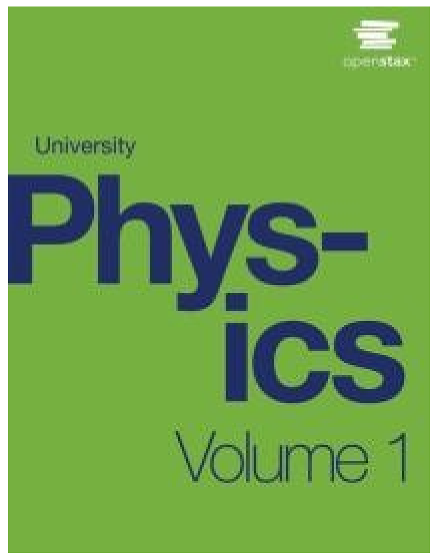
UNIVERSITY PHYSICS

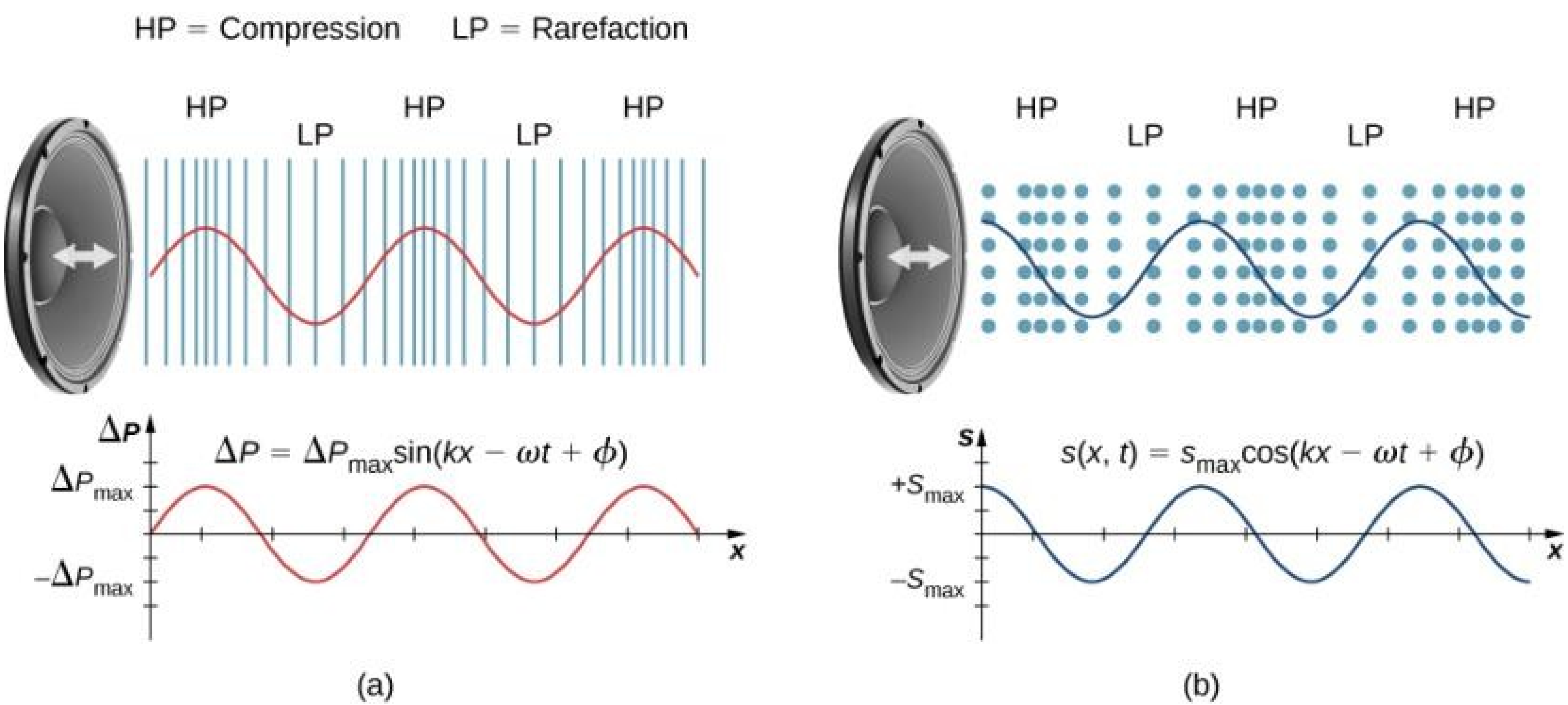
Chapter 17 SOUND

PowerPoint Image Slideshow



Sound waves

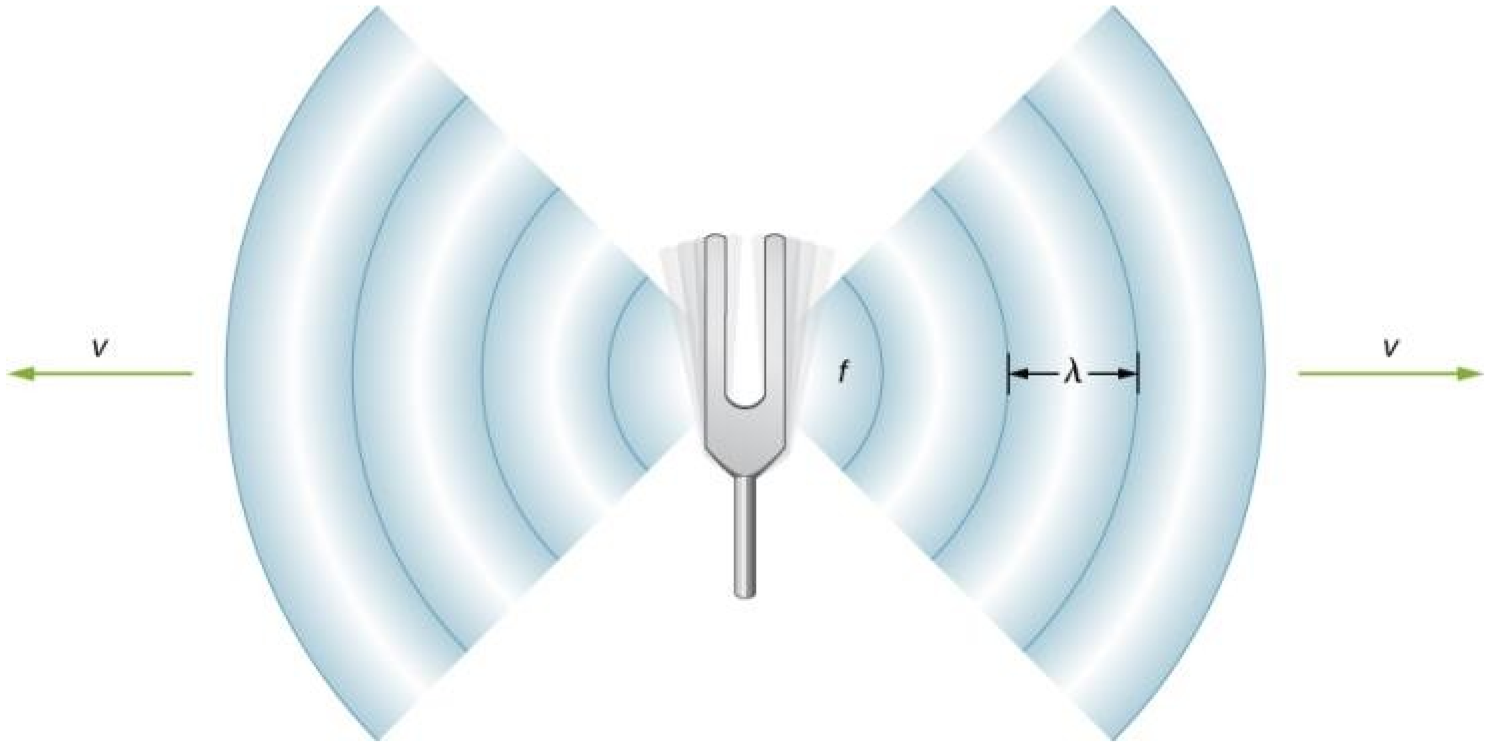
FIGURE 17.3



a) A vibrating cone of a speaker, moving in the positive *x*-direction, compresses the air in front of it and expands the air behind it. As the speaker oscillates, it creates another compression and rarefaction as those on the right move away from the speaker. After many vibrations, a series of compressions and rarefactions moves out from the speaker as a sound wave. The red graph shows the gauge pressure of the air versus the distance from the speaker. Pressures vary only slightly from atmospheric pressure for ordinary sounds. Note that gauge pressure is modeled with a sine function, where the crests of the function line up with the compressions and the troughs line up with the rarefactions.

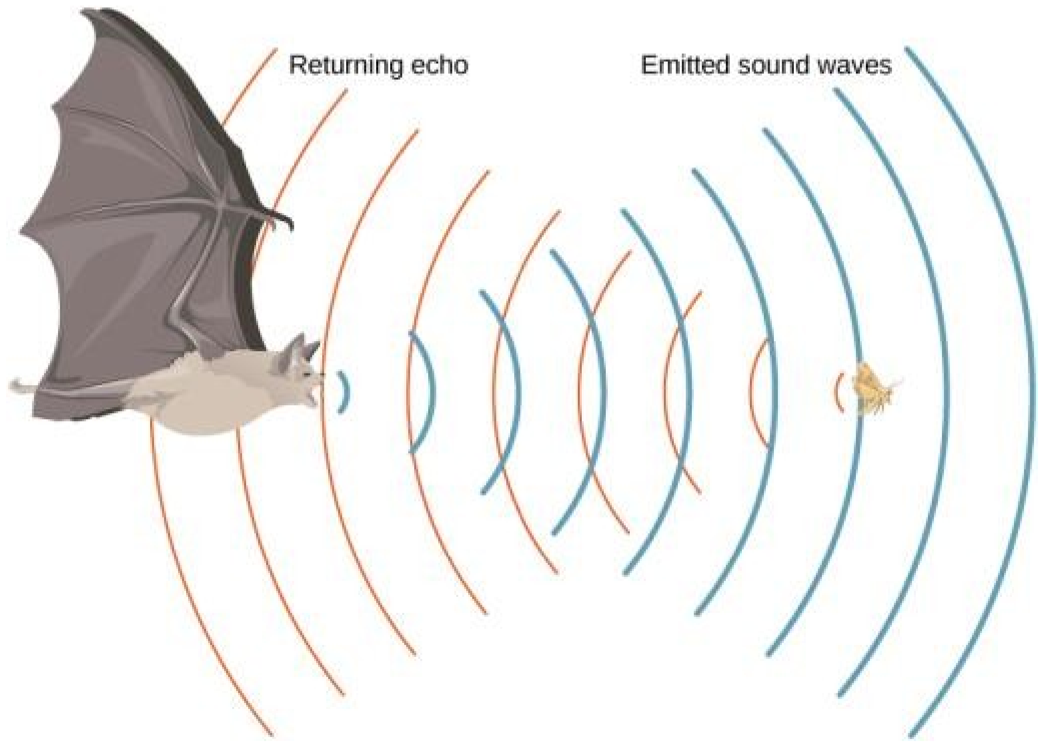
b) Sound waves can also be modeled using the displacement of the air molecules. The blue graph shows the displacement of the air molecules versus the position from the speaker and is modeled with a cosine function. Notice that the displacement is zero for the molecules in their equilibrium position and are centered at the compressions and rarefactions. Compressions are formed when molecules on either side of the equilibrium molecules are displaced toward the equilibrium position. Rarefactions are formed when the molecules are displaced away from the equilibrium position.

