# Chapter 28: Physical Optics: Interference and Diffraction

5. The figure shows two students listening to two coherent sound sources. Both students hear constructive interference.

Since student A is equidistant from both speakers the difference in path lengths from each speaker is zero. For student B to also hear constructive interference (and for the wavelength to be a maximum) the path length difference between him and the two speakers must be equal to one wavelength. Calculate the distance of student B from each speaker. Set the wavelength equal to the difference in distances. Divide the speed of sound by the wavelength to calculate the frequency.
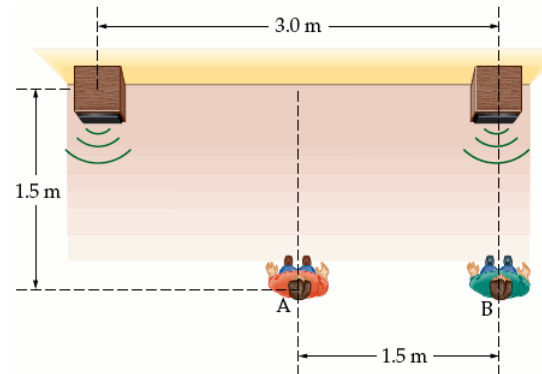
1. Calculate the distance to the far speaker:
$$\ell_2 = \sqrt{(1.5 \text{ m})^2 + (3.0 \text{ m})^2} = 3.354 \text{ m}$$

2. Subtract the distances:
$$\ell_2 - \ell_1 = \lambda = 3.354 - 1.50 = 1.854 \text{ m}$$

3. Divide the speed of sound by the wavelength:
$$f = \frac{v}{\lambda} = \frac{343 \text{ m/s}}{1.854 \text{ m}} = \boxed{0.18 \text{ kHz}}$$

9. The image shows three people standing 3.00 m in front of two speakers that are separated by 0.800 m. The people are each standing 1.00 m apart with the middle person directly in front of the midpoint between the speakers. The speakers are oscillating in phase.

Larry, at the midpoint, is equidistant from each speaker and will hear maximum intensity at all frequencies. Moe and Curly will hear minimum intensity when the difference in their distances from each speaker is a half-integral wavelength. Use the Pythagorean theorem to determine their distances from the speakers. Set $\Delta\ell = \frac{1}{2}\lambda$ for the lowest frequency and $\Delta\ell = \frac{3}{2}\lambda$ for the second lowest frequency and solve for the wavelength. Then divide the speed of sound by the wavelength to calculate the frequency.
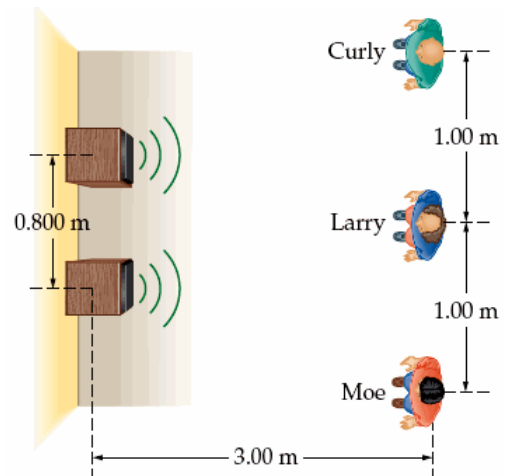
1. Find Moe's distance to the near speaker:
$$\ell_1 = \sqrt{(1.00 \text{ m} - 0.40 \text{ m})^2 + (3.00 \text{ m})^2} = 3.059 \text{ m}$$

2. Find Moe's distance to the far speaker:
$$\ell_2 = \sqrt{(1.00 \text{ m} + 0.40 \text{ m})^2 + (3.00 \text{ m})^2} = 3.311 \text{ m}$$

3. Set the difference equal to a half wavelength:
$$\tfrac{1}{2}\lambda = \ell_2 - \ell_1 \implies \lambda = 2(3.311 \text{ m} - 3.059 \text{ m}) = 0.502 \text{ m}$$

4. Divide the speed by the wavelength:
$$f = \frac{v}{\lambda} = \frac{343 \text{ m/s}}{0.502 \text{ m}} = \boxed{0.68 \text{ kHz}}$$

5. Set $\Delta\ell = \frac{3}{2}\lambda$ to find λ:
$$\tfrac{3}{2}\lambda = \ell_2 - \ell_1 \implies \lambda = \tfrac{2}{3}(3.311 \text{ m} - 3.059 \text{ m}) = 0.167 \text{ m}$$

6. Divide the speed by the wavelength:
$$f = \frac{v}{\lambda} = \frac{343 \text{ m/s}}{0.167 \text{ m}} = \boxed{2.0 \text{ kHz}}$$
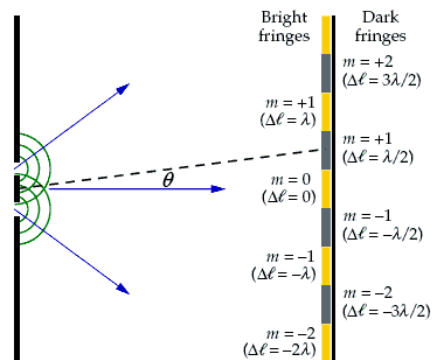
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18. The first dark fringe in Young's two-slit experiment occurs at $\theta = 0.31°$ as shown in the figure.

Solve equation 28-2 for the wavelength with $m = 1$ for the ratio of the slit separation (d) to the wavelength (λ).

