Practice Problems

14.1 Wave Properties pages 328–335

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1. A sound wave produced by a clock chime is heard 515 m away 1.50 s later.

a. What is the speed of sound of the clock's chime in air?

$$v = \frac{d}{t} = \frac{515\ \text{m}}{1.50\ \text{s}} = 343\ \text{m/s}$$

b. The sound wave has a frequency of 436 Hz. What is its period?

$$T = \frac{1}{f} = \frac{1}{436\ \text{Hz}} = 2.29\ \text{ms}$$

c. What is its wavelength?

$$\lambda = \frac{v}{f} = \frac{d}{ft}$$

$$\lambda = \frac{515\ \text{m}}{(436\ \text{Hz})(1.50\ \text{s})} = 0.787\ \text{m}$$

2. A hiker shouts toward a vertical cliff 685 m away. The echo is heard 4.00 s later.

Echo is reflection (down and back) so t = 2.00 s

a. What is the speed of sound of the hiker's voice in air?

$$v = \frac{d}{t} = \frac{685\ \text{m}}{2.00\ \text{s}} = 343\ \text{m/s}$$

b. The wavelength of the sound is 0.750 m. What is its frequency?

$$v = \lambda f$$

$$f = \frac{v}{\lambda} = \frac{343\ \text{m/s}}{0.750\ \text{m}} = 457\ \text{Hz}$$

c. What is the period of the wave?

$$T = \frac{1}{f} = \frac{1}{457\ \text{Hz}} =$$

$$= \frac{1}{457\ \text{s}^{-1}} = 2.19 \times 10^{-3}\ \text{s, or}$$

2.19 ms

3. If you want to increase the wavelength of waves in a rope, should you shake it at a higher or lower frequency?

at a lower frequency, because wavelength varies inversely with frequency

4. What is the speed of a periodic wave disturbance that has a frequency of 2.50 Hz and a wavelength of 0.600 m?

$$v = \lambda f = (0.600\ \text{m})(2.50\ \text{Hz}) = 1.50\ \text{m/s}$$

5. The speed of a transverse wave in a string is 15.0 m/s. If a source produces a disturbance that has a frequency of 5.00 Hz, what is its wavelength?

$$\lambda = \frac{v}{f} = \frac{15.0\ \text{m/s}}{5.00\ \text{Hz}} = 3.00\ \text{m}$$

6. Five pulses are generated every 0.100 s in a tank of water. What is the speed of propagation of the wave if the wavelength of the surface wave is 1.20 cm?

$$\frac{0.100\ \text{s}}{5\ \text{pulses}} = 0.0200\ \text{s/pulse, so}$$

$$T = 0.0200\ \text{s}$$

$$v = \frac{\lambda}{T} = \frac{1.20\ \text{cm}}{0.0200\ \text{s}} = 60.0\ \text{cm/s}$$

$$= 0.600\ \text{m/s}$$

7. A periodic longitudinal wave that has a frequency of 20.0 Hz travels along a coil spring. If the distance between successive compressions is 0.400 m, what is the speed of the wave?

$$v = \lambda f = (0.400\ \text{m})(20.0\ \text{Hz}) = 8.00\ \text{m/s}$$

14.2 Wave Behavior pages 336–343

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8. A pulse is sent along a spring. The spring is attached to a lightweight thread that is tied to a wall, as shown in **Figure 14–9.**

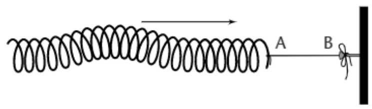

FIGURE 14-9

a. What happens when the pulse reaches point A?

The pulse is partially reflected, partially transmitted.

b. Is the pulse reflected from point A erect or inverted?

erect, because reflection is from a less dense medium

c. What happens when the transmitted pulse reaches point B?

It is almost totally reflected from the wall.

d. Is the pulse reflected from point B erect or inverted?

inverted, because reflection is from a more dense medium

This pulse is traveling to the RIGHT in the UP position. When it hits the wall, it will reflect (go to the LEFT) and INVERT.

9. A long spring runs across the floor of a room and out the door. A pulse is sent along the spring. After a few seconds, an inverted pulse returns. Is the spring attached to the wall in the next room or is it lying loose on the floor?

Pulse inversion means rigid boundary; spring is attached to wall.

10. A pulse is sent along a thin rope that is attached to a thick rope, which is tied to a wall, as shown in **Figure 14–10.**

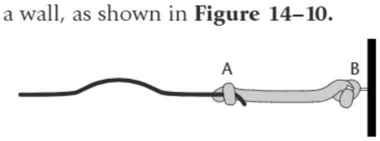

FIGURE 14-10

http://somup.com/c0eoFHyk3T (0:59)
Refraction & Reflection of a Pulse in Different Media.

a. What happens when the pulse reaches point A? Point B?