FIGURE 17.5



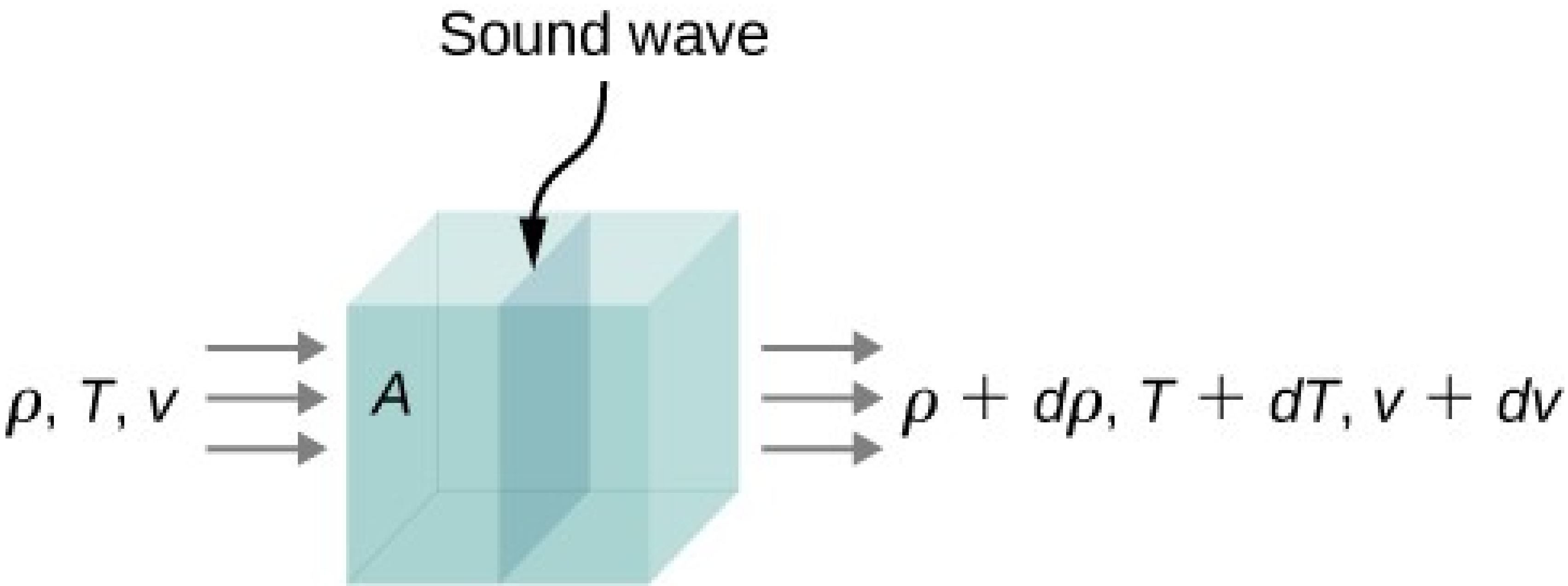
A sound wave emanates from a source, such as a tuning fork, vibrating at a frequency *f*. It propagates at speed *v* and has a wavelength .

FIGURE 17.6



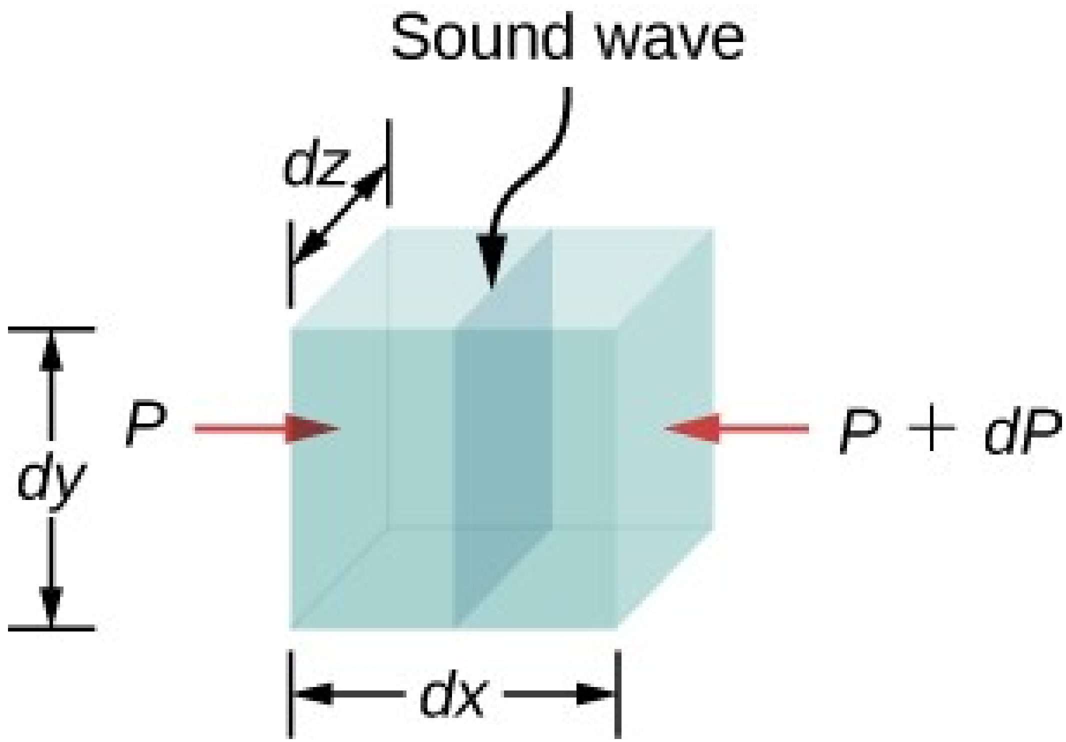
A bat uses sound echoes to find its way about and to catch prey. The time for the echo to return is directly proportional to the distance.

FIGURE 17.8



A sound wave moves through a volume of fluid. The density, temperature, and velocity of the fluid change from one side to the other.

FIGURE 17.9



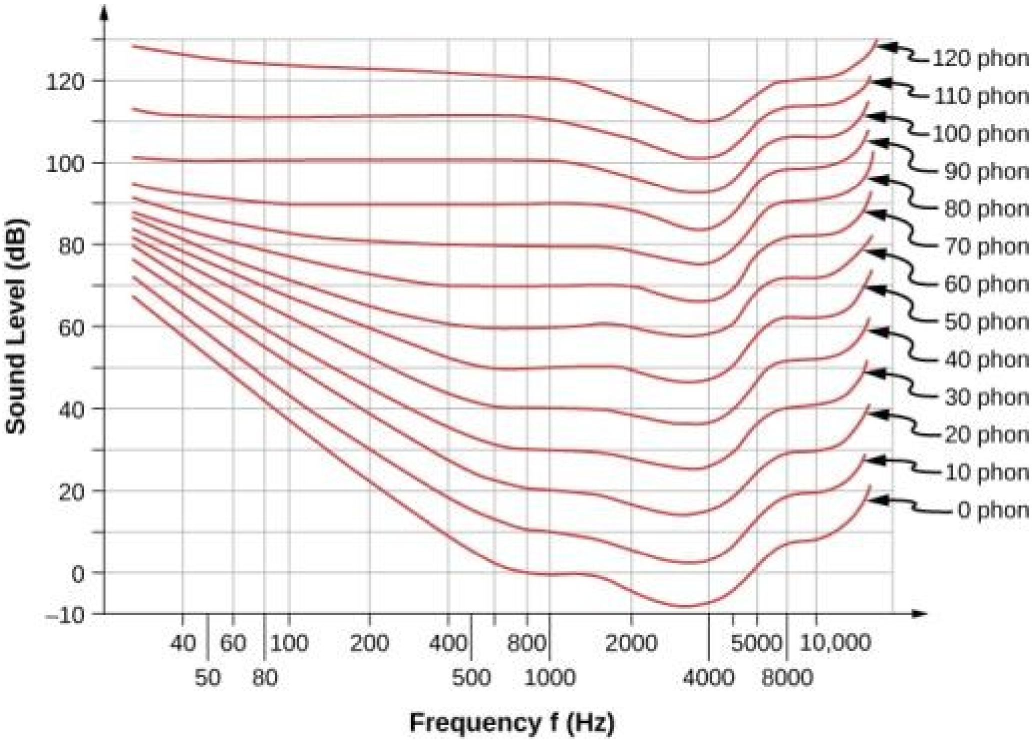
A sound wave moves through a volume of fluid. The force on each face can be found by the pressure times the area.

FIGURE 17.10

Because they travel at the same speed in a given medium, low-frequency sounds must have a greater wavelength than high-frequency sounds. Here, the lower-frequency sounds are emitted by the large speaker, called a woofer, whereas the higher-frequency sounds are emitted by the small speaker, called a tweeter.

Intensity

FIGURE 17.15



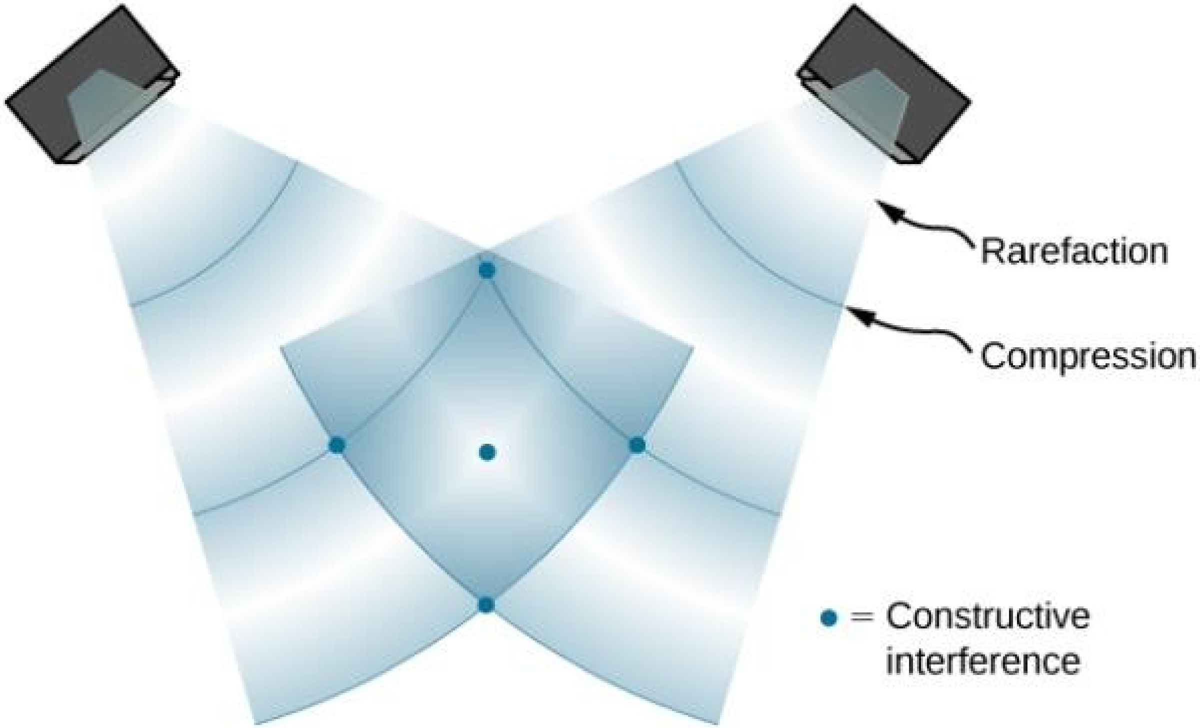
$$\beta(dB) = 10 \log_{10} \frac{I}{I_0}$$

$$I_0 = 10^{-12} W/m^2$$

The relationship of loudness in phons to intensity level (in decibels) and intensity (in watts per meter squared) for persons with normal hearing. The curved lines are equal-loudness curves—all sounds on a given curve are perceived as equally loud. Phons and decibels are defined to be the same at 1000 Hz.

Interference

FIGURE 17.16



When sound waves are produced by a speaker, they travel at the speed of sound and move out as spherical waves. Here, two speakers produce the same steady tone (frequency). The result is points of high-intensity sound (highlighted), which result from two crests (compression) or two troughs (rarefaction) overlapping. Destructive interference results from a crest and trough overlapping. The points where there is constructive interference in the figure occur because the two waves are in phase at those points. Points of destructive interference (Figure 17.17) are the result of the two waves being out of phase.

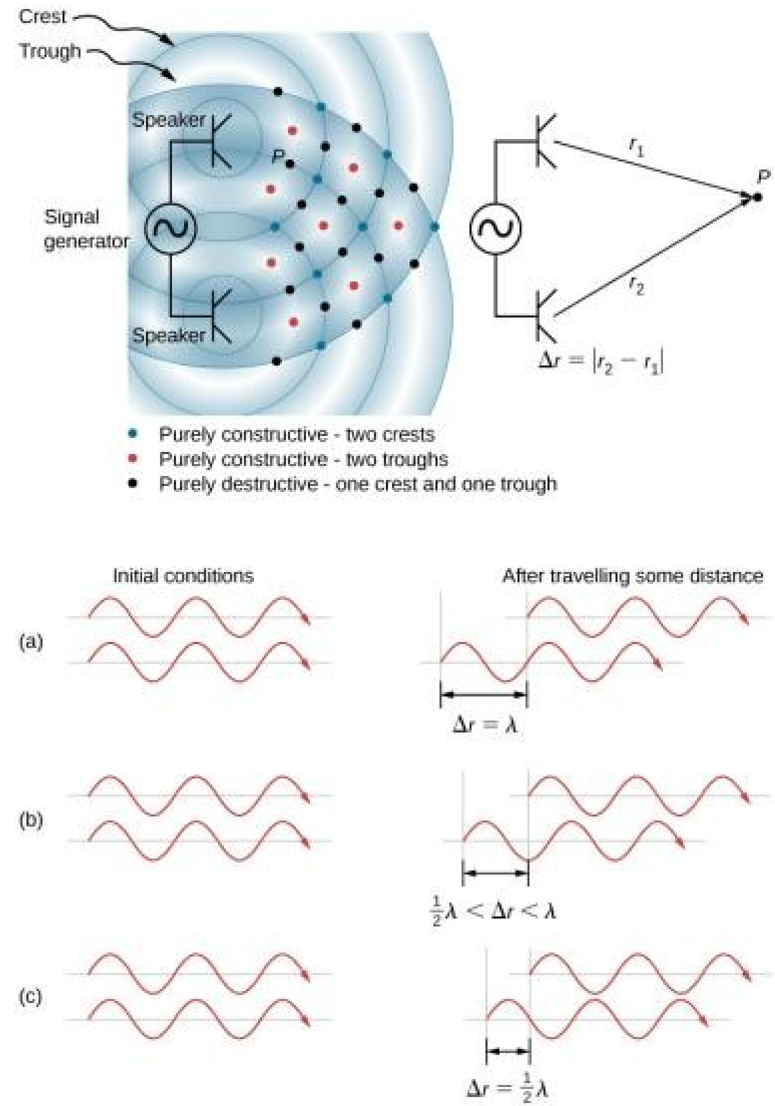
FIGURE 17.17

Two speakers being driven by a single signal generator. The sound waves produced by the speakers are in phase and are of a single frequency. The sound waves interfere with each other. When two crests or two troughs coincide, there is constructive interference, marked by the red and blue dots. When a trough and a crest coincide, destructive interference occurs, marked by black dots. The phase difference is due to the path lengths traveled by the individual waves. Two identical waves travel two different path lengths to a point *P*.

