

- P12.20 (a) 1.50 s; (b) 73.4 N/m;
(c) 19.7 m below the bridge; (d) 1.06 rad/s;
(e) 2.01 s; (f) 3.50 s
- P12.46 (a) 0.3681 m/s; (b) 3.51 cm;
(c) see the solution; (d) 0.040 6 J;
(e) 0.027 7 J

P12.22 $\delta \text{Cambridge} = 1.001\ 5$
 δTrobo

P12.48 (a) $x = (-2\text{ m})\sin[(10\text{ s}^{-1})t]$;
(b) at $x = \pm 1.73\text{ m}$; (c) 0.098 0 m;
(d) 0.052 4 s

P12.24 1.42 s; 0.499 m

P12.50 (a) decreased by 0.735 m;
(b) increased by 0.730 s;
(c) decreased by 120 J;
(d) see the solution

P12.26 (a) see the solution;
(b) 9.85 m/s² agreeing with the accepted
value within 0.5%;
(c) 9.85 m/s²

P12.52 (a) 3.56 Hz; (b) 2.79 Hz; (c) 2.10 Hz

P12.28 (a) 2.09 s; (b) 4.08%

P12.54 (a) $\frac{1}{2}\left(M + \frac{m}{3}\right)v^2$; (b) $2\pi\sqrt{\frac{M + \frac{m}{3}}{k}}$

P12.30 see the solution

P12.56 (a) $k = 1.74\text{ N/m} \pm 6\%$;
(b) $k = 1.82\text{ N/m} \pm 3\%$ showing agreement;
(c) 8 grams $\pm 12\%$ showing agreement

P12.32 see the solution

P12.58 (a) see the solution; (b) see the solution;
(c) see the solution; (d) see the solution;
(e) see the solution; (f) 0.281 Hz;
(g) decreases; (h) increases; (i) increases;
(j) decreases

P12.34 (a) 2.95 Hz; (b) 2.85 cm

P12.60 (a) see the solution; (b) 42.2 min;
(c) they arrive at the same time

P12.36 either 1.31 Hz or 0.641 Hz

P12.40 (a) 0.500 m/s; (b) 8.56 cm

P12.38 1.56 cm

P12.42 (a) 15.8 cm; (b) -15.9 cm;
(c) see the solution; (d) 51.1 m; (e) 50.7 m

P12.44 (a) $\frac{4\pi^2 m}{T^2}$; (b) $m\left(\frac{T'}{T}\right)^2$

Chapter 13

Mechanical Waves

CHAPTER OUTLINE

- 13.1 Propagation of a Disturbance
- 13.2 The Wave Model
- 13.3 The Traveling Wave
- 13.4 The Speed of Transverse Waves on Strings
- 13.5 Reflection and Transmission of Waves
- 13.6 Rate of Energy Transfer by Sinusoidal Waves on Strings
- 13.7 Sound Waves
- 13.8 The Doppler Effect
- 13.9 Connection—Seismic Waves

ANSWERS TO QUESTIONS

- Q13.1 To use a slinky to create a longitudinal wave, pull a few coils back and release. For a transverse wave, jostle the end coil side to side.
- Q13.2 From $v = \sqrt{\frac{T}{\mu}}$, we must increase the tension by a factor of 4.
- Q13.3 It depends on from what the wave reflects. If reflecting from a less dense string, the reflected part of the wave will be right side up.
- Q13.4 The section of rope moves up and down in SHM. Its speed is always changing. The wave continues on with constant speed in one direction, setting further sections of the rope into up-and-down motion.
- Q13.5 As the source frequency is doubled, the speed of waves on the string stays constant and the wavelength is reduced by one half.
- Q13.6 As the source frequency is doubled, the speed of waves on the string stays constant.
- Q13.7 Higher tension makes wave speed higher. Greater linear density makes the wave move more slowly.
- Q13.8 As the wave passes from the massive string to the less massive string, the wave speed will increase according to $v = \sqrt{\frac{T}{\mu}}$. The frequency will remain unchanged. Since $v = f\lambda$, the wavelength must increase.
- Q13.9 Amplitude is increased by a factor of $\sqrt{2}$. The wave speed does not change.
- Q13.10 Sound waves are longitudinal because elements of the medium—parcels of air—move parallel and antiparallel to the direction of wave motion.

Q13.11 We assume that a perfect vacuum surrounds the clock. The sound waves require a medium for them to travel to your ear. The hammer on the alarm will strike the bell, and the vibration will spread as sound waves through the body of the clock. If a bone of your skull were in contact with the clock, you would hear the bell. However, in the absence of a surrounding medium like air or water, no sound can be radiated away. A larger-scale example of the same effect: Colossal storms raging on the Sun are deadly still for us.

Q13.12 What happens to the sound energy within the clock? Here is the answer: As the sound wave travels through the steel and plastic, traversing joints and going around corners, its energy is converted into additional internal energy, raising the temperature of the materials. After the sound has died away, the clock will glow very slightly brighter in the infrared portion of the electromagnetic spectrum.

The frequency increases by a factor of 2 because the wave speed, which is dependent only on the medium through which the wave travels, remains constant.

