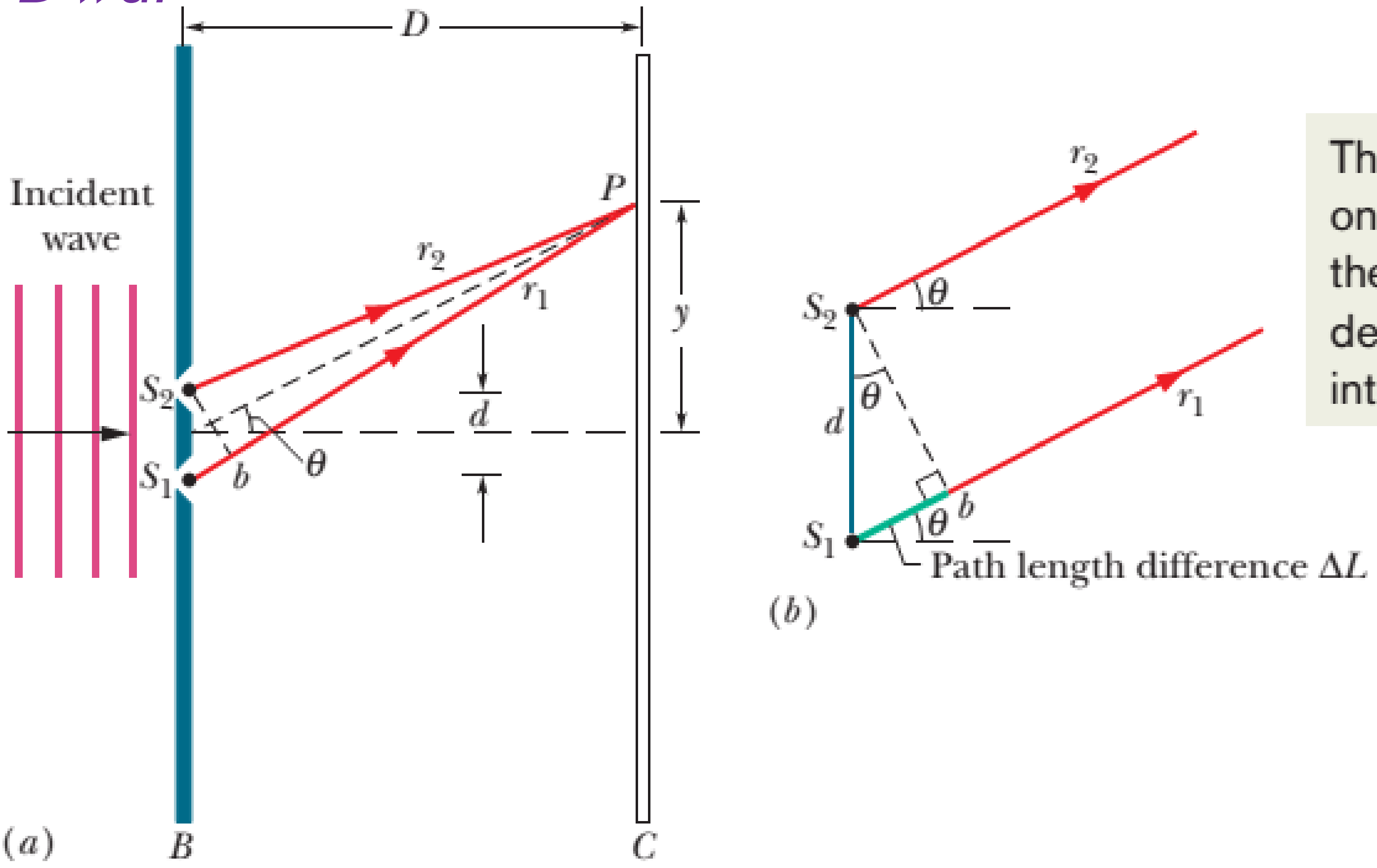
diffracted wavs diffracted wavs interference



Locating the Fringes:

Path Length Difference: The phase difference between two waves can change if the waves travel paths of different lengths.