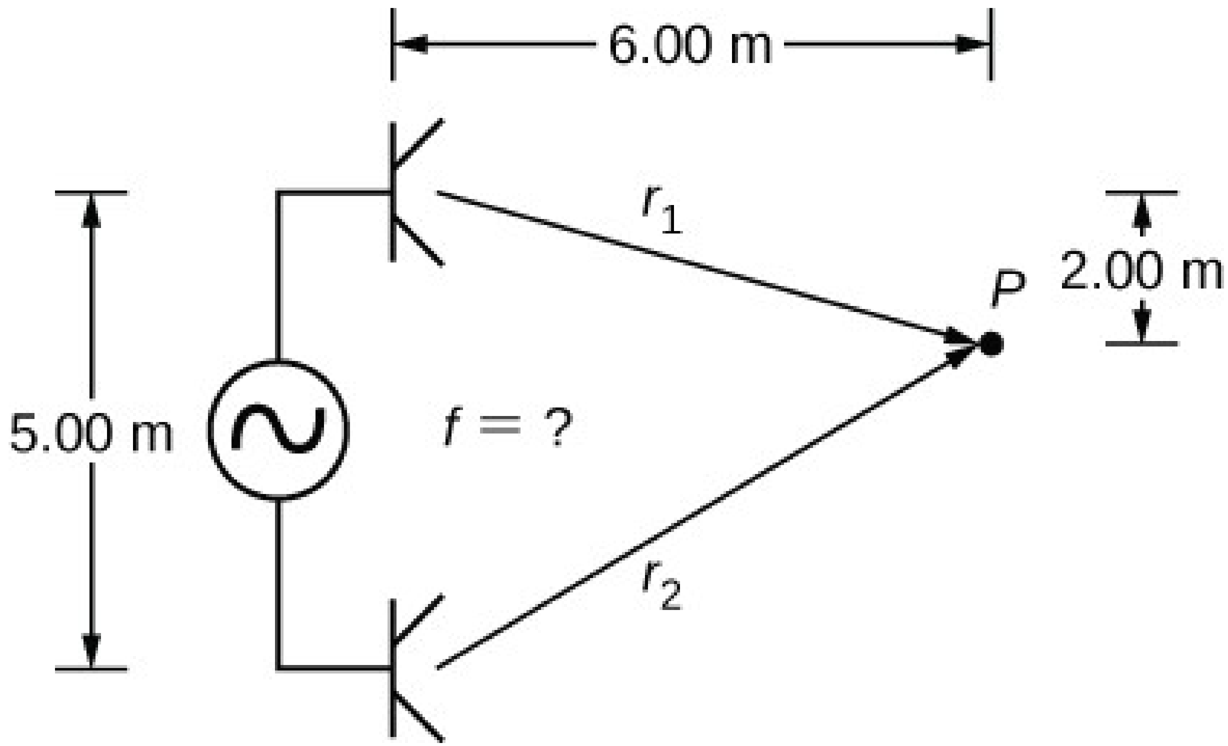
a) The difference in the path lengths is one wavelength, resulting in total constructive interference and a resulting amplitude equal to twice the original amplitude.

b) The difference in the path lengths is less than one wavelength but greater than one half a wavelength, resulting in an amplitude greater than zero and less than twice the original amplitude.

c) The difference in the path lengths is one half of a wavelength, resulting in total destructive interference and a resulting amplitude of zero.



EXAMPLE 17.5.1



Two speakers are separated by 5.00 m and are being driven by a signal generator at an unknown frequency. A student with a sound-level meter walks out 6.00 m and down 2.00 m, and finds the first minimum intensity, as shown below. What is the frequency supplied by the signal generator? Assume the wave speed of sound is $v=343.00 m/s$.

EXAMPLE 17.5.2

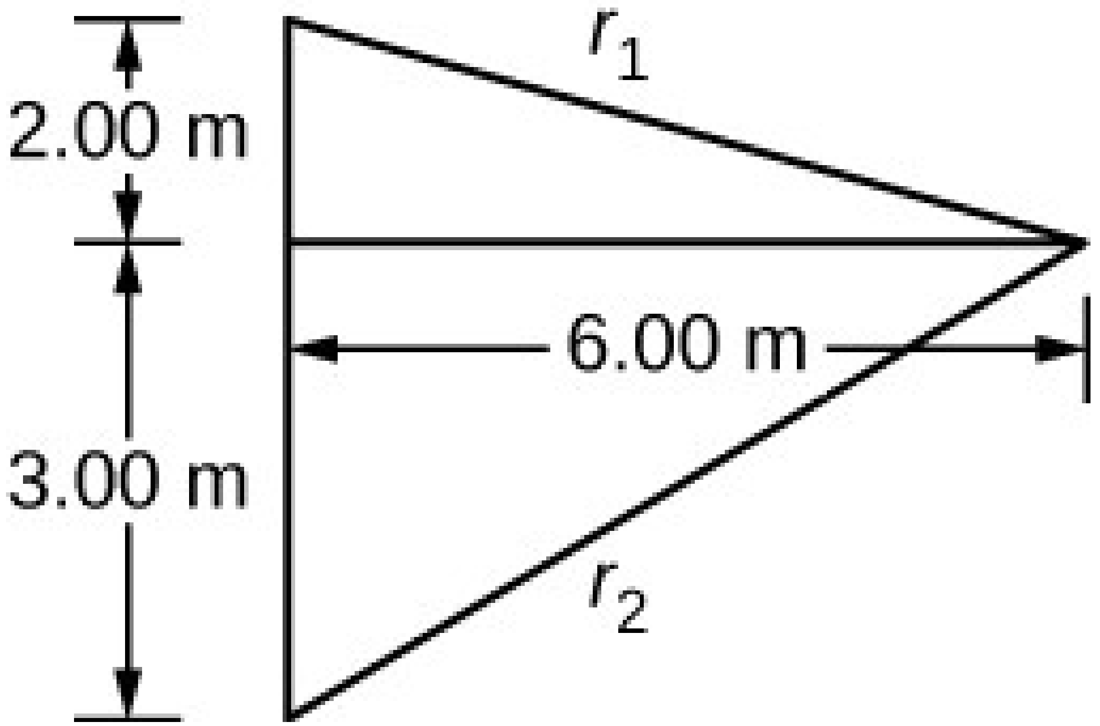
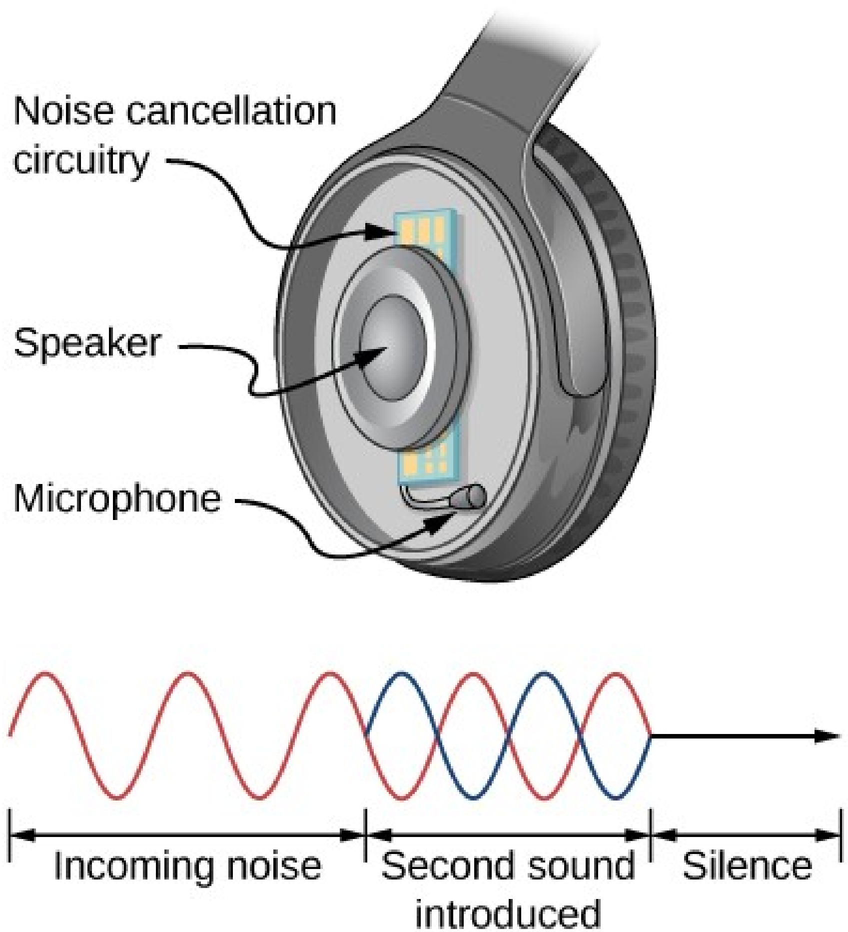


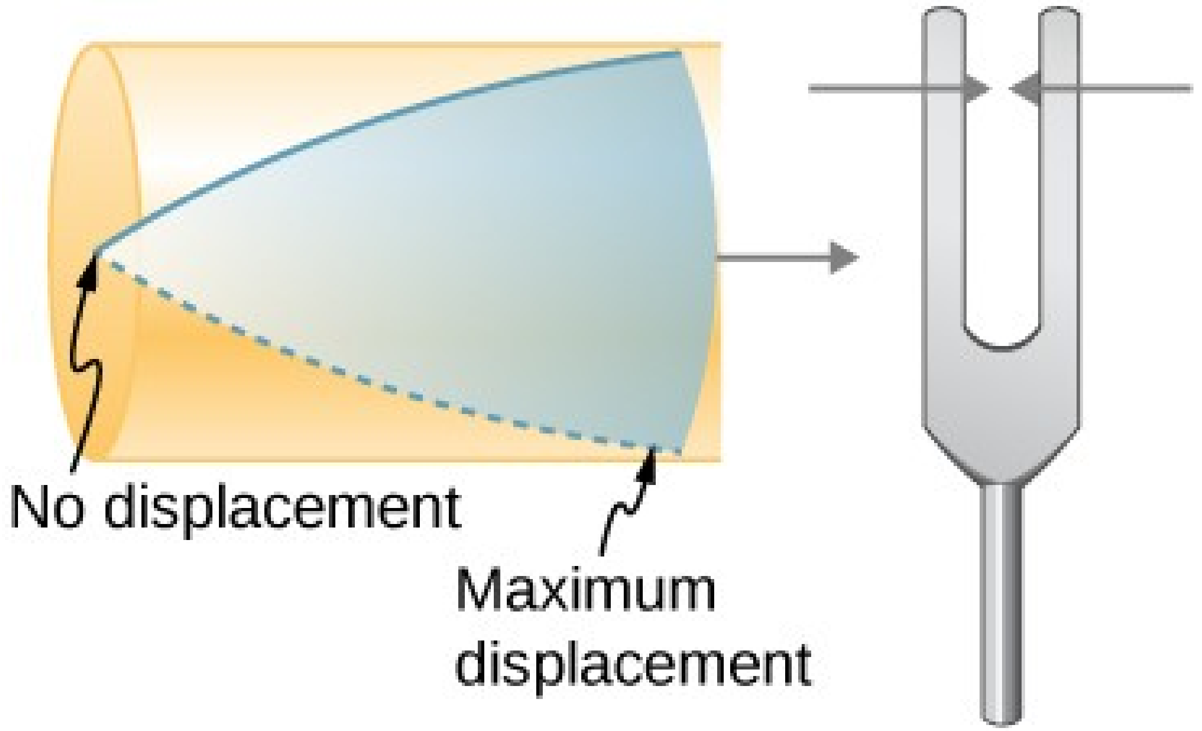
FIGURE 17.18



Headphones designed to cancel noise with destructive interference create a sound wave exactly opposite to the incoming sound. These headphones can be more effective than the simple passive attenuation used in most ear protection. Such headphones were used on the record-setting, around-the-world nonstop flight of the *Voyager* aircraft in 1986 to protect the pilots' hearing from engine noise.