The pulse is partially reflected, partially transmitted; it is almost totally reflected from the wall.

b. Is the pulse reflected from A displaced in the same direction as the incident pulse, or is it inverted? What about the pulse reflected from point B?

inverted, because reflection is from a more dense medium; inverted, because reflection is from a more dense medium

Chapter Review Problems

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Section 14.1

Level 1

32. The Sears Building in Chicago sways back and forth in the wind with a frequency of about 0.10 Hz. What is its period of vibration?

$$T = \frac{1}{f} = \frac{1}{0.10\ \text{Hz}} = 1.0 \times 10^{1}\ \text{s}$$

33. An ocean wave has a length of 10.0 m. A wave passes a fixed location every 2.0 s. What is the speed of the wave?

$$v = \lambda f = (10.0\ \text{m})\frac{1}{2.0\ \text{s}} = 5.0\ \text{m/s}$$

34. Water waves in a shallow dish are 6.0 cm long. At one point, the water oscillates up and down at a rate of 4.8 oscillations per second.

a. What is the speed of the water waves?

$$v = \lambda f = (0.060\ \text{m})(4.8\ \text{Hz}) = 0.29\ \text{m/s}$$

b. What is the period of the water waves?

$$T = \frac{1}{f} = \frac{1}{4.8\ \text{Hz}} = 0.21\ \text{s}$$

35. Water waves in a lake travel 4.4 m in 1.8 s. The period of oscillation is 1.2 s.

a. What is the speed of the water waves?

$$v = \frac{d}{t} = \frac{4.4\text{ m}}{1.8\text{ s}} = 2.4\text{ m/s}$$

b. What is their wavelength?

$$\lambda = \frac{v}{f} = vT = (2.4\text{ m/s})(1.2\text{ s})$$

$$= 2.9\text{ m}$$

36. The frequency of yellow light is 5.0×10^{14} Hz. Find the wavelength of yellow light. The speed of light is 300 000 km/s.

$$\lambda = \frac{c}{f} = \frac{3.00 \times 10^{8}\text{ m/s}}{5.0 \times 10^{14}\text{ Hz}}$$

$$= 6.0 \times 10^{-7}\text{ m}$$

37. AM-radio signals are broadcast at frequencies between 550 kHz and 1600 kHz (kilohertz) and travel 3.0×10^{8} m/s.

a. What is the range of wavelengths for these signals?

$$v = \lambda f$$

$$\lambda_1 = \frac{v}{f_1} = \frac{3.0 \times 10^{8}\text{ m/s}}{5.5 \times 10^{5}\text{ Hz}}$$

$$= 550\text{ m}$$

$$\lambda_2 = \frac{v}{f_2} = \frac{3.0 \times 10^{8}\text{ m/s}}{1.6 \times 10^{6}\text{ Hz}}$$

$$= 190\text{ m}$$

Range is 190 m to 550 m.

b. FM frequencies range between 88 MHz and 108 MHz (megahertz) and travel at the same speed. What is the range of FM wavelengths?

$$\lambda = \frac{v}{f} = \frac{3.0 \times 10^{8}\text{ m/s}}{8.8 \times 10^{7}\text{ Hz}}$$

$$= 3.4\text{ m}$$

$$\lambda = \frac{v}{f} = \frac{3.0 \times 10^{8}\text{ m/s}}{1.08 \times 10^{8}\text{ Hz}}$$

$$= 2.8\text{ m}$$

Range is 2.8 m to 3.4 m.

38. A sonar signal of frequency 1.00×10^{6} Hz has a wavelength of 1.50 mm in water.

a. What is the speed of the signal in water?

$$v = \lambda f = (1.50 \times 10^{-3}\text{ m})(1.00 \times 10^{6}\text{ Hz})$$

$$= 1.50 \times 10^{3}\text{ m/s}$$

b. What is its period in water?

$$T = \frac{1}{f} = \frac{1}{1.00 \times 10^{6}\text{ Hz}}$$

$$= 1.00 \times 10^{-6}\text{ s}$$

c. What is its period in air?

1.00×10^{-6} s

The period and frequency remain unchanged.

39. A sound wave of wavelength 0.70 m and velocity 330 m/s is produced for 0.50 s.

a. What is the frequency of the wave?

$$v = \lambda f$$

$$\text{so } f = \frac{v}{\lambda} = \frac{330\text{ m/s}}{0.70\text{ m}}$$

$$= 470\text{ Hz}$$

b. How many complete waves are emitted in this time interval?

$$ft = (470\text{ Hz})(0.50\text{ s})$$

$$= 240\text{ complete waves}$$

c. After 0.50 s, how far is the front of the wave from the source of the sound?

$$d = vt$$

$$= (330\text{ m/s})(0.50\text{ s})$$

$$= 170\text{ m}$$

40. The speed of sound in water is 1498 m/s. A sonar signal is sent straight down from a ship at a point just below the water surface, and 1.80 s later the reflected signal is detected. How deep is the ocean beneath the ship?