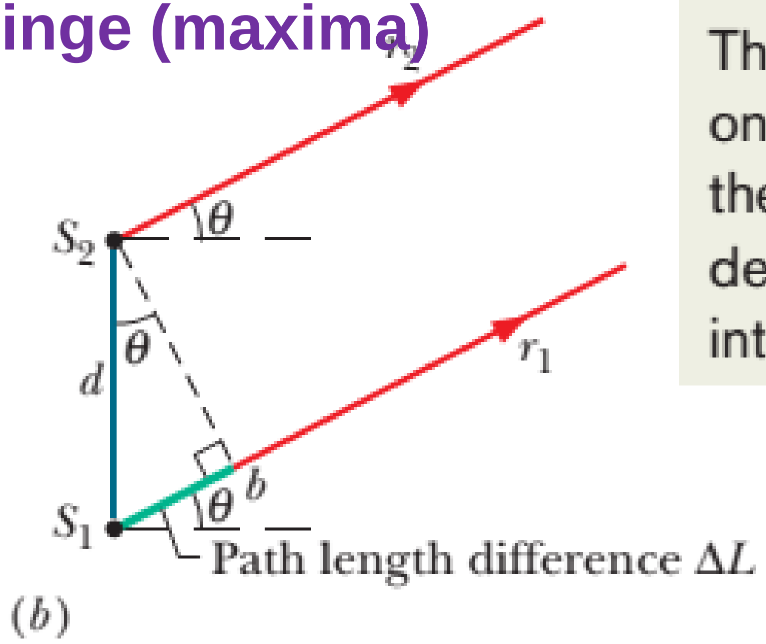
What appears at each point on the viewing screen in a Young's double-slit interference experiment is determined by the path length difference ΔL of the rays reaching that point. *If $D \gg d$.*



The ΔL shifts one wave from the other, which determines the interference.

Condition for maximum and minimum:

In phase (Constructive interference): bright fringe (maxima)



The ΔL shifts one wave from the other, which determines the interference.

$$\sin\theta = \frac{\Delta L}{d}$$

Path length difference, $\Delta L = d \sin\theta$

$\Delta L = 0,\ 2\,\frac{\lambda}{2},\ 4\,\frac{\lambda}{2},\ 6\,\frac{\lambda}{2},\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$

$d \sin\theta = 0,\ \lambda,\ 2\lambda,\ 3\lambda, \ldots\ldots\ldots\ldots$

$d \sin\theta = m\lambda$ for $m = 0, 1, 2, 3 \ldots$ (maxima-bright fringe)

Out of phase (Destructive interference): dark fringe (minima)

$\Delta L = 1\,\frac{\lambda}{2},\ 3\,\frac{\lambda}{2},\ 5\,\frac{\lambda}{2}, \ldots\ldots\ldots\ldots\ldots$

$d \sin\theta = (m + \frac{1}{2})\,\lambda$ for $m = 0, 1, 2, 3 \ldots$ (minima-dark fringe)

Find the angle to any fringe:

bright fringe: d sinθ = mλ for m = 0, 1, 2, 3 . . .

(1) m = 0: central maximum

$d \sin\theta = (0)\lambda$ $\sin\theta = 0$ $\theta = \sin^{-1} 0$ $\theta = 0$

(2) m = 1: first bright fringe/ first maxima

$d \sin\theta = 1\lambda$ $\sin\theta = \frac{\lambda}{d}$ $\theta = \sin^{-1}(\frac{\lambda}{d})$

(3) m = 2: second bright fringe/ second maxima

$d \sin\theta = 2\lambda$ $\sin\theta = \frac{2\lambda}{d}$ $\theta = \sin^{-1}(\frac{2\lambda}{d})$

dark fringe: $d \sin\theta = (m + \frac{1}{2})\,\lambda$ for m = 0, 1, 2, 3 . . .