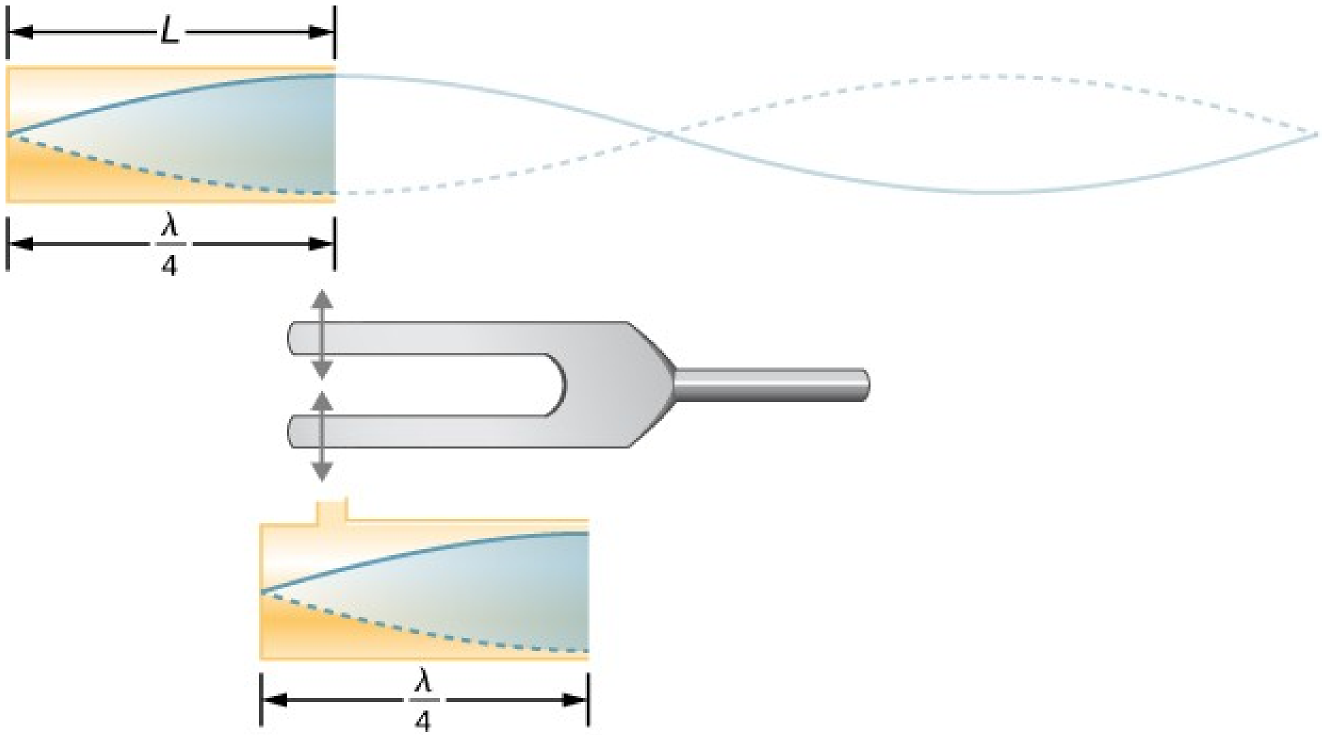
Standing waves in pipes

FIGURE 17.19



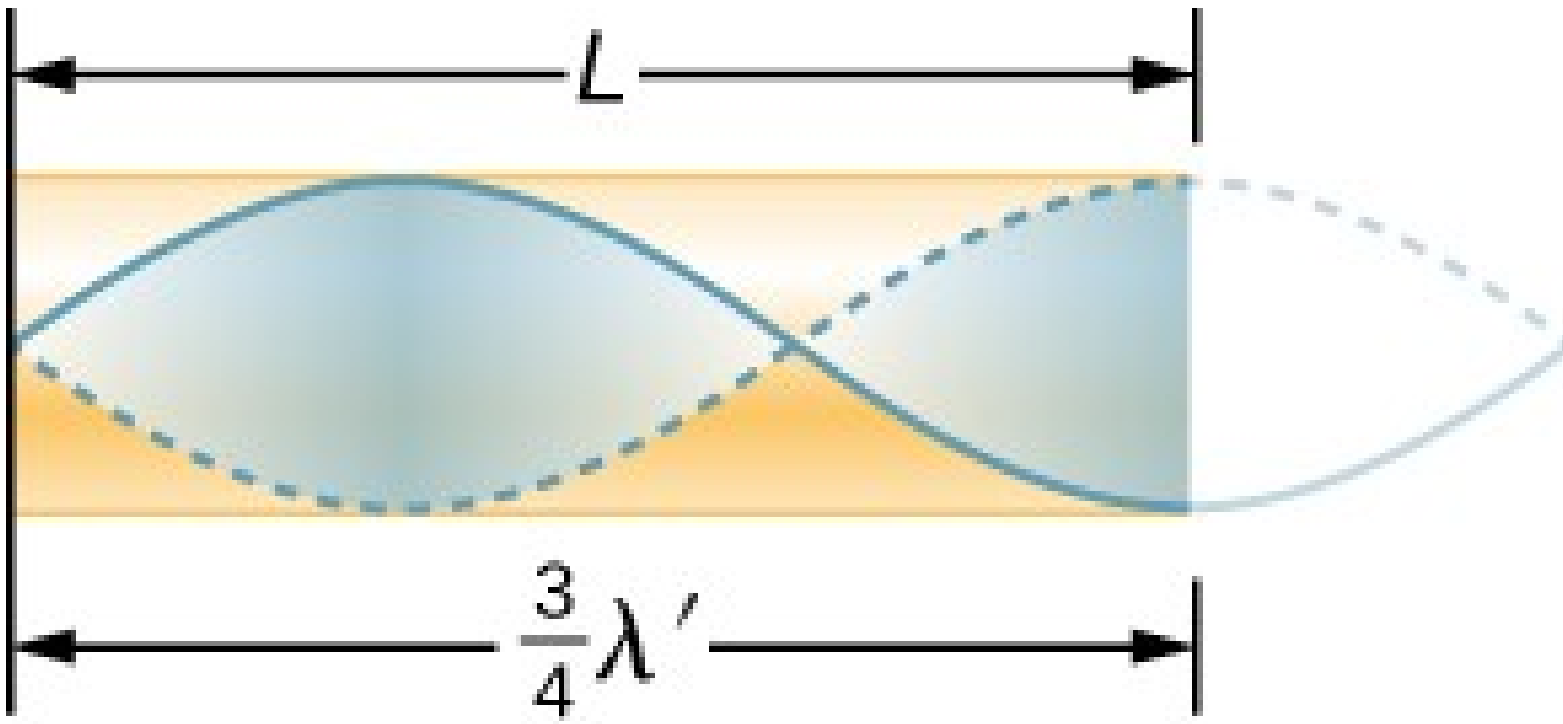
Resonance of air in a tube closed at one end, caused by a tuning fork that vibrates at the lowest frequency that can produce resonance (the fundamental frequency). A node exists at the closed end and an antinode at the open end.

FIGURE 17.20



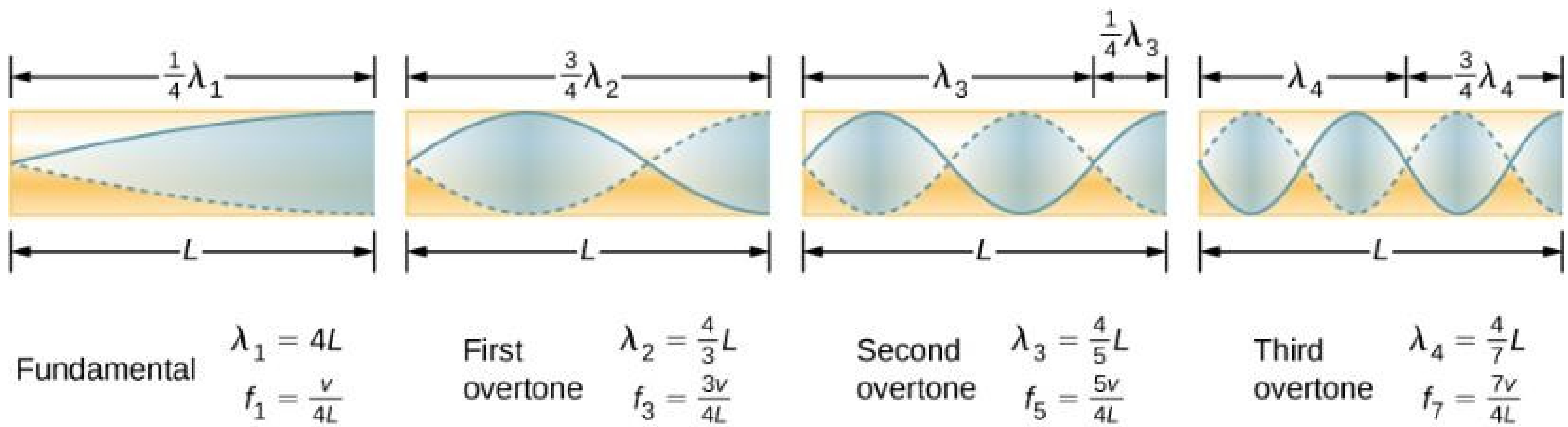
The same standing wave is created in the tube by a vibration introduced near its closed end.

FIGURE 17.21



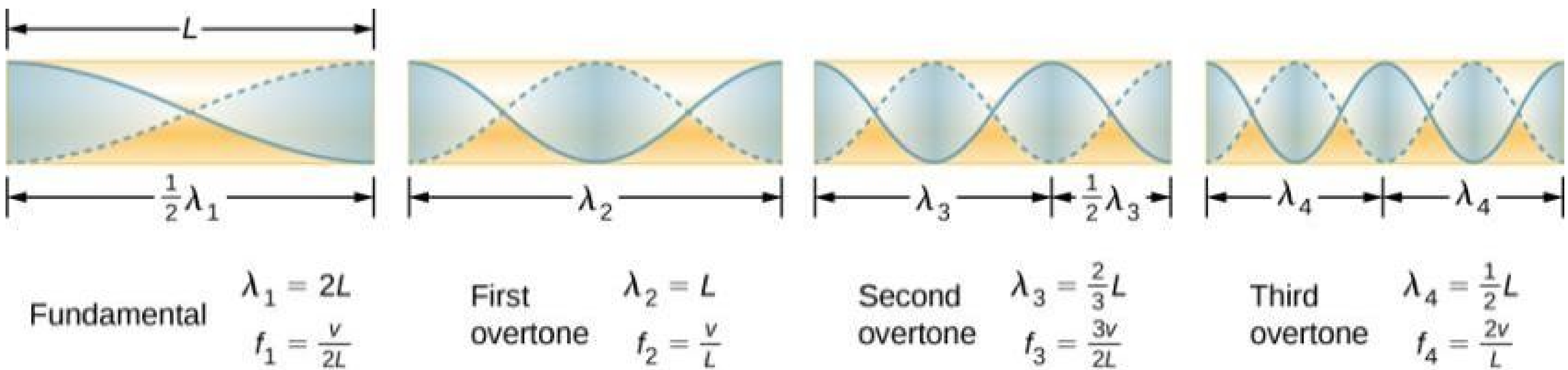
Another resonance for a tube closed at one end. This standing wave has maximum air displacement at the open end and none at the closed end. The wavelength is shorter, with three-fourths $'$ equaling the length of the tube, so that $' = 4L/3$. This higher-frequency vibration is the first overtone.