The time for the wave to travel down and back up is 1.80 s. The time one way is half 1.80 s or 0.900 s.

$d = vt = (1498\ \text{m/s})(0.900\ \text{s}) = 1350\ \text{m}$

41. The time needed for a water wave to change from the equilibrium level to the crest is 0.18 s.

↑ ↓ crest

↓ ↑ trough

0.18 s = the time for ¼ λ.

a. What fraction of a wavelength is this?

$\frac{1}{4}$ **wavelength**

b. What is the period of the wave?

$T = 4(0.18\ \text{s}) = 0.72\ \text{s}$

c. What is the frequency of the wave?

$f = \frac{1}{T} = \frac{1}{0.72\ \text{s}} = 1.4\ \text{Hz}$

Level 2

42. Pepe and Alfredo are resting on an offshore raft after a swim. They estimate that 3.0 m separates a trough and an adjacent crest of surface waves on the lake. They count 14 crests that pass by the raft in 20.0 s. Calculate how fast the waves are moving.

$\lambda = 2(3.0\ \text{m}) = 6.0\ \text{m}$

$f = \frac{14\ \text{waves}}{20.0\ \text{s}}$

$= 0.70\ \text{Hz}$

$v = \lambda f = (6.0\ \text{m})(0.70\ \text{Hz})$

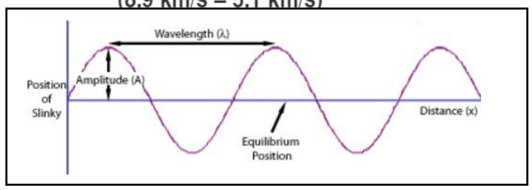
$= 4.2\ \text{m/s}$

43. The velocity of the transverse waves produced by an earthquake is 8.9 km/s, and that of the longitudinal waves is 5.1 km/s. A seismograph records the arrival of the transverse waves 73 s before the arrival of the longitudinal waves. How far away was the earthquake?

$d = vt$. We don't know t, only the difference in time Δt. The transverse distance, $d_T = v_T t$, is the same as the longitudinal distance, $d_L = v_L(t + \Delta t)$. Use $v_T t = v_L(t + \Delta t)$, and solve for t:

$$t = \frac{v_L \Delta t}{v_T - v_L}$$

$$t = \frac{(5.1\ \text{km/s})(73\ \text{sec})}{(8.9\ \text{km/s} - 5.1\ \text{km/s})} = 98\ \text{s}$$



44. The velocity of a wave on a string depends on how hard the string is stretched, and on the mass per unit length of the string. If F_T is the tension in the string, and μ is the mass/unit length, then the velocity, v, can be determined.

$$v = \sqrt{\frac{F_T}{\mu}}$$

A piece of string 5.30 m long has a mass of 15.0 g. What must the tension in the string be to make the wavelength of a 125-Hz wave 120.0 cm?

$v = \lambda f = (1.200\ \text{m})(125\ \text{Hz})$

$= 1.50 \times 10^2\ \text{m/s}$

and $\mu = \frac{m}{L} = \frac{1.50 \times 10^{-2}\ \text{kg}}{5.30\ \text{m}}$

$= 2.83 \times 10^{-3}\ \text{kg/m}$

Now $v = \sqrt{\frac{F_T}{\mu}}$, so

$F_T = v^2\mu = (1.50 \times 10^2\ \text{m/s})^2 \times (2.83 \times 10^{-3}\ \text{kg/m})$

$= 63.7\ \text{N}$

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Section 14.2

Level 1

45. Sketch the result for each of the three cases shown in **Figure 14-21,** when centers of the two wave pulses lie on the dashed line so that the pulses exactly overlap.

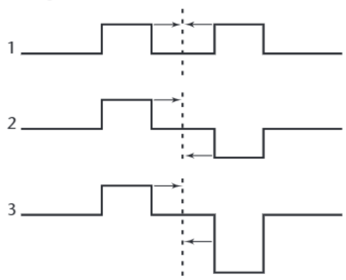

FIGURE 14-21

1. The amplitude is doubled.

2. The amplitudes cancel each other.

3. If the amplitude of the first pulse is $\frac{1}{2}$ of the second, the resultant pulse is $\frac{1}{2}$ the amplitude of the second.

46. If you slosh the water back and forth in a bathtub at the correct frequency, the water rises first at one end and then at the other. Suppose you can make a standing wave in a 150-cm-long tub with a frequency of 0.30 Hz. What is the velocity of the water wave?