(1) m = 0: first dark fringe/ first minima

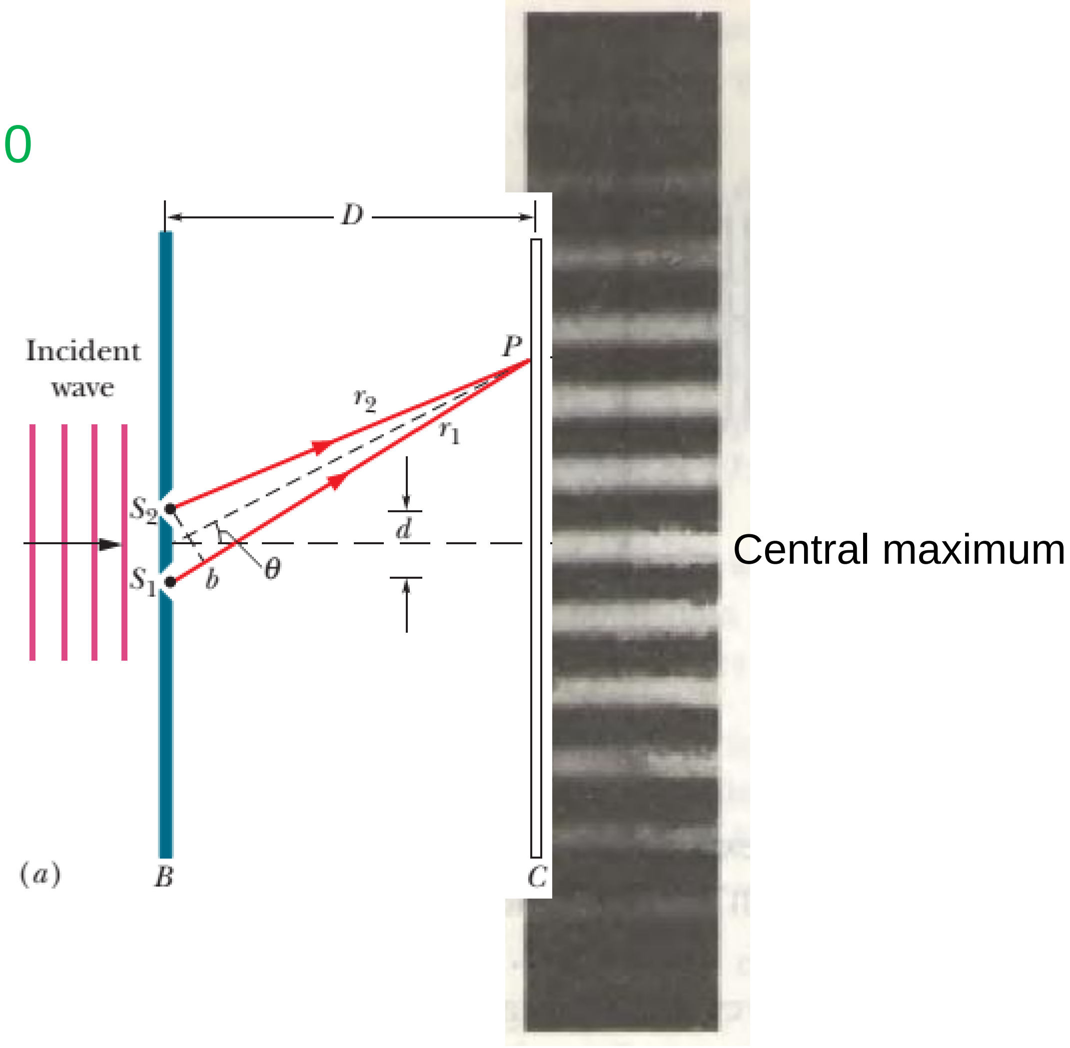
$d \sin\theta = (0 + \frac{1}{2})\,\lambda$ $\sin\theta = \frac{\lambda}{2d}$ $\theta = \sin^{-1}(\frac{\lambda}{2d})$

(2) m = 1: second dark fringe/ second minima

$d \sin\theta = (1 + \frac{1}{2})\,\lambda$ $d \sin\theta = (\frac{3\lambda}{2})$ $\theta = \sin^{-1}(\frac{3\lambda}{2d})$

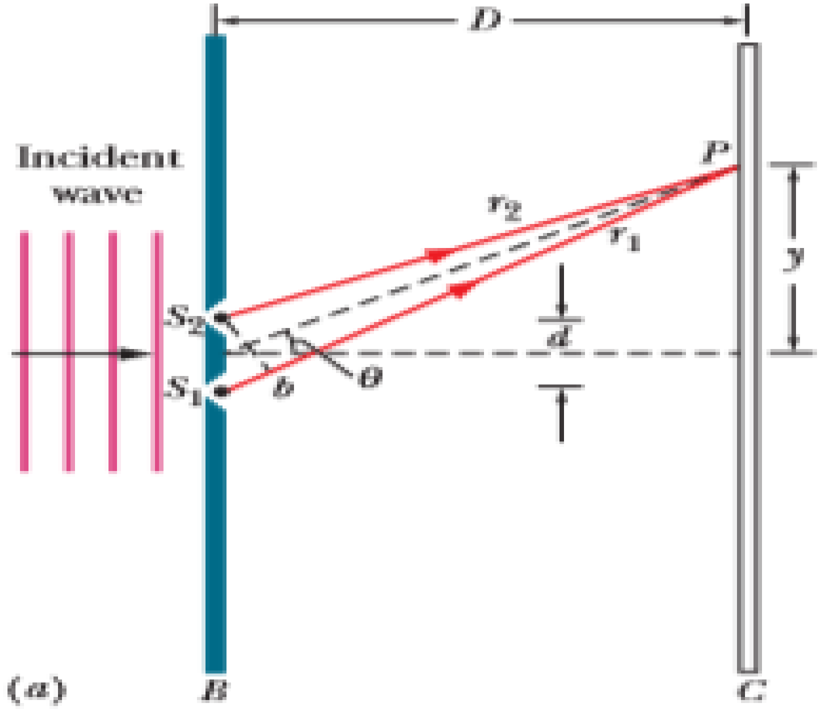
(3) m = 2: third dark fringe/ third minima