Calculate the ratio of slit spacing to wavelength:

$$d \sin \theta = \left(m - \tfrac{1}{2}\right)\lambda$$

$$\frac{d}{\lambda} = \frac{\left(m - \tfrac{1}{2}\right)}{\sin \theta} = \frac{\left(1 - \tfrac{1}{2}\right)}{\sin 0.31°} = \boxed{92}$$

Bright fringes | Dark fringes

$m = +2$ $(\Delta \ell = 3\lambda/2)$
$m = +1$ $(\Delta \ell = \lambda)$
$m = +1$ $(\Delta \ell = \lambda/2)$
$m = 0$ $(\Delta \ell = 0)$
$m = -1$ $(\Delta \ell = -\lambda/2)$
$m = -1$ $(\Delta \ell = -\lambda)$
$m = -2$ $(\Delta \ell = -3\lambda/2)$
$m = -2$ $(\Delta \ell = -2\lambda)$

20. The image shows the diffraction pattern of light passing through two slits onto a screen 1.00 m away. The distance between the two third-order minima is 22.0 cm. The width of the central maximum is shown as x.

Calculate the angle of the third-order minimum by dividing half the distance between the two minima by the screen distance and taking the inverse tangent of the dividend. Use that angle to solve equation 28-2 for the ratio of the wavelength to the slit separation distance. Then use that ratio to calculate the angle θ_1 to the first minimum. Use equation 28-3 to calculate the distance y_1 to the first minimum. Finally, double that distance to find the full width of the central maximum.

Solution: 1. Find the angle to the third-order minimum:

$$y = L \tan \theta_3$$

$$\theta_3 = \tan^{-1} \frac{y}{L} = \tan^{-1} \left[\frac{\tfrac{1}{2}(22.0 \text{ cm})}{100 \text{ cm}} \right] = 6.277°$$

2. Calculate the ratio λ/d using the third-order ($m = 3$) fringe and equation 28-2:

$$d \sin \theta_3 = \left(3 - \tfrac{1}{2}\right)\lambda$$

$$\frac{\lambda}{d} = \frac{\sin 6.277°}{2.5} = 0.04374$$

3. Calculate the angle to the first minimum:

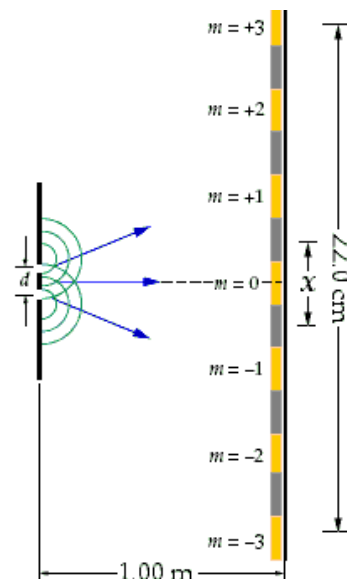$$\sin \theta_1 = \left(m - \tfrac{1}{2}\right)\frac{\lambda}{d}$$

$$\theta_1 = \sin^{-1}\left[\left(1 - \tfrac{1}{2}\right)(0.04374)\right] = 1.253°$$

4. Find the distance y_1 to the first minimum:

$$y_1 = L \tan \theta_1 = (100 \text{ cm}) \tan(1.253°) = 2.187 \text{ cm}$$

5. Double the result to find the entire width of the central maximum:

$$x = 2y_1 = 2(2.187 \text{ cm}) = \boxed{4.37 \text{ cm}}$$

$m = +3$
$m = +2$
$m = +1$
$m = 0$
$m = -1$
$m = -2$
$m = -3$

22.0 cm

1.00 m

22. A two-slit interference pattern produced by 546 nm light is observed on a screen that is 8.75 m from the slits. The first-order maximum is 5.36 cm above the central maxima.

Use equation 28-3 to find the angle for the first-order maximum, and then insert the angle into equation 28-1 to solve for the slit separation distance.

1. Find the angle to the first bright fringe:

$$\theta = \tan^{-1}\frac{y}{L} = \tan^{-1}\frac{5.36 \text{ cm}}{875 \text{ cm}} = 0.351°$$

2. Solve equation 28-1 for d:

$$d = \frac{m\lambda}{\sin \theta} = \frac{(1)546 \text{ nm}}{\sin(0.351°)} = \boxed{89.1 \ \mu m}$$

26. The figure shows the interference patterns for (a) green light and (b) another color of light passing through the same two slits.

Set the angle for the fifth-order minimum (using equation 28-2) of the green light equal to the fifth-order maximum (using equation 28-1) of the unknown wavelength, and solve for the wavelength.

(a)

(b)
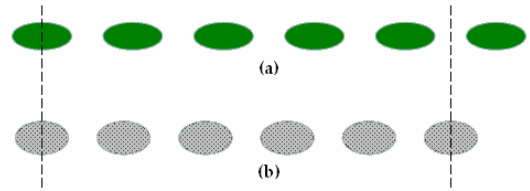
1. (a) From equation 28-1 we see that the angular separation is proportional to the wavelength. Because the fringes in part (b) of the figure have a smaller angular separation, the second wavelength must be less than 505 nm.

2. (b) Solve equation 28-2 for the fifth-order minima:

$$d \sin \theta = \left(m - \tfrac{1}{2}\right)\lambda = \left(5 - \tfrac{1}{2}\right)(505 \text{ nm}) = 2273 \text{ nm}$$

3. Insert the same $d \sin \theta$ into equation 28-1 and solve for the wavelength:

$$\lambda = \frac{d \sin \theta}{m} = \frac{2273 \text{ nm}}{5} = \boxed{455 \text{ nm}}$$