$d = 3.0$ m

$v = \frac{d}{t} = df = (3.0 \text{ m})(0.30 \text{ Hz})$

$= 0.90$ m/s

Level 2

47. The wave speed in a guitar string is 265 m/s. The length of the string is 63 cm. You pluck the center of the string by pulling it up and letting go. Pulses move in both directions and are reflected off the ends of the string.

a. How long does it take for the pulse to move to the string end and return to the center?

$d = 2(63 \text{ cm})/2 = 63$ cm

so $t = \frac{d}{v} = \frac{0.63 \text{ m}}{265 \text{ m/s}} = 2.4 \times 10^{-3}$ s

b. When the pulses return, is the string above or below its resting location?

Pulses are inverted when reflected from a more dense medium, so returning pulse is down (below).

c. If you plucked the string 15 cm from one end of the string, where would the two pulses meet?

15 cm from the other end, where the distances traveled are the same

Critical Thinking Problems

48. Gravel roads often develop regularly spaced ridges that are perpendicular to the road. This effect, called washboarding, occurs because most cars travel at about the same speed and the springs that connect the wheels to the cars oscillate at about the same frequency. If the ridges are 1.5 m apart and cars travel at about 5 m/s, what is the frequency of the springs' oscillation?

$v = \lambda f$

$f = \frac{v}{\lambda} = \frac{5 \text{ m/s}}{1.5 \text{ m}} = 3$ Hz

15 Sound

Practice Problems

15.1 Properties of Sound
pages 350–355

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1. Find the frequency of a sound wave moving in air at room temperature with a wavelength of 0.667 m.

$v = \lambda f$

So $f = \frac{v}{\lambda} = \frac{343 \text{ m/s}}{0.667 \text{ m}} = 514 \text{ Hz}$

2. The human ear can detect sounds with frequencies between 20 Hz and 16 kHz. Find the largest and smallest wavelengths the ear can detect, assuming that the sound travels through air with a speed of 343 m/s at 20°C.

From $v = \lambda f$ the largest wavelength is

$\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{20 \text{ Hz}} = 17 \text{ m} = 20 \text{ m}$

the smallest is

$\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{16000 \text{ Hz}} = 0.021 \text{ m}$

3. If you clap your hands and hear the echo from a distant wall 0.20 s later, how far away is the wall?

Assume that $v = 343$ m/s

$2d = vt = (343 \text{ m/s})(0.20 \text{ s}) = 68.6 \text{ m}$

$d = \frac{68.6 \text{ m}}{2} = 34 \text{ m}$

4. What is the frequency of sound in air at 20°C having a wavelength equal to the diameter of a 15 in. (38 cm) woofer loudspeaker? Of a 3.0 in. (7.6 cm) tweeter?

Woofer diameter 38 cm:

$f = \frac{v}{\lambda} = \frac{343 \text{ m/s}}{0.38 \text{ m}} = 0.90 \text{ kHz}$

Tweeter diameter 7.6 cm:

$f = \frac{v}{\lambda} = \frac{343 \text{ m/s}}{0.076 \text{ m}} = 4.5 \text{ kHz}$

15.2 The Physics of Music
pages 357–367

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5. A 440-Hz tuning fork is held above a closed pipe. Find the spacings between the resonances when the air temperature is 20°C.

Resonance spacing is $\frac{\lambda}{2}$ so using $v = \lambda f$ the resonance spacing is

$\frac{\lambda}{2} = \frac{v}{2f} = \frac{343 \text{ m/s}}{2(440 \text{ Hz})} = 0.39 \text{ m}$

Resonance for instruments is λ/2 because the sound travels back (λ/2) and forth (λ/2).

6. The 440-Hz tuning fork is used with a resonating column to determine the velocity of sound in helium gas. If the spacings between resonances are 110 cm, what is the velocity of sound in He?

Resonance spacing $= \frac{\lambda}{2} = 1.10$ m so

$\lambda = 2.20$ m

and $v = f\lambda = (440 \text{ Hz})(2.20 \text{ m})$

$= 970 \text{ m/s}$

7. The frequency of a tuning fork is unknown. A student uses an air column at 27°C and finds resonances spaced by 20.2 cm. What is the frequency of the tuning fork?

From the previous Example Problem $v = 347$ m/s at 27°C and the resonance spacing gives

$\frac{\lambda}{2} = 0.202 \text{ m}$

or $\lambda = 0.404$ m

Using $v = \lambda f$,

$f = \frac{v}{\lambda} = \frac{347 \text{ m/s}}{0.404 \text{ m}} = 859 \text{ Hz}$

8. A bugle can be thought of as an open pipe. If a bugle were straightened out, it would be 2.65 m long.

a. If the speed of sound is 343 m/s, find the lowest frequency that is resonant in a bugle (ignoring end corrections).

$\lambda_1 = 2L = 2(2.65\ \text{m}) = 5.30\ \text{m}$

so that the lowest frequency is

$f_1 = \frac{v}{\lambda_1} = \frac{343\ \text{m/s}}{5.30\ \text{m}} = 64.7\ \text{Hz}$

b. Find the next two higher resonant frequencies in the bugle.

