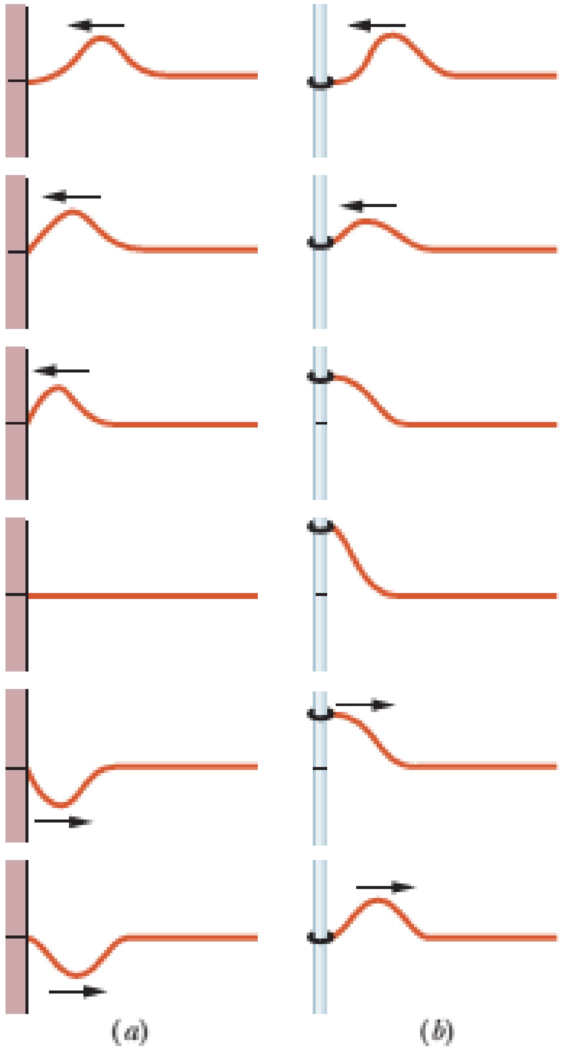
Lesson 20

Reflections at a Boundary:

Hard reflection: incident pulse is up and reflected pulse is down. reflected pulse is inverted. out of phase. destructive interference. node.



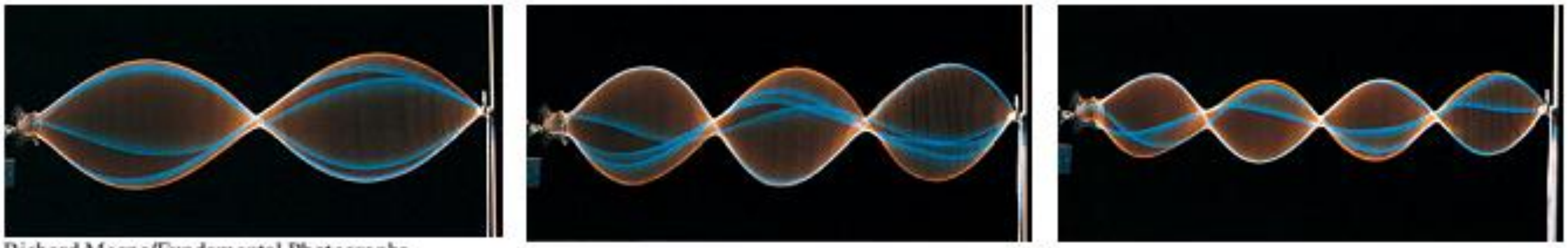
Soft reflection: incident pulse is up and reflected pulse is also up. reflected pulse is not inverted. in phase. constructive interference. antinode.

Fig. (a) Wall: hard reflection and (b) Rod: soft reflection

Standing waves and resonance:

Consider a string, such as a guitar string, that is stretched between two clamps. Suppose we send a continuous sinusoidal wave of a certain frequency along the string, say, toward the right. When the wave reaches the right end, it reflects and begins to travel back to the left. That left-going wave then overlaps the wave that is still traveling to the right.

For certain frequencies, the interference produces a standing wave pattern (or oscillation mode) with nodes and large antinodes like those in Fig. 16-20. Such a standing wave is said to be produced at resonance, and the string is said to resonate at these certain frequencies, called resonant frequencies.