FIGURE 17.22



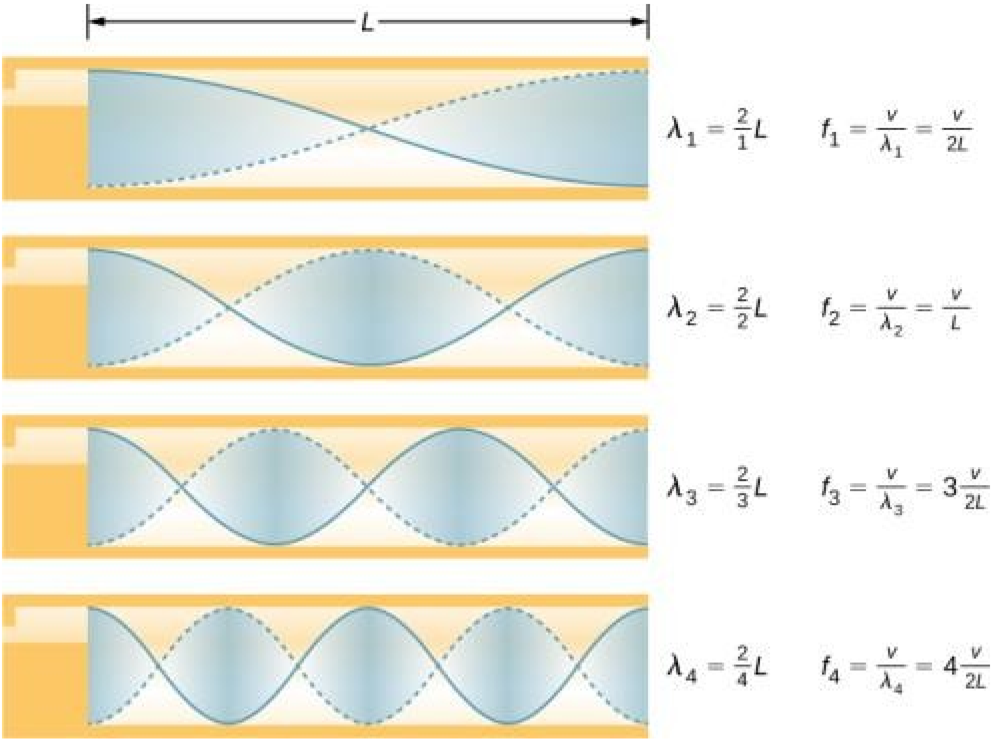
The fundamental and three lowest overtones for a tube closed at one end. All have maximum air displacements at the open end and none at the closed end.

FIGURE 17.23



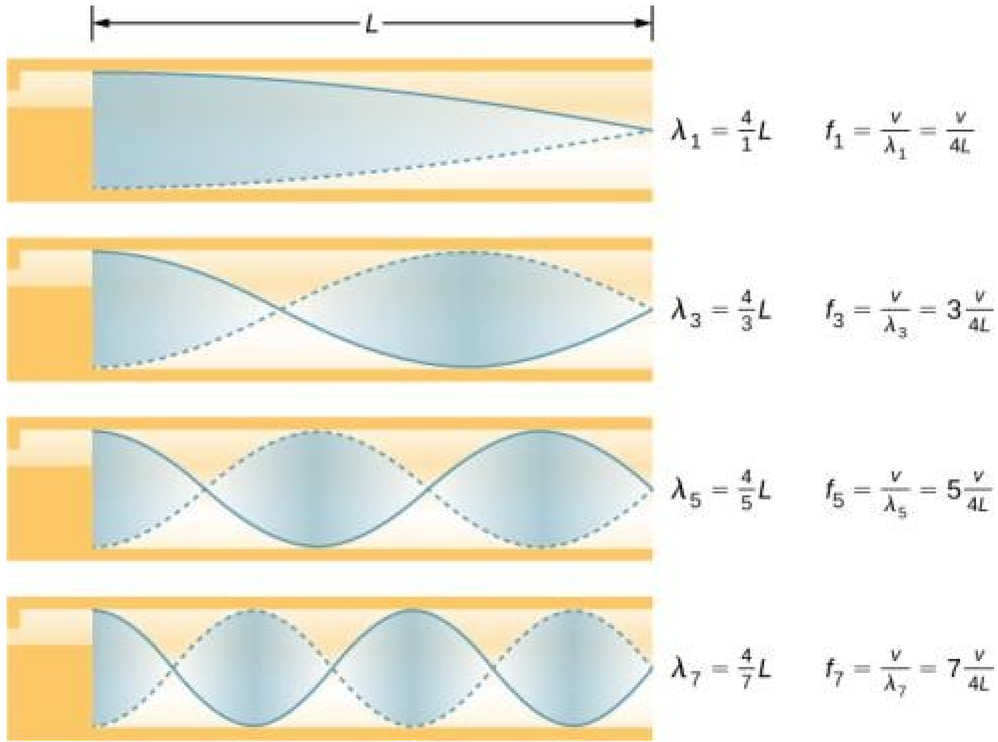
The resonant frequencies of a tube open at both ends, including the fundamental and the first three overtones. In all cases, the maximum air displacements occur at both ends of the tube, giving it different natural frequencies than a tube closed at one end.

FIGURE 17.24



Some musical instruments can be modeled as a pipe open at both ends.

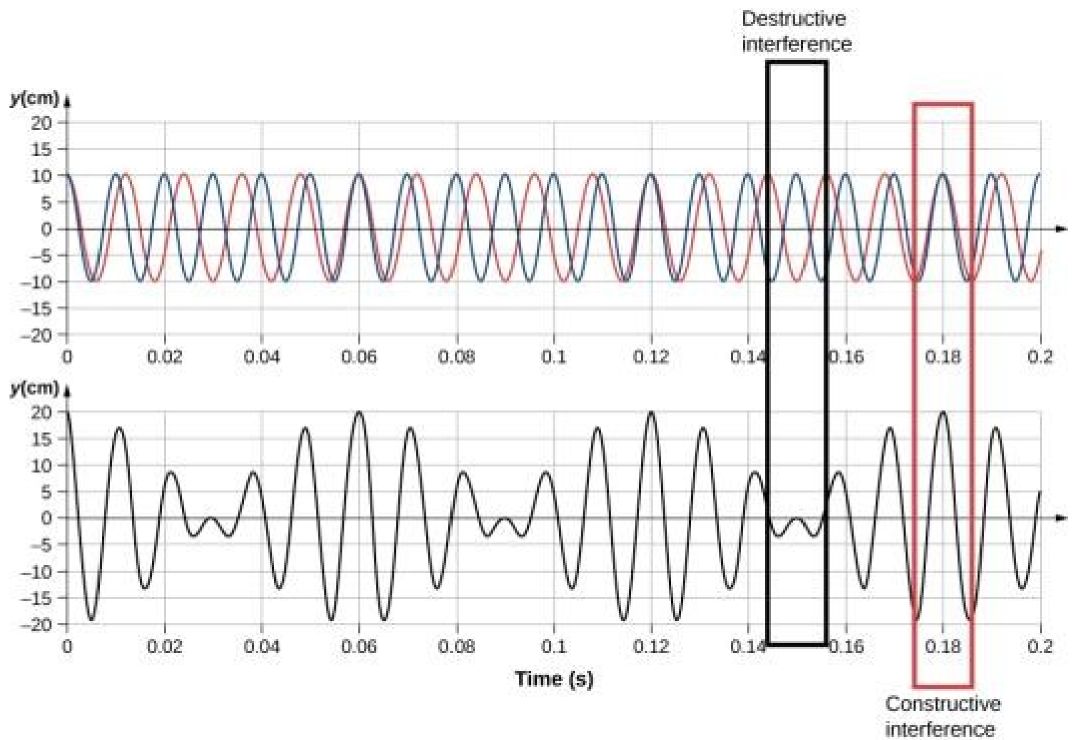
FIGURE 17.25



Some musical instruments can be modeled as a pipe closed at one end.

Beats

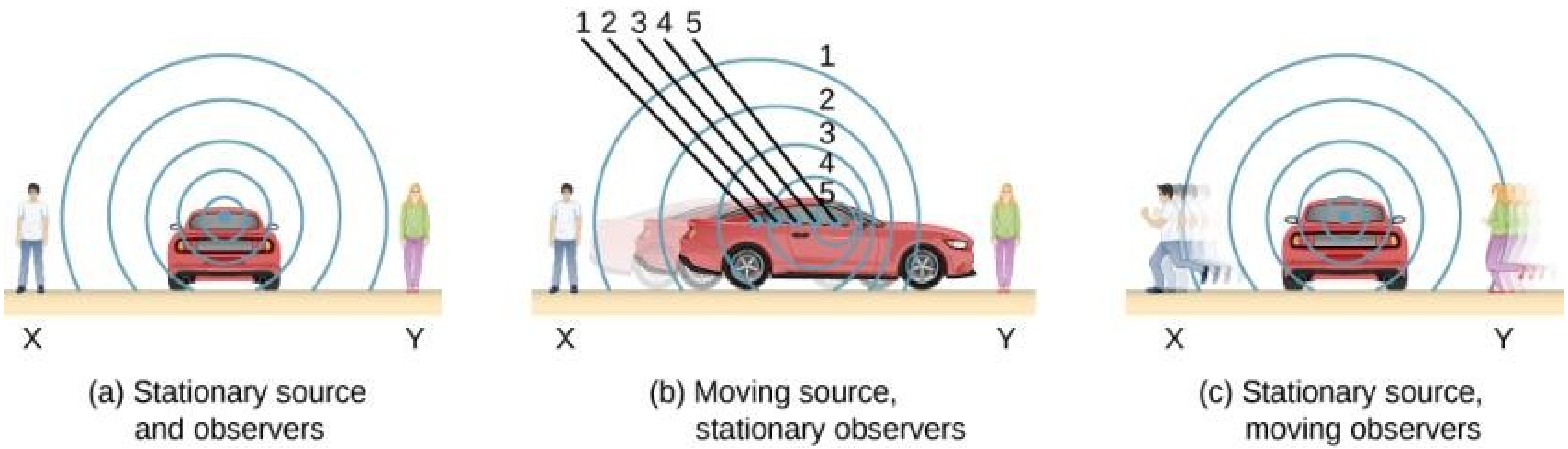
FIGURE 17.29



Beats produced by the constructive and destructive interference of two sound waves that differ in frequency.

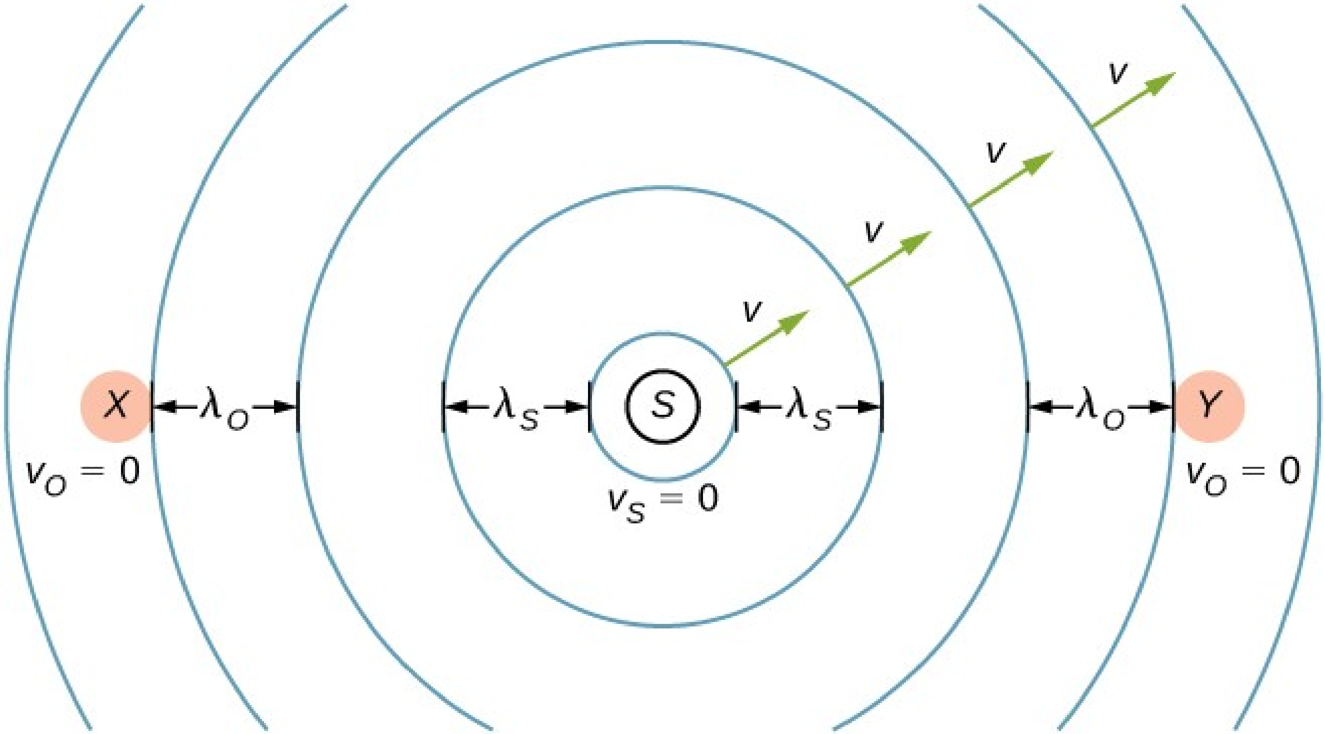
Doppler effect

FIGURE 17.30



Sounds emitted by a source spread out in spherical waves. (a) When the source, observers, and air are stationary, the wavelength and frequency are the same in all directions and to all observers. (b) Sounds emitted by a source moving to the right spread out from the points at which they were emitted. The wavelength is reduced, and consequently, the frequency is increased in the direction of motion, so that the observer on the right hears a higher-pitched sound. The opposite is true for the observer on the left, where the wavelength is increased and the frequency is reduced. (c) The same effect is produced when the observers move relative to the source. Motion toward the source increases frequency as the observer on the right passes through more wave crests than she would if stationary. Motion away from the source decreases frequency as the observer on the left passes through fewer wave crests than he would if stationary.