$f_2 = \frac{v}{\lambda_2} = \frac{v}{L} = \frac{343\ \text{m/s}}{2.65\ \text{m}} = 129\ \text{Hz}$

$f_3 = \frac{v}{\lambda_3} = \frac{3v}{2L} = \frac{3(343\ \text{m/s})}{2(2.65\ \text{m})} = 194\ \text{Hz}$

9. A soprano saxophone is an open pipe. If all keys are closed, it is approximately 65 cm long. Using 343 m/s as the speed of sound, find the lowest frequency that can be played on this instrument (ignoring end corrections).

The lowest resonant frequency corresponds to the wavelength given by $\frac{\lambda}{2} = L$, the length of the pipe.

$\lambda = 2L = 2(0.65\ \text{m}) = 1.3\ \text{m}$

so $f = \frac{v}{\lambda} = \frac{343\ \text{m/s}}{1.3\ \text{m}} = 260\ \text{Hz}$

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10. A 330.0-Hz and a 333.0-Hz tuning fork are struck simultaneously. What will the beat frequency be?

$\text{Beat frequency} = |f_2 - f_1|$

$= |333.0\ \text{Hz} - 330.0\ \text{Hz}|$

$= 3.0\ \text{Hz}$

Chapter Review Problems

pages 369–371

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Section 15.1

Level 1

24. You hear the sound of the firing of a distant cannon 6.0 s after seeing the flash. How far are you from the cannon?

$d = v_s t = (343\ \text{m/s})(6.0\ \text{s}) = 2.1\ \text{km}$

25. If you shout across a canyon and hear an echo 4.0 s later, how wide is the canyon?

$d = vt = (343\ \text{m/s})(4.0\ \text{s}) = 1400\ \text{m}$

is the total distance traveled. The distance to the wall is

$\frac{1}{2}(1400) = 7.0 \times 10^2\ \text{m}$

26. A sound wave has a frequency of 9800 Hz and travels along a steel rod. If the distance between compressions, or regions of high pressure, is 0.580 m, what is the speed of the wave?

$v = \lambda f = (0.580\ \text{m})(9800\ \text{Hz})$

$= 5700\ \text{m/s}$

27. A rifle is fired in a valley with parallel vertical walls. The echo from one wall is heard 2.0 s after the rifle was fired. The echo from the other wall is heard 2.0 s after the first echo. How wide is the valley?

The time it takes sound to go to wall 1 and back is 2.0 s. The time it takes to go to the wall is half the total time, or 1.0 s,

$d_1 = v_s t_1 = (343\ \text{m/s})(1.0\ \text{s})$

$= 3.4 \times 10^2\ \text{m}$

The total time for the sound to go to wall 2 is half of 4.0 s or 2.0 s.

$d_2 = v_s t_2 = (343\ \text{m/s})(2.0\ \text{s})$

$= 6.8 \times 10^2\ \text{m}$

The total distance is

$d_1 + d_2 = 1.02 \times 10^3\ \text{m} = 1.0\ \text{km}$

28. A certain instant camera determines the distance to the subject by sending out a sound wave and measuring the time needed for the echo to return to the camera. How long would it take the sound wave to return to the camera if the subject were 3.00 m away?

The total distance the sound must travel is 6.00 m.

$$v = \frac{d}{t}$$

$$\text{so } t = \frac{d}{v} = \frac{6.00 \text{ m}}{343 \text{ m/s}} = 0.0175 \text{ s}$$

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29. Sound with a frequency of 261.6 Hz travels through water at a speed of 1435 m/s. Find the sound's wavelength in water. Don't confuse sound waves moving through water with surface waves moving through water.

$$v = \lambda f$$

$$\text{so } \lambda = \frac{v}{f} = \frac{1435 \text{ m/s}}{261.6 \text{ Hz}} = 5.485 \text{ m}$$

30. If the wavelength of a 4.40×10^2 Hz sound in freshwater is 3.30 m, what is the speed of sound in water?

$$v = \lambda f = (3.30 \text{ m})(4.40 \times 10^2 \text{ Hz})$$
$$= 1.45 \times 10^3 \text{ m/s}$$

31. Sound with a frequency of 442 Hz travels through steel. A wavelength of 11.66 m is measured. Find the speed of the sound in steel.

$$v = \lambda f = (11.66 \text{ m})(442 \text{ Hz})$$
$$= 5.15 \times 10^3 \text{ m/s}$$

32. The sound emitted by bats has a wavelength of 3.5 mm. What is the sound's frequency in air?

$$f = \frac{v}{\lambda} = \frac{343 \text{ m/s}}{0.0035 \text{ m}} = 9.8 \times 10^4 \text{ Hz}$$