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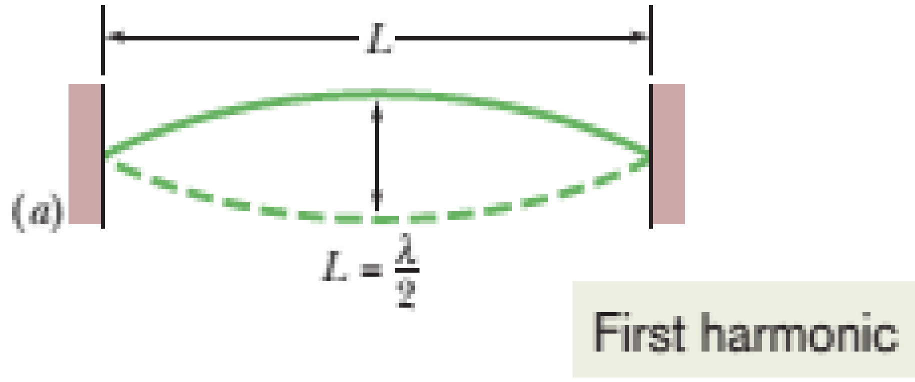
node = 2

antinode = 1

loop = 1

$\frac{\lambda}{2} = L$ or $\lambda = \frac{2L}{1}$

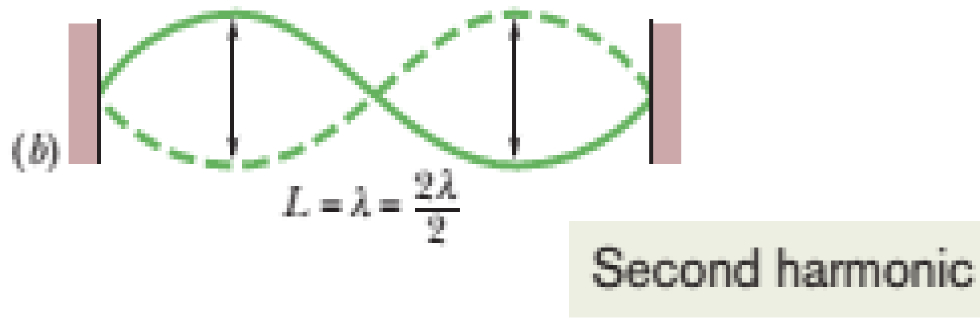


node = 2+1

antinode = 1+1

loop = 1+1

$\frac{\lambda}{2} + \frac{\lambda}{2} = L$ or $\lambda = \frac{2L}{2}$

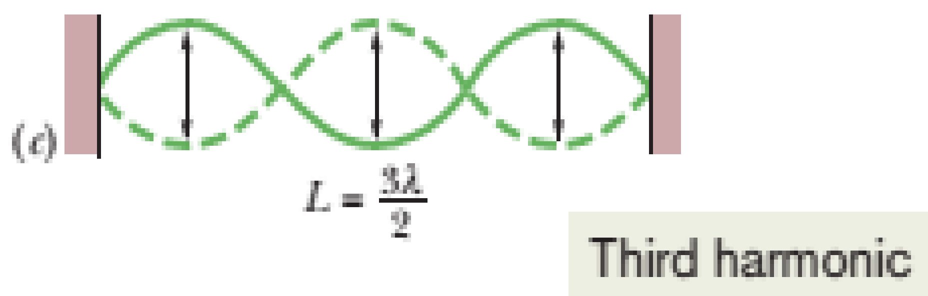


node = 3+1

antinode = 2+1

loop = 2+1

$\frac{\lambda}{2} + \frac{\lambda}{2} + \frac{\lambda}{2} = L$ or $\lambda = \frac{2L}{3}$



Thus, a standing wave can be set up on a string of length L by a wave with a wavelength equal to one of the values, $\lambda = \frac{2L}{n}$ for n = 1, 2, 3. ……..

The resonant frequencies that corresponds to these wavelengths follow from the equation

$$v = f\,\lambda$$

$$f = \frac{v}{\frac{2L}{n}}$$

$$f = \frac{n}{2L}v \qquad v = \sqrt{\frac{\tau}{\mu}}$$

Resonant frequency, $f = \frac{n}{2L}\sqrt{\frac{\tau}{\mu}}$

Oscillation mode: n = 1, 2, 3,………………….