FIGURE 17.31



A stationary source sends out sound waves at a constant frequency f_s, with a constant wavelength $_s$, at the speed of sound *v*. Two stationary observers *X* and *Y*, on either side of the source, observe a frequency $f_o = f_s$, with a wavelength $_o = _s$.

FIGURE 17.32

$$f_o = f_s \frac{v \pm v_o}{v \pm v_s}$$

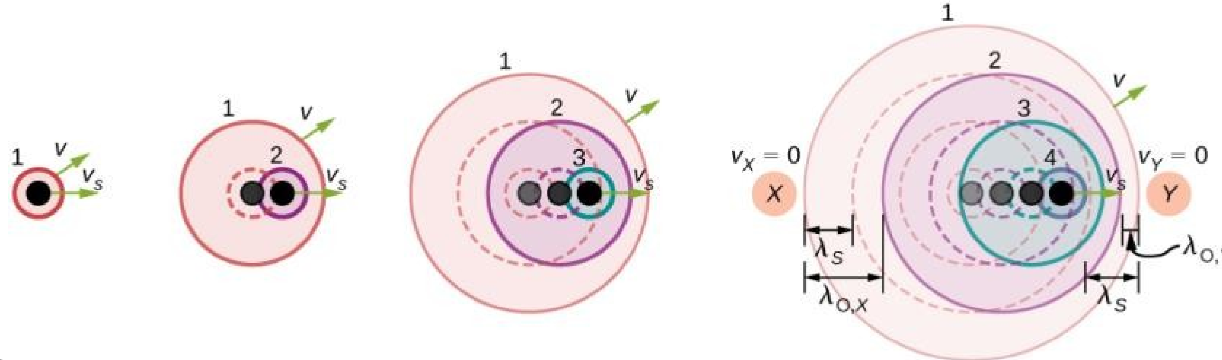
$v = speed\ of\ sound$

$v_o = speed\ of\ observer$

$v_s = speed\ of\ source$

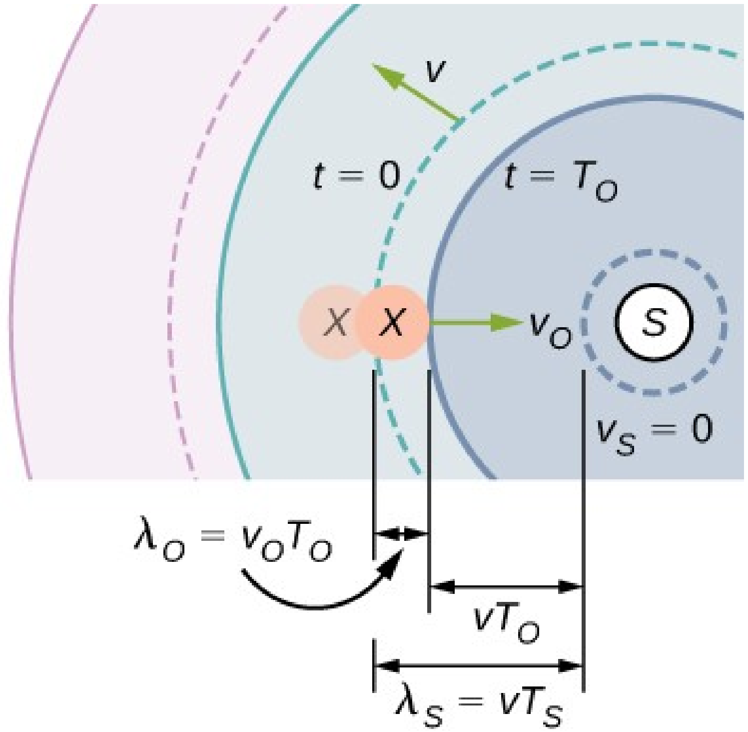
Upper sign approaching

Lower sign receding



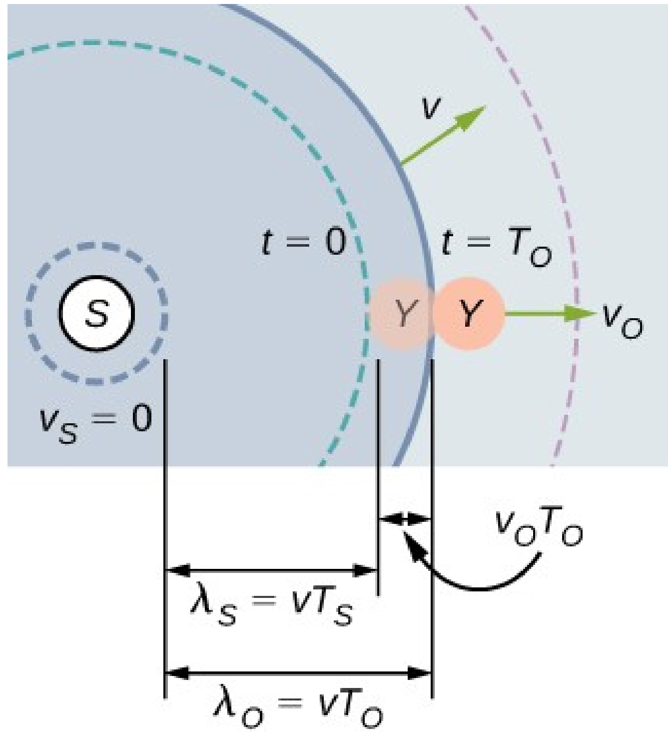
A source moving at a constant speed v_s away from an observer X. The moving source sends out sound waves at a constant frequency f_s, with a constant wavelength ${}_s$, at the speed of sound v. Snapshots of the source at an interval of T_s are shown as the source moves away from the stationary observer X. The solid lines represent the position of the sound waves after four periods from the initial time. The dotted lines are used to show the positions of the waves at each time period. The observer hears a wavelength of ${}_o = {}_s + x = {}_s + v_s T_s$.

FIGURE 17.33



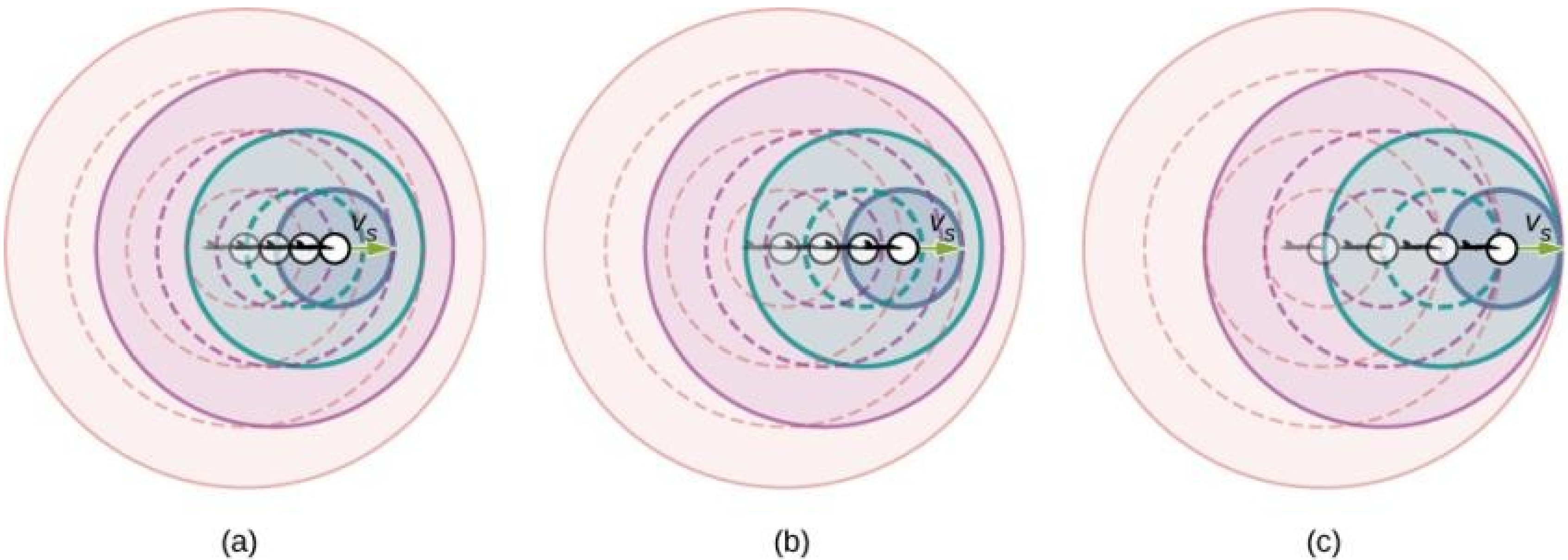
A stationary source emits a sound wave with a constant frequency f_s, with a constant wavelength $_s$ moving at the speed of sound v. Observer X moves toward the source with a constant speed v_o, and the figure shows the initial and final position of observer X. Observer X observes a frequency higher than the source frequency. The dotted lines show the position of the waves at $t = 0$. The solid lines show the position of the waves at $t = T_o$.

FIGURE 17.34



A stationary source emits a sound wave with a constant frequency f_s, with a constant wavelength $_s$ moving at the speed of sound v. Observer Y moves away from the source with a constant speed v_o, and the figure shows initial and final position of the observer Y. Observer Y observes a frequency lower than the source frequency. The dotted lines show the position of the waves at $t = 0$. The solid lines show the position of the waves at $t = T_o$.

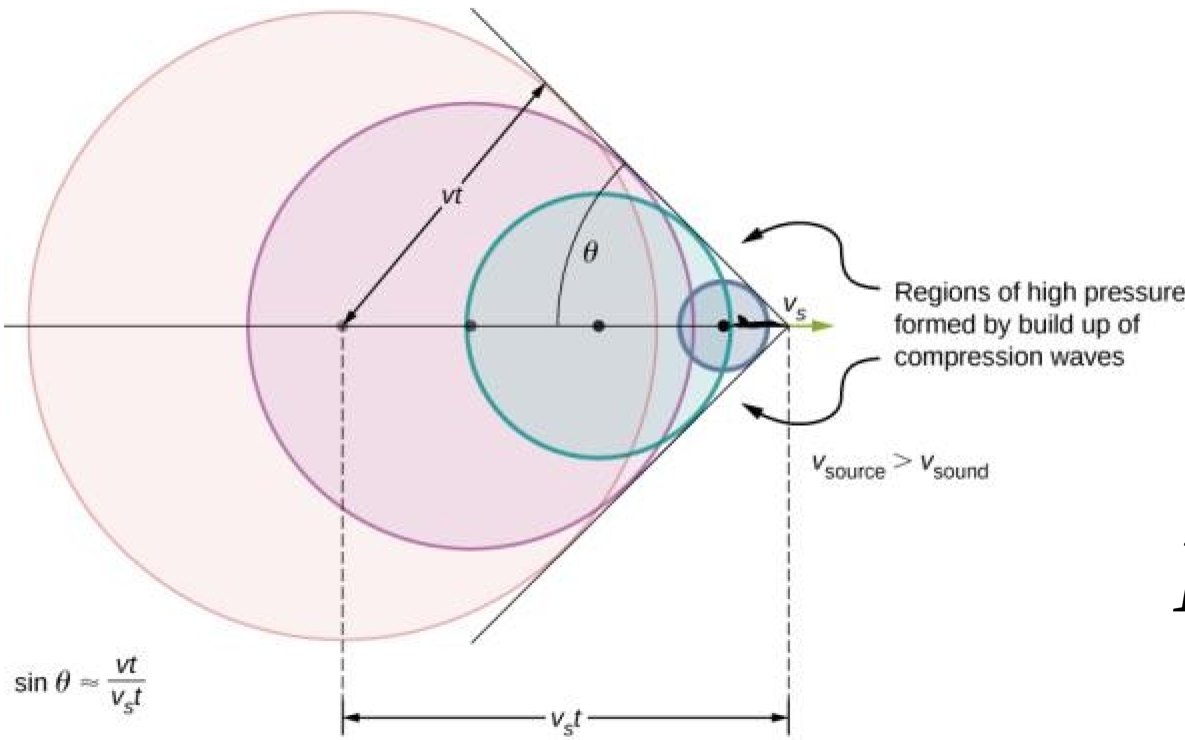
FIGURE 17.35



Because of the Doppler shift, as a moving source approaches a stationary observer, the observed frequency is higher than the source frequency. The faster the source is moving, the higher the observed frequency. In this figure, the source in (b) is moving faster than the source in (a). Shown are four time steps, the first three shown as dotted lines. (c) If a source moves at the speed of sound, each successive wave interfere with the previous one and the observer observes them all at the same instant.