33. Ultrasound with a frequency of 4.25 MHz can be used to produce images of the human body. If the speed of sound in the body is the same as in salt water, 1.50 km/s, what is the wavelength of the pressure wave in the body?

$$v = \lambda f$$

$$\text{so } \lambda = \frac{v}{f} = \frac{1.50 \times 10^3 \text{ m/s}}{4.25 \times 10^6 \text{ Hz}}$$
$$= 3.53 \times 10^{-4} \text{ m}$$

34. The equation for the Doppler shift of a sound wave of speed v reaching a moving detector is

$$f_d = f_s \left(\frac{v + v_d}{v - v_s}\right)$$

where v_d is the speed of the detector, v_s is the speed of the source, f_s is the frequency of the source, f_d is the frequency of the detector. If the detector moves toward the source, v_d is positive; if the source moves toward the detector, v_s is positive. A train moving toward a detector at 31 m/s blows a 305-Hz horn. What frequency is detected by

a. a stationary train?

$$f_d = f_s \left(\frac{v + v_d}{v - v_s}\right)$$
$$= \frac{(305 \text{ Hz})(343 \text{ m/s} + 0)}{343 \text{ m/s} - 31 \text{ m/s}}$$
$$= 335 \text{ Hz}$$

b. a train moving toward the first train at 21 m/s?

$$f_d = f_s \left(\frac{v + v_d}{v - v_s}\right)$$
$$= \frac{(305 \text{ Hz})(343 \text{ m/s} + 21 \text{ m/s})}{343 \text{ m/s} - 31 \text{ m/s}}$$
$$= 356 \text{ Hz}$$

35. The train in problem 34 is moving away from the detector. Now what frequency is detected by

a. a stationary train?

$$f_d = f_s \left(\frac{v + v_d}{v - v_s}\right)$$
$$= (305 \text{ Hz}) \left[\frac{343 \text{ m/s} + 0}{343 \text{ m/s} - (-31 \text{ m/s})}\right]$$
$$= 2.80 \times 10^2 \text{ Hz}$$

35. (continued)

b. a train moving away from the first train at a speed of 21 m/s?

$$f_d = f_s\left(\frac{v + v_d}{v - v_s}\right)$$

$$= (305\ \text{Hz})\left[\frac{343\ \text{m/s} + (-21\ \text{m/s})}{343\ \text{m/s} - (-31\ \text{m/s})}\right]$$

$$= 2.60 \times 10^2\ \text{Hz}$$

36. Adam, an airport employee, is working near a jet plane taking off. He experiences a sound level of 150 dB.

a. If Adam wears ear protectors that reduce the sound level to that of a chain saw (110 dB), what decrease in dB will be required?

Chain saw is 110 dB, so 40 dB reduction is needed.

b. If Adam now hears something that sounds like a whisper, what will a person not wearing the protectors hear?

A soft whisper is 10 dB, so the actual level would be 50 dB, or that of an average classroom.

37. A rock band plays at an 80-dB sound level. How many times greater is the sound pressure from another rock band playing at

a. 100 dB?

Each 20 dB increases pressure by a factor of 10, so 10 times greater pressure.

b. 120 dB?

10 × 10 = 100 times greater pressure

Level 2

38. If your drop a stone into a mine shaft 122.5 m deep, how soon after you drop the stone do you hear it hit the bottom of the shaft?

First find the time it takes the stone to fall down the shaft by $d = \frac{1}{2}gt^2$, so

$$t = \sqrt{\frac{d}{\frac{1}{2}g}} = \sqrt{\frac{-122.5\ \text{m}}{\frac{1}{2}(-9.80\ \text{m/s}^2)}} = 5.00\ \text{s}$$

The time it takes the sound to come back up is found with $d = v_s t$, so

$$t = \frac{d}{v_s} = \frac{122.5\ \text{m}}{343\ \text{m/s}} = 0.357\ \text{s}$$

The total time is 5.00 s + 0.357 s = 5.36 s.

Section 15.2

Level 1

39. A slide whistle has a length of 27 cm. If you want to play a note one octave higher, the whistle should be how long?

$$\lambda = \frac{4L}{3} = \frac{4(27\ \text{cm})}{3} = 36\ \text{cm}$$

A note one octave higher is the first overtone of the fundamental. Resonances are spaced by 1/2 wavelength. Since the original whistle length of 27 cm = 3/4 the wavelength of the first overtone (octave), then the shortest whistle length for the first overtone equals

$$\frac{3\lambda}{4} - \frac{\lambda}{2} = \frac{\lambda}{4} = \frac{36\ \text{cm}}{4} = 9.0\ \text{cm}$$

40. An open vertical tube is filled with water, and a tuning fork vibrates over its mouth. As the water level is lowered in the tube, resonance is heard when the water level has dropped 17 cm, and again after 49 cm of distance exists from the water to the top of the tube. What is the frequency of the tuning fork?