If n = 1, $f_1 = \frac{1}{2L}\sqrt{\frac{\tau}{\mu}}$; *fundamenta mode or first harmonic*

If n = 2, $f_2 = \frac{2}{2L}\sqrt{\frac{\tau}{\mu}}$; *second harmonic*

If n = 3, $f_3 = \frac{3}{2L}\sqrt{\frac{\tau}{\mu}}$; *thrid harmonic*

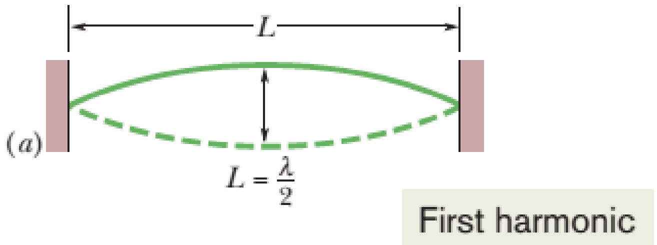
44. A 125 cm length of string has a mass 2.00 g and tension 7.00 N between fixed supports. (a) What is the wave speed for this string? (b) What is the lowest resonant frequency of this string?

Here, $L = 125 \text{ cm} = \frac{125}{100} = 1.25 \text{ m}$

$m = 2.00 \text{ gm} = \frac{2}{1000} \text{ kg} = 0.002 \text{ kg}$

$\tau = 7.00 \text{ N}$

$\mu = \frac{m}{L} = \frac{0.002}{1.25} \text{ kg/m} = 0.0016 \text{ kg/m}$

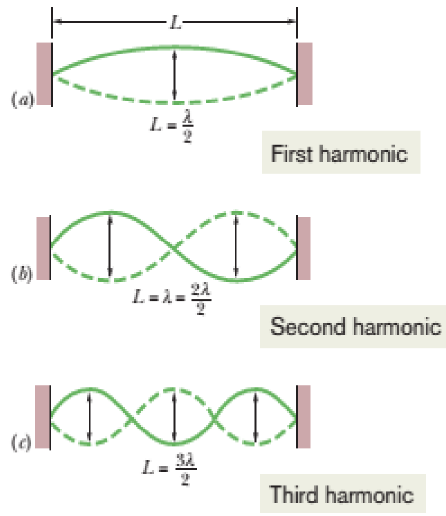


(a) $v = \sqrt{\frac{\tau}{\mu}} = \sqrt{\frac{7.00}{0.0016}} = \sqrt{(4375)} = 66.14 \text{ m/s}$ Ans.

(b) For the lowest resonant frequency, n = 1: $f = \frac{n}{2L}\sqrt{\frac{\tau}{\mu}}$

$f_1 = \frac{1}{2L}\sqrt{\frac{\tau}{\mu}} = \frac{1}{2L} v = \frac{1}{2(1.25)}(66.14) = 26.46 \text{ Hz}$ Ans.

85. A 120 cm length of string is stretched between fixed supports. What are the (a) longest, (b) second longest, and (c) third longest wavelength for waves traveling on the string if standing waves are to be set up? (d) Sketch those standing waves.



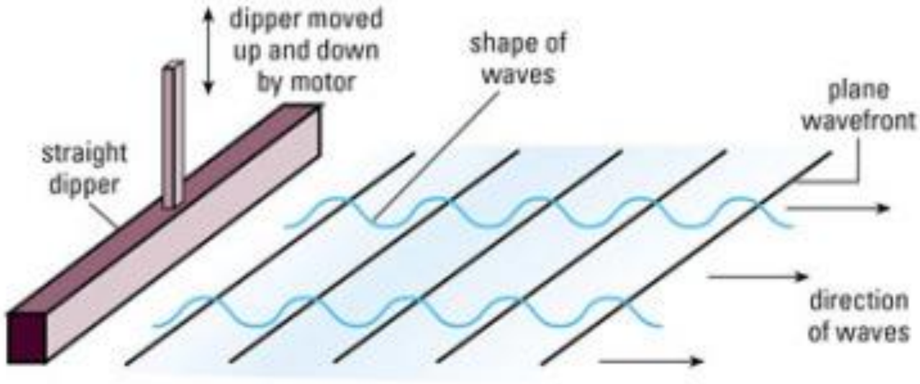
Here, $L = 120\text{ cm} = \frac{120}{100}\text{ m} = 1.20\text{ m}$