Shock waves

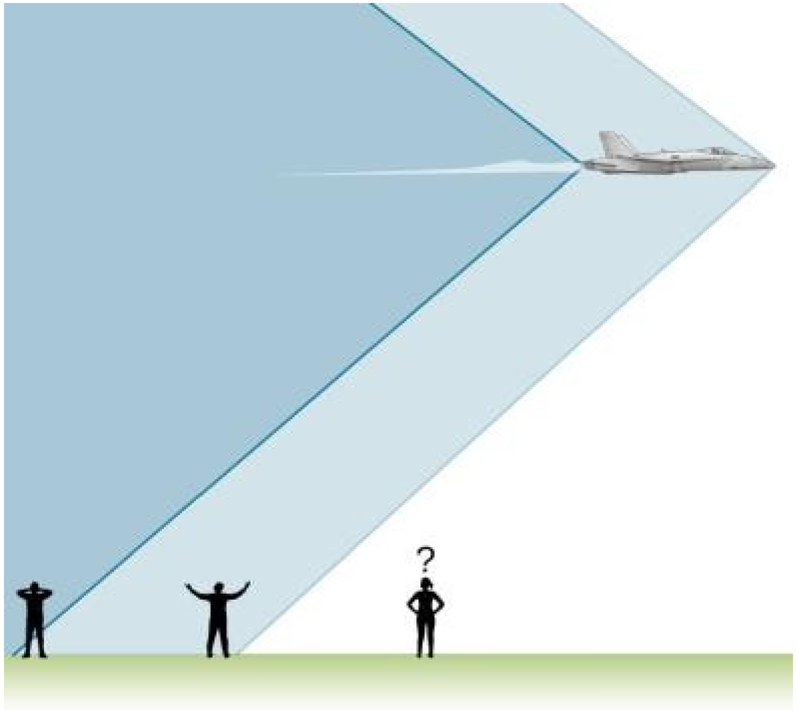
FIGURE 17.36



$$M = \frac{v_s}{v}$$

Sound waves from a source that moves faster than the speed of sound spread spherically from the point where they are emitted, but the source moves ahead of each wave. Constructive interference along the lines shown (actually a cone in three dimensions) creates a shock wave called a sonic boom. The faster the speed of the source, the smaller the angle .

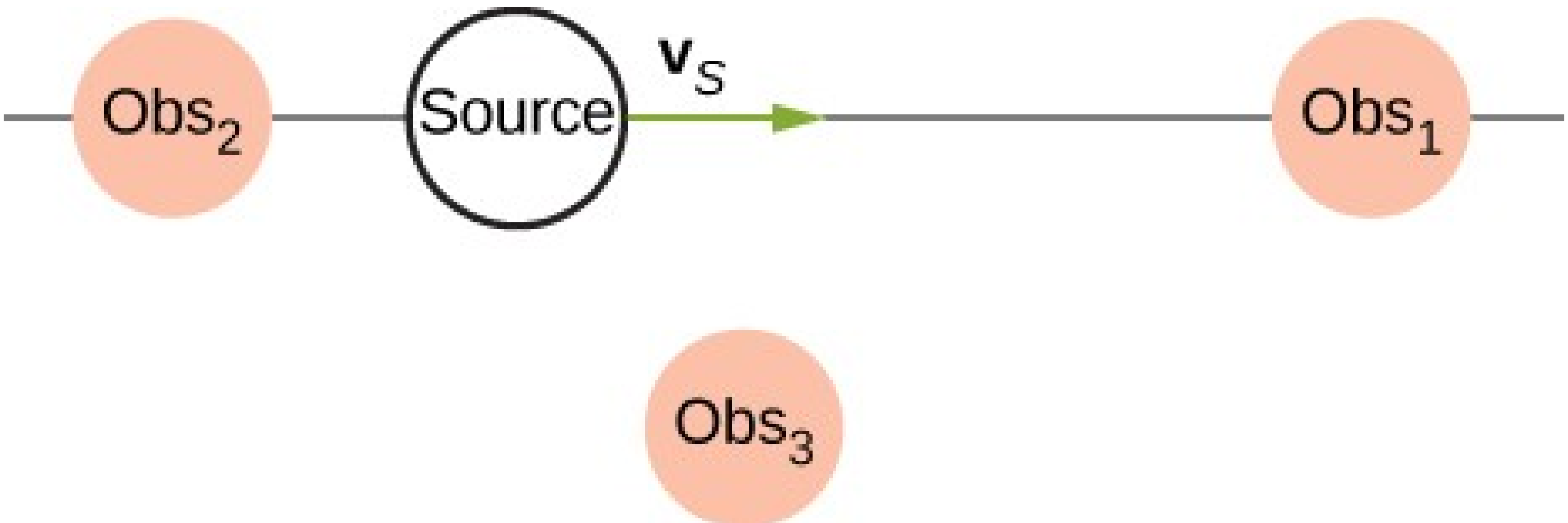
FIGURE 17.37



Two sonic booms experienced by observers, created by the nose and tail of an aircraft as the shock wave sweeps along the ground, are observed on the ground after the plane has passed by.

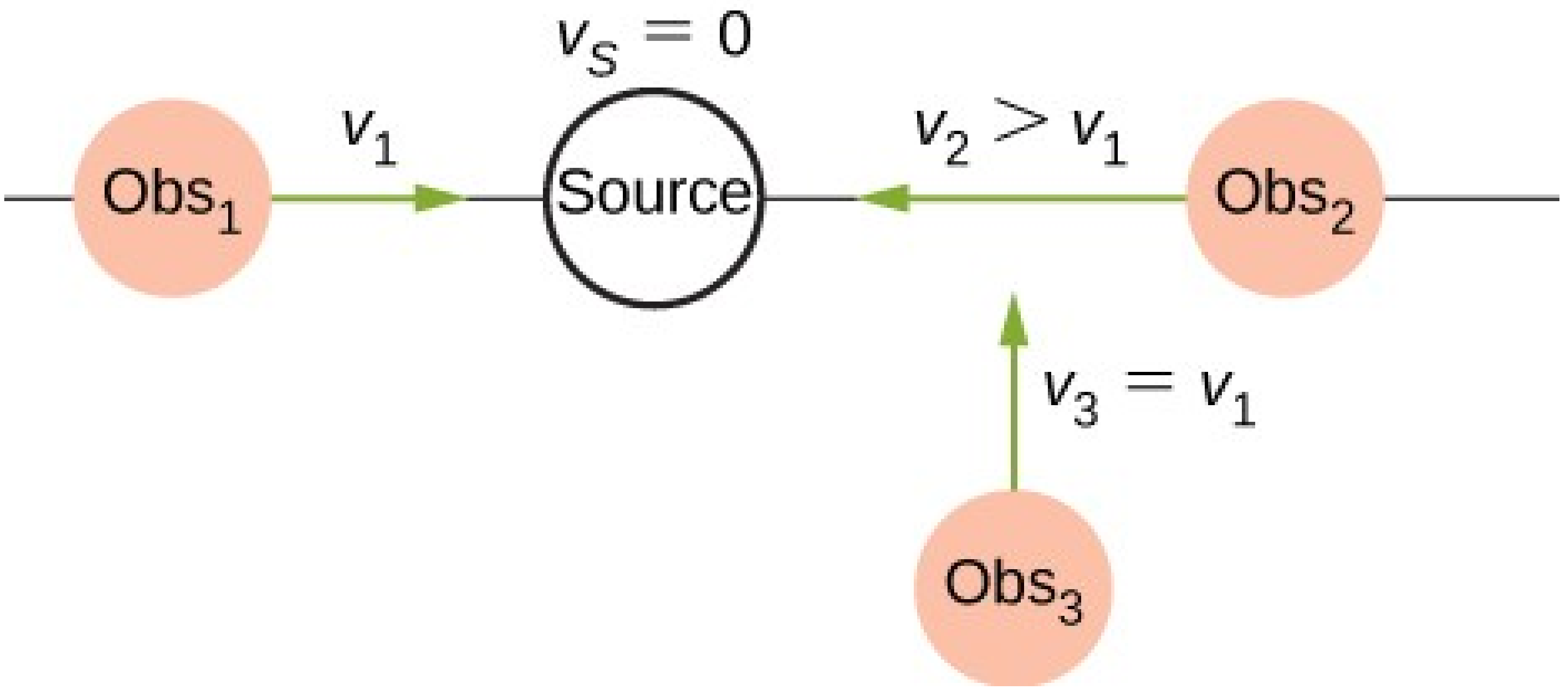
Examples

EXERCISE 23



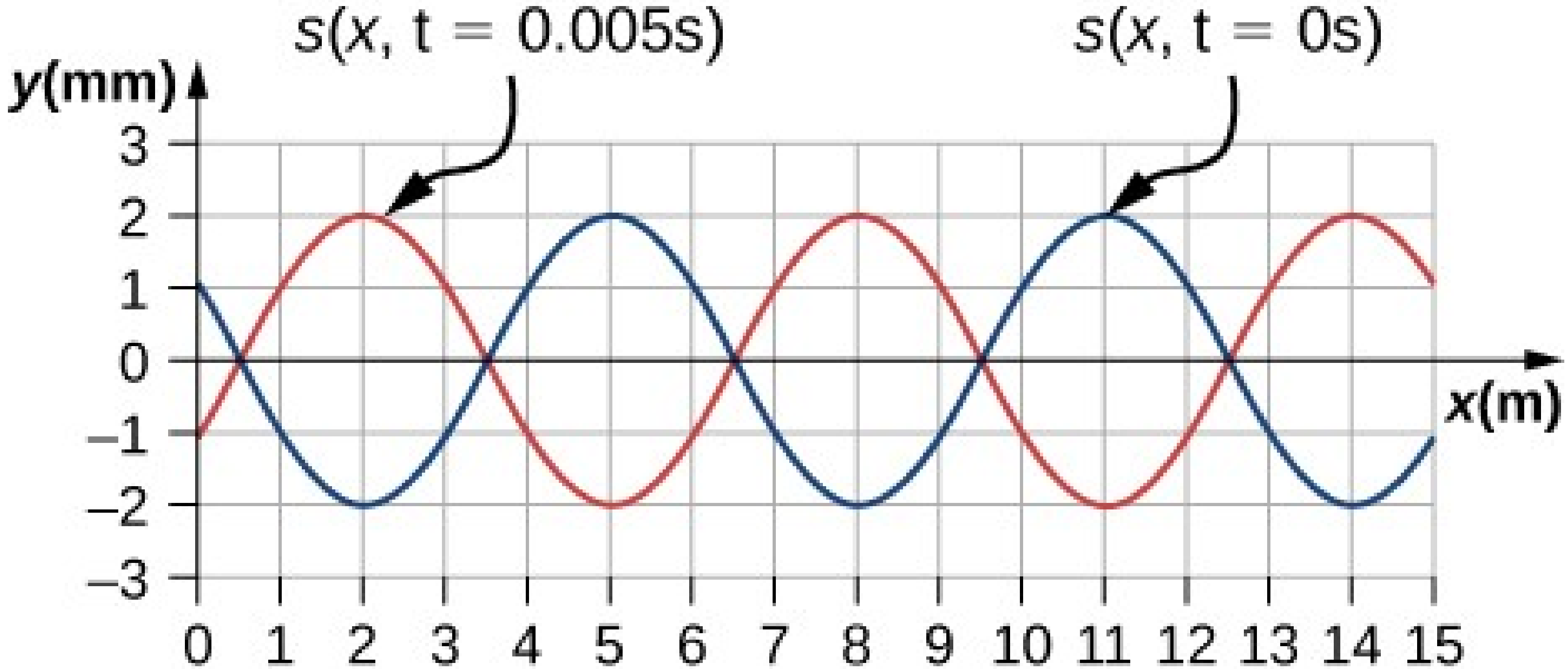
Three stationary observers observe the Doppler shift from a source moving at a constant velocity. The observers are stationed as shown below. Which observer will observe the highest frequency? Which observer will observe the lowest frequency? What can be said about the frequency observed by observer 3?