49 cm − 17 cm = 32 cm

or 0.32 m

Since the tube is closed at one end, 1/2 λ exists between points of resonance.

$$\frac{1}{2}\lambda = 0.32\ \text{m}$$

So λ = 0.64 m

$$f = \frac{v}{\lambda} = \frac{343\ \text{m/s}}{0.64\ \text{m}} = 540\ \text{Hz}$$

41. The auditory canal, leading to the eardrum, is a closed pipe 3.0 cm long. Find the approximate value (ignoring end correction) of the lowest resonance frequency.

$$L = \frac{\lambda}{4}$$

$$v = \lambda f$$

$$\text{So } f = \frac{v}{4L} = \frac{343 \text{ m/s}}{4 \times 0.030 \text{ m}} = 2.9 \text{ kHz}$$

Instruments represent λ/2. E.g. a guitar string vibrates back and forth to make 1 λ. Open instruments (e.g. flute, trumpet, etc.) are the same. Their length is λ/2 for the sound wave.

42. If you hold a 1.0-m aluminum rod in the center and hit one end with a hammer, it will oscillate like an open pipe. Antinodes of air pressure correspond to nodes of molecular motion, so there is a pressure antinode in the center of the bar. The speed of sound in aluminum is 5150 m/s. What would be the lowest frequency of oscillation?

The rod length is $\frac{1}{2}\lambda$, so $\lambda = 2.0$ m

$$f = \frac{v}{\lambda} = \frac{5150 \text{ m/s}}{2.0 \text{ m}} = 2.6 \text{ kHz}$$

43. The lowest note on an organ is 16.4 Hz.

a. What is the shortest open organ pipe that will resonate at this frequency?

$$\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{16.4 \text{ Hz}} = 20.9 \text{ m}$$

$$L = \frac{\lambda}{2} = \frac{20.9 \text{ m}}{2} = 10.5 \text{ m}$$

b. What would be the pitch if the same organ pipe were closed?

Since a closed pipe produces a fundamental with wavelength twice as long as that of an open pipe, of the same length, the pitch would be $\frac{1}{2}(16.4 \text{ Hz}) = 8.20$ Hz

Beats are caused by diffraction (interference) of waves that are close in frequency.

44. One tuning fork has a 445-Hz pitch. When a second fork is struck, beat notes occur with a frequency of 3 Hz. What are the two possible frequencies of the second fork?

445 Hz − 3 Hz = 442 Hz

and 445 Hz + 3 Hz = 448 Hz

45. A flute acts as an open pipe and sounds a note with a 370-Hz pitch. What are the frequencies of the second, third, and fourth harmonics of this pitch?

$f_2 = 2f_1 = (2)(370 \text{ Hz}) = 740$ Hz

$f_3 = 3f_1 = (3)(370 \text{ Hz}) = 1110 \text{ Hz} = 1100$ Hz

$f_4 = 4f_1 = (4)(370 \text{ Hz}) = 1480 \text{ Hz} = 1500$ Hz

46. A clarinet sounds the same note, with a pitch of 370 Hz, as in problem 45. The clarinet, however, produces harmonics that are only odd multiples of the fundamental frequency. What are the frequencies of the lowest three harmonics produced by this instrument?

$3f = (3)(370 \text{ Hz}) = 1110 \text{ Hz} = 1100$ Hz

$5f = (5)(370 \text{ Hz}) = 1850 \text{ Hz} = 1900$ Hz

$7f = (7)(370 \text{ Hz}) = 2590 \text{ Hz} = 2600$ Hz

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Level 2

47. During normal conversation, the amplitude of a pressure wave is 0.020 Pa.

a. If the area of the eardrum is 0.52 cm^2, what is the force on the eardrum?

$F = PA = (0.020 \text{ N/m}^2)(0.52 \times 10^{-4} \text{ m}^2) = 1.0 \times 10^{-6}$ N

b. The mechanical advantage of the bones in the inner ear is 1.5. What force is exerted on the oval window?

$$MA = \frac{F_r}{F_e}$$

so $F_r = (MA)(F_r)$

$F_r = (1.5)(1.0 \times 10^{-6} \text{ N}) = 1.5 \times 10^{-6}$ N

c. The area of the oval window is 0.026 cm^2. What is the pressure increase transmitted to the liquid in the cochlea?

$$P = \frac{F}{A} = \frac{1.5 \times 10^{-6} \text{ N}}{0.026 \times 10^{-4} \text{ m}^2} = 0.58 \text{ Pa}$$

48. One closed organ pipe has a length of 2.40 m.

a. What is the frequency of the note played by this pipe?