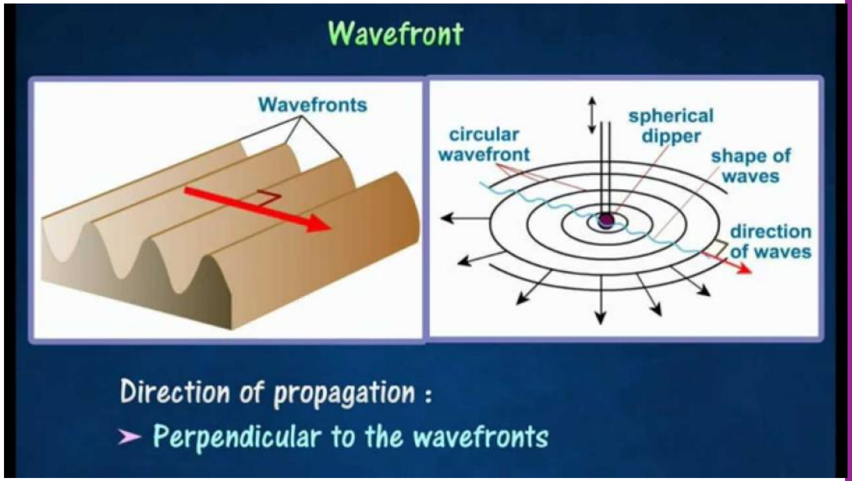
(a) $\frac{\lambda}{2} = L$ $\quad \lambda = 2L = 2\,(1.20) = 2.40\text{ m}$ Ans.

(b) $\frac{\lambda}{2} + \frac{\lambda}{2} = L$ $\quad \frac{2\lambda}{2} = L$ $\quad \lambda = L = 1.20\text{m}$ Ans.

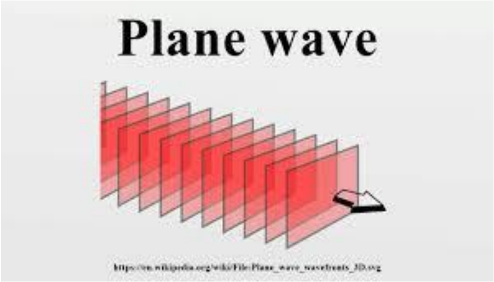
(c) $\frac{\lambda}{2} + \frac{\lambda}{2} + \frac{\lambda}{2} = L$ $\quad \frac{3\lambda}{2} = L$ $\quad \lambda = \frac{2L}{3} = \frac{2(1.20)}{3} = 0.80\text{ m}$ Ans.

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.

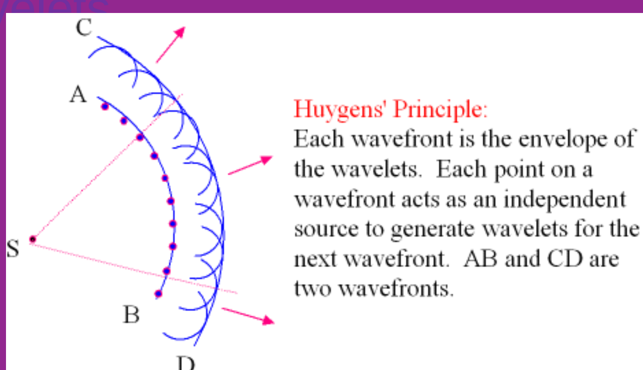


Circular wave on the water surface generated by a small ball oscillating in the vertical direction.

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.