EXERCISE 24



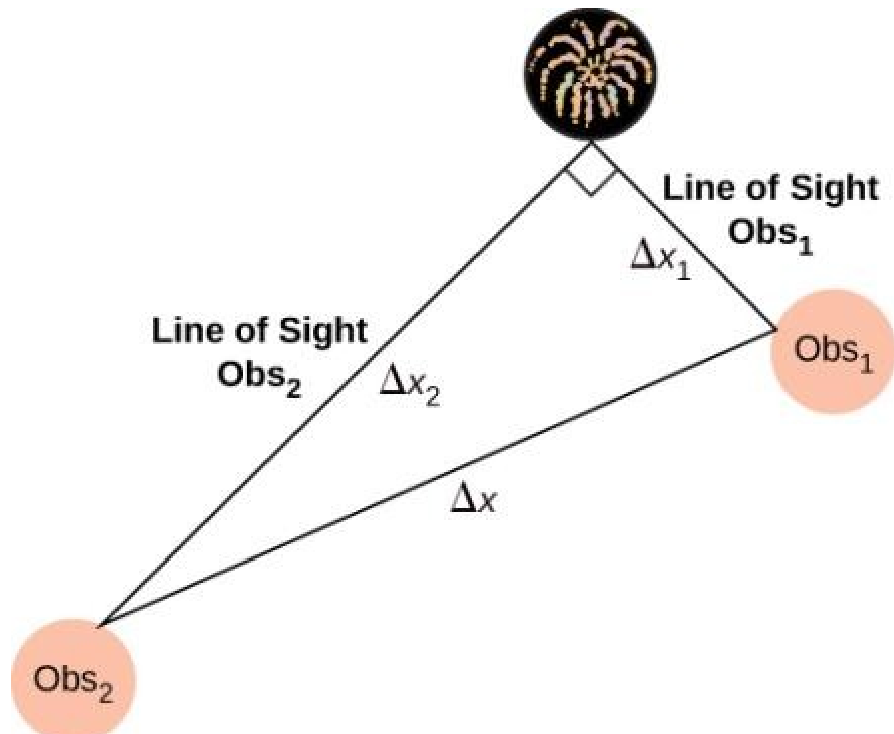
Shown below is a stationary source and moving observers. Describe the frequencies observed by the observers for this configuration.

EXERCISE 41



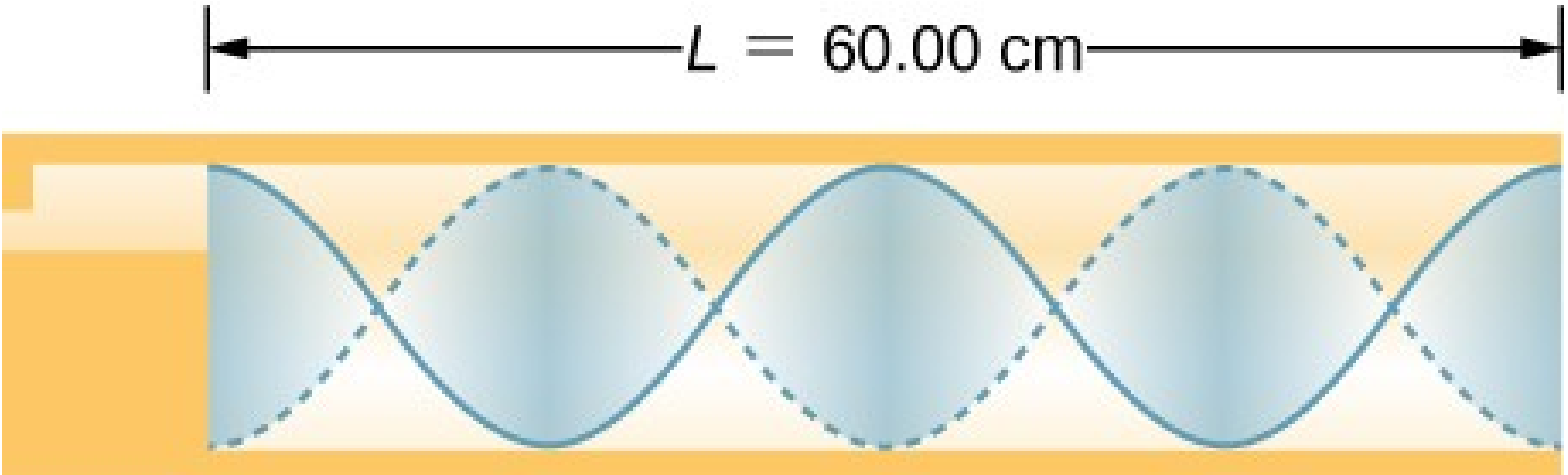
Consider the graph shown below of a compression wave. Shown are snapshots of the wave function for (blue) and (orange). What are the wavelength, maximum displacement, velocity, and period of the compression wave?

EXERCISE 55



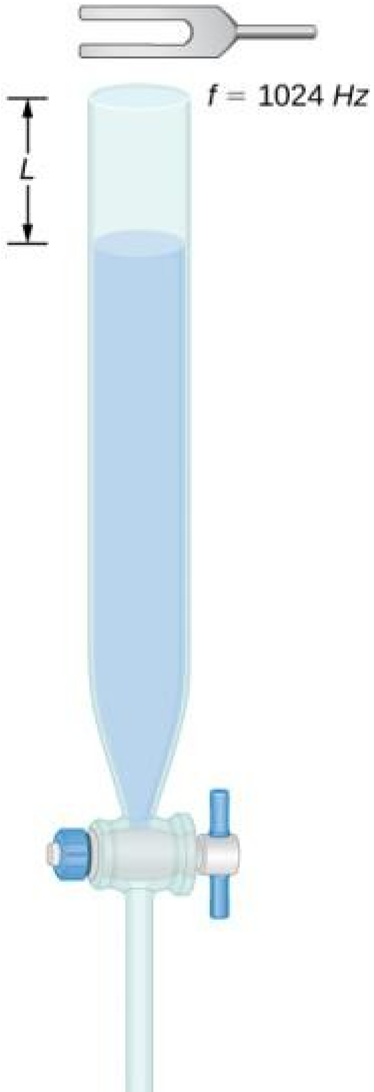
During a 4th of July celebration, an M80 firework explodes on the ground, producing a bright flash and a loud bang. The air temperature of the night air is 95F. Two observers see the flash and hear the bang. The first observer notes the time between the flash and the bang as 0.10 second. The second observer notes the difference as 0.15 seconds. The line of sight between the two observers meet at a right angle as shown below. What is the distance between the two observers?

EXERCISE 96



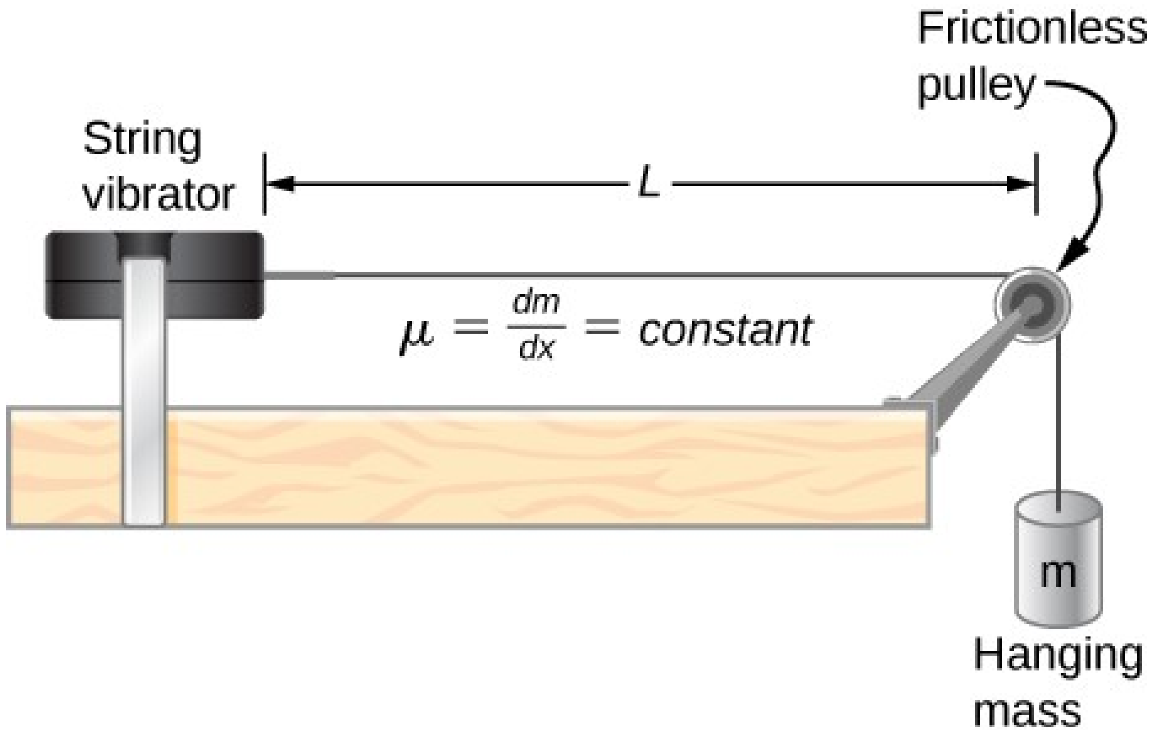
Consider the sound created by resonating the tube shown below. The air temperature is 30 C. What are the wavelength, wave speed, and frequency of the sound produced?

EXERCISE 130



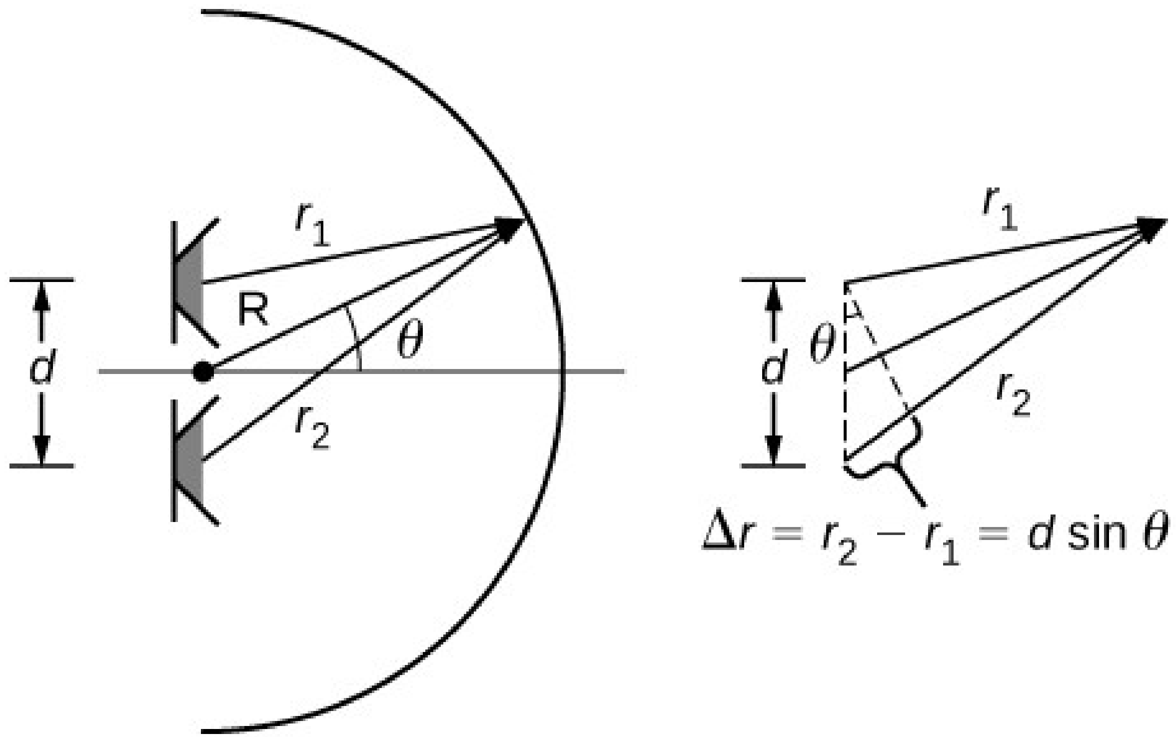
A tube filled with water has a valve at the bottom to allow the water to flow out of the tube. As the water is emptied from the tube, the length L of the air column changes. A 1024-Hz tuning fork is placed at the opening of the tube. Water is removed from the tube until the n = 5 mode of a sound wave resonates. What is the length of the air column if the temperature of the air in the room is 28.0 °C?

EXERCISE 131



Consider the following figure. The length of the string between the string vibrator and the pulley is The linear density of the string is 6 g/m. The string vibrator can oscillate at any frequency. The hanging mass is 2.00 kg. (a)What are the wavelength and frequency of mode? (b) The string oscillates the air around the string. What is the wavelength of the sound if the speed of the sound is 343 m/s?

EXERCISE 141



Two speakers producing the same frequency of sound are a distance of d apart. Consider an arc along a circle of radius R, centered at the midpoint of the speakers, as shown below. (a) At what angles will there be maxima? (b) At what angle will there be minima?