$\lambda = 4\lambda = (4)(2.40 \text{ m}) = 9.60$ m

$v = \lambda f$

$$f = \frac{v}{\lambda} = \frac{343 \text{ m/s}}{9.60 \text{ m}} = 35.7 \text{ Hz}$$

48. (continued)

b. When a second pipe is played at the same time, a 1.40-Hz beat note is heard. By how much is the second pipe too long?

$f = 35.7\text{ Hz} - 1.40\text{ Hz} = 34.3\text{ Hz}$

$v = \lambda f$

$\lambda = \frac{v}{f} = \frac{343\text{ m/s}}{34.3\text{ Hz}} = 10.0\text{ m}$

$\lambda = 4L$

$L = \frac{\lambda}{4} = \frac{10.0\text{ m}}{4} = 2.50\text{ m}$

The difference in lengths is $2.50\text{ m} - 2.40\text{ m} = 0.10\text{ m}$.

49. One open organ pipe has a length of 836 mm. A second open pipe should have a pitch one major third higher. The pipe should be how long?

$L = \frac{\lambda}{2}$ so $\lambda = 2L$

and $v = \lambda f$

So $f = \frac{v}{2L} = \frac{343\text{ m/s}}{(2)(0.836\text{ m})} = 205\text{ Hz}$

The ratio of a frequency one major third higher is 5:4, so

$(205\text{ Hz})\left(\frac{5}{4}\right) = 256\text{ Hz}$

The length of the second pipe is

$L = \frac{v}{2f} = \frac{343\text{ m/s}}{(2)(256\text{ Hz})} = 6.70 \times 10^2\text{ mm}$

50. In 1845, French scientist B. Ballot first tested the Doppler shift. He had a trumpet player sound an A, 440 Hz, while riding on a flatcar pulled by a locomotive. At the same time, a stationary trumpeter played the same note. Ballot heard 3.0 beats per second. How fast was the train moving toward him? (Refer to problem 34 for the Doppler shift equation.)

$fd = 440\text{ Hz} + 3.0\text{ Hz} = 443\text{ Hz}$

$f_d = f_s\left(\frac{v + v_d}{v - v_s}\right)$

so $(v - v_s)f_d = (v + v_d)f_s$

and $v_s = v - \frac{(v + v_d)f_s}{f_d}$

$= 343\text{ m/s} - \frac{(343\text{ m/s} + 0)(440\text{ Hz})}{443\text{ Hz}}$

$= 2.3\text{ m/s}$

51. You try to repeat Ballot's experiment. You plan to have a trumpet played in a rapidly moving car. Rather than listening for beat notes, however, you want to have the car move fast enough so that the moving trumpet sounds a major third above a stationary trumpet. (Refer to problem 34 for the Doppler shift equation.)

a. How fast would the car have to move?

major third ratio $= \frac{5}{4}$

$f_d = f_s\left(\frac{v + v_d}{v - v_s}\right)$

so $(v - v_s)f_d = (v + v_d)f_s$

and $v_s = v - \frac{(v + v_d)f_s}{f_d}$

$= v - (v + v_d)\frac{f_s}{f_d}$

$= 343\text{ m/s} - (343\text{ m/s} + 0)\left(\frac{4}{5}\right)$

$= 68.6\text{ m/s}$

b. Should you try the experiment?

$v = (68.6\text{ m/s})\left(\frac{3600\text{ s}}{\text{hr}}\right)\left(\frac{1\text{ mi}}{1609\text{ m}}\right)$

$= 153$ mph, so the car would be moving dangerously fast

No, do not try the experiment.

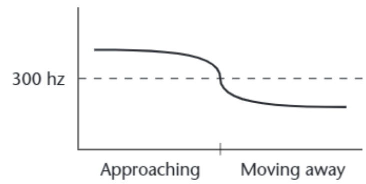
Critical Thinking Problems

52. Suppose that the frequency of a car horn (when not moving) is 300 Hz. What would the graph of the frequency versus time look like as the car approached and then moved past you? Complete a rough sketch.

The graph should show a fairly steady frequency above 300 Hz as it approaches and a fairly steady frequency below 300 Hz as it moves away.

52. (continued)

53. Describe how you could use a stopwatch



to estimate the speed of sound if you were near the green on a 200-m golf hole as another group of golfers were hitting their tee shots. Would your estimate of their velocities be too large or too small?

You could start the watch when you saw the hit and stop the watch when the sound reached you. The speed would be calculated by dividing the distance, 200 m, by the time. The time estimate would be too large because you could anticipate the impact by sight, but you could not anticipate the sound. The calculated velocity would be too small.

54. A light wave coming from a point on the left edge of the sun is found by astronomers to have a slightly higher frequency than light from the right side. What do these measurements tell you about the sun's motion?

The sun must be rotating on its axis in the same manner as Earth. The Doppler shift indicates that the left side of the sun is coming toward us, while the right side is moving away.