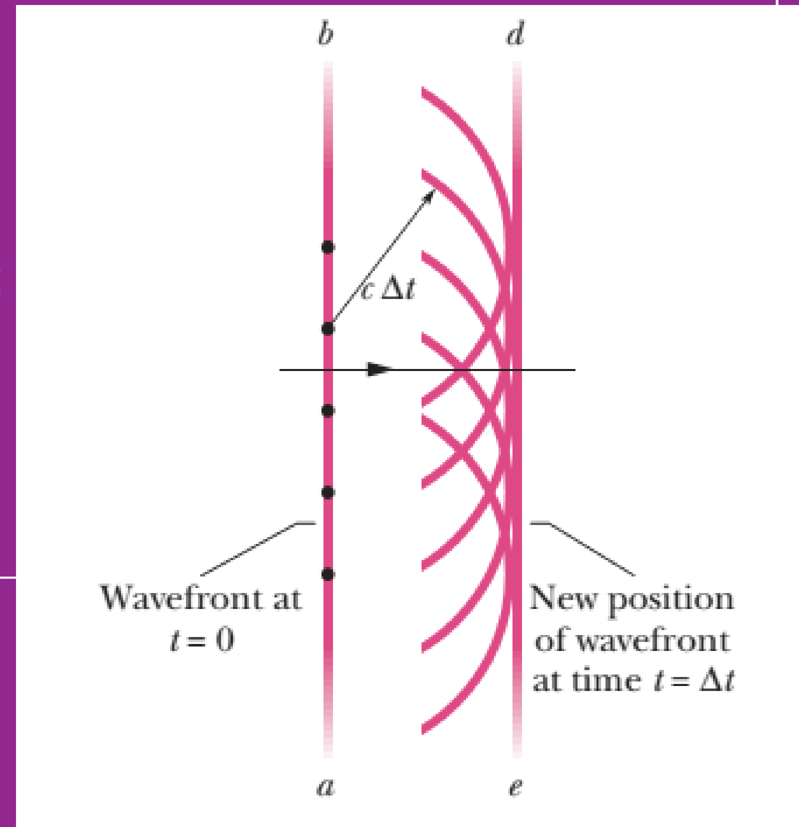
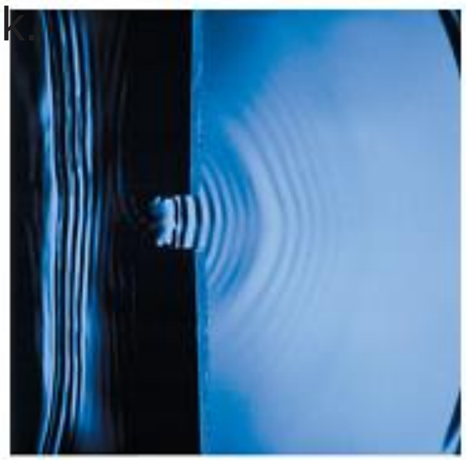


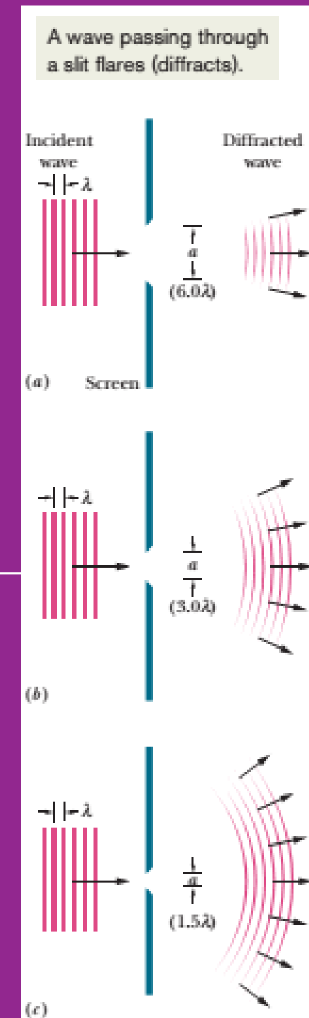
Figure 35-2 The propagation of a plane wave in vacuum, as portrayed by Huygens' principle.

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

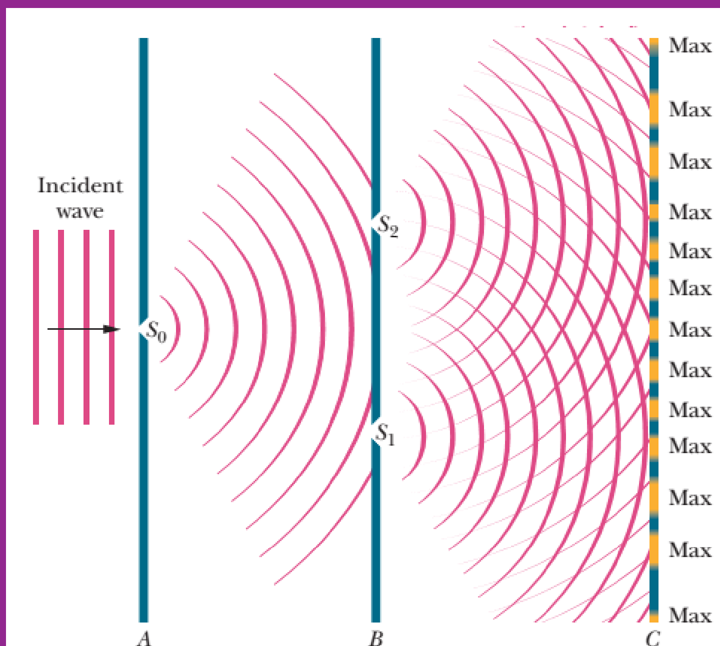


35-2 YOUNG'S INTERFERENCE EXPERIMENT:

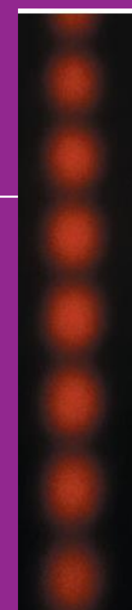
To form Interference, the incident light satisfy two conditions:

(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.



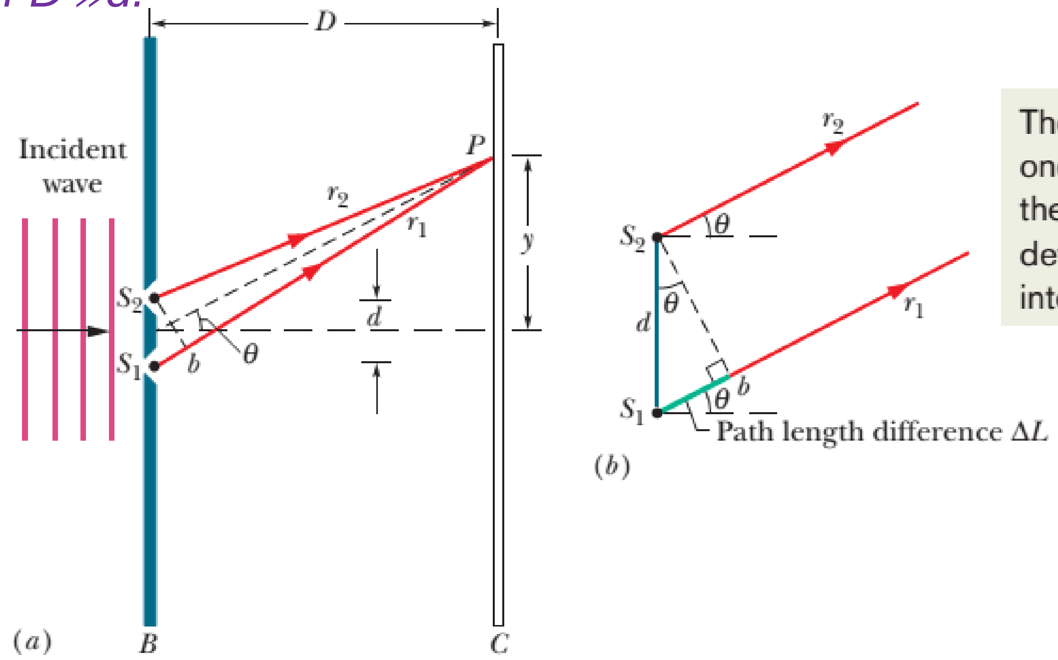
diffracted wavs diffracted wavs interference



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.

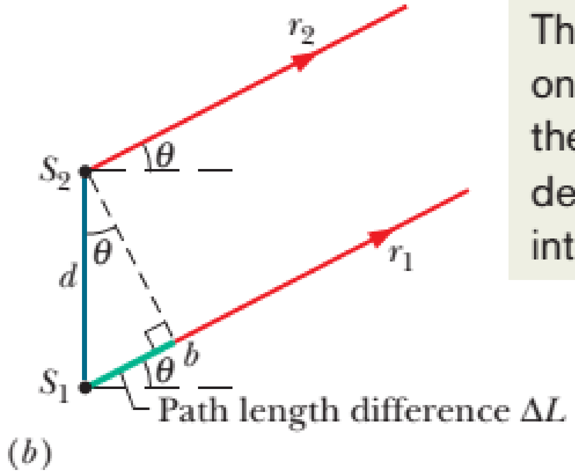
Condition for maximum and minimum:

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

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

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

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



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

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

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

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

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

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