$d \sin\theta = (2 + \frac{1}{2})\,\lambda$ $d \sin\theta = (\frac{5\lambda}{2})$ $\theta = \sin^{-1}(\frac{5\lambda}{2d})$



What is the distance on screen C in Fig. 35-10a between adjacent maxima near the center of the interference. Assume that θ in Fig.35-10 is small enough to permit use of the approximations $\sin\theta \approx \tan\theta \approx \theta$,in which θ is expressed in radian measure. pattern?

Solution : the maximum's vertical distance y_m from the center of the pattern is related to its angle θ from the central axis by



$$\tan\theta \approx \theta = \frac{y_m}{D}$$

From maxima, $[d \sin\theta = m\lambda]$,

$$\sin\theta \approx \theta = \frac{m\lambda}{d}$$

If we equate our two expressions for angle θ and then solve for y_m,

$$\frac{y_m}{D} = \frac{m\lambda}{d}$$

$$\text{Or,}\quad y_m = \frac{m\lambda D}{d} \quad \text{.........} (1)$$

For the next maximum,

$$y_{m+1} = \frac{(m+1)\lambda D}{d} \quad \text{.........} (2)$$

We find the distance between these adjacent maxima by subtracting Eq.1 from Eq. 2 :

$$\Delta y = \mathbf{y_{m+1}} - y_m = \frac{\lambda D}{d} \quad \text{.......} (3)$$

Problem 20.

Monochromatic green light, of wavelength 550 nm, illuminates two parallel narrow slits 7.70 μm apart. Calculate the angular deviation (θ in Fig. 35-10) of the third-order bright fringe (a) in radians and (b) in degrees.

Solution : (a) We use $m = 3$: For maxima, $d \sin\theta = m\lambda$

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

$$\rightarrow \theta = \sin^{-1}\left(\frac{m\lambda}{d}\right) = \sin^{-1}\left(\frac{(3 \times 550\times\mathbf{10^{-9}}}{7.76\times\mathbf{10^{-6}}}\right) = 0.216 \text{ rad}$$

(b) $\theta = (0.216)\left(\frac{180°}{\pi}\right) = 12.4°$.

Problem 93. If the distance between the first and tenth minima of a double-slit pattern is 18.0 mm and the slits are separated by 0.150 mm with the screen 50.0 cm from the slits, what is the wavelength of the light used?

Solution : The condition for a is $d \sin\theta = (m + ½)\lambda$, If θ is small, $\sin\theta \approx \theta$

Then, $\rightarrow d\,\theta = (m + ½)\,\lambda \rightarrow \theta = \dfrac{(m + ½)\,\lambda}{d}$ .... (1)

and the distance from the minimum to the central fringe is

$$y = D \tan\theta \approx D\,\theta = (m + ½)\frac{D\lambda}{d} \quad \text{[using (1)]}$$

$$y = \frac{m\,D\lambda}{d} + \frac{D\lambda}{2d}$$

Taking the derivative,

$$\Delta y = \frac{\Delta m\, D\lambda}{d} \quad ; \quad \text{Here, first minima, } m = 0\text{ ; tenth minima, } m = 9 \rightarrow \Delta m = 9$$

the wavelength, $\lambda = \dfrac{d\,\Delta y}{\Delta m D} = \dfrac{(0.5 \times 10^{-3})(18 \times 10^{-3})}{9\,(50 \times 10^{-2})} = 6 \times 10^{-7}$ m $= 600$ nm