Q13.13 When listening, you are approximately the same distance from all of the members of the group. If different frequencies traveled at different speeds, then you might hear the higher pitched frequencies before you heard the lower ones produced at the same time. Although it might be interesting to think that each listener heard his or her own personal performance depending on where they were seated, a time lag like this could make a Beethoven sonata sound as if it were written by Charles Ives.

Q13.14 He saw the first wave he encountered, light traveling at 3.00×10^8 m/s. At the same moment, infrared as well as visible light began warming his skin, but some time was required to raise the temperature of the outer skin layers before he noticed it. The meteor produced compressional waves in the air and in the ground. The wave in the ground, which can be called either sound or a seismic wave, traveled much faster than the wave in air, since the ground is much stiffer against compression. Our witness received it next and noticed it as a little earthquake. He was no doubt unable to distinguish the P and S waves. The first air-compression wave he received was a shock wave with an amplitude on the order of meters. It transported him off his doorstep. Then he could hear some additional direct sound, reflected sound, and perhaps the sound of the falling trees.

Q13.15 For the sound from a source not to shift in frequency, the radial velocity of the source relative to the observer must be zero; that is, the source must not be moving toward or away from the observer. The source can be moving in a plane perpendicular to the line between it and the observer. Other possibilities: The source and observer might both have zero velocity. They might have equal velocities relative to the medium. The source might be moving around the observer on a sphere of constant radius. Even if the source speeds up on the sphere, slows down, or stops, the frequency heard will be equal to the frequency emitted by the source.

Q13.16 Wind can change a Doppler shift but cannot cause one. Both v_o and v_s in our equations must be interpreted as speeds of observer and source relative to the air. If source and observer are moving relative to each other, the observer will hear one shifted frequency in still air and a different shifted frequency if wind is blowing. If the distance between source and observer is constant, there will never be a Doppler shift.

Q13.17 Let $\Delta t = t_s - t_p$ represent the difference in arrival times of the two waves at a station at distance $d = v_s t_s = v_p t_p$ from the hypocenter. Then $d = \Delta t \left(\frac{1}{v_s} - \frac{1}{v_p} \right)^{-1}$. Knowing the distance from the first station places the hypocenter on a sphere around it. A measurement from a second station limits it to another sphere, which intersects with the first in a circle. Data from a third non-collinear station will generally limit the possibilities to a point.

SOLUTIONS TO PROBLEMS

Section 13.1 Propagation of a Disturbance

P13.1 Replace x by $x - vt = x - 4.5t$

to get

$$y = \frac{6}{(x - 4.5t)^2 + 3}$$

P13.2

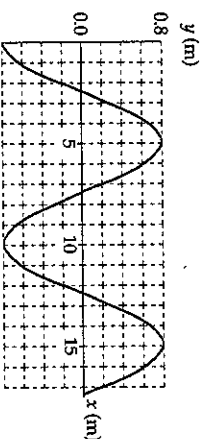
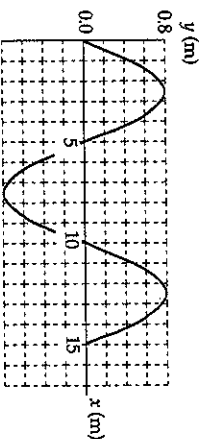


FIG. P13.2

Section 13.2 The Wave Model

Section 13.3 The Traveling Wave

$$\text{P13.3} \quad f = \frac{40.0 \text{ vibrations}}{30.0 \text{ s}} = \frac{4}{3} \text{ Hz} \quad v = \frac{425 \text{ cm}}{10.0 \text{ s}} = 42.5 \text{ cm/s}$$

$$\lambda = \frac{v}{f} = \frac{42.5 \text{ cm/s}}{\frac{4}{3} \text{ Hz}} = 31.9 \text{ cm} = \boxed{0.319 \text{ m}}$$

P13.4 Using data from the observations, we have $\lambda = 1.20$ m and $f = \frac{8.00}{12.0}$ s. Therefore,

$$v = \lambda f = (1.20 \text{ m}) \left(\frac{8.00}{12.0 \text{ s}} \right) = \boxed{0.800 \text{ m/s}}.$$

P13.5 Let $u = 10\pi t - 3\pi x + \frac{\pi}{4}$

$$\frac{du}{dt} = 10\pi - 3\pi \frac{dx}{dt} = 0 \text{ at a point of constant phase}$$

$$\frac{dx}{dt} = \frac{10}{3} = \boxed{3.33 \text{ m/s}}$$

The velocity is in the positive x -direction.

(b) $y(0.100, 0) = (0.350 \text{ m}) \sin(-0.300\pi + \frac{\pi}{4}) = -0.0548 \text{ m} = \boxed{-5.48 \text{ cm}}$

(c) $k = \frac{2\pi}{\lambda} = 3\pi$; $\lambda = \boxed{0.667 \text{ m}}$ $\omega = 2\pi f = 10\pi$; $f = \boxed{5.00 \text{ Hz}}$

(d) $v_y = \frac{\partial y}{\partial t} = (0.350)(10\pi) \cos(10\pi t - 3\pi x + \frac{\pi}{4})$ $v_{y, \text{max}} = (10\pi)(0.350) = \boxed{11.0 \text{ m/s}}$

P13.6 $y = (0.0200 \text{ m}) \sin(2.11x - 3.62t)$ in SI units $A = \boxed{2.00 \text{ cm}}$

$k = 2.11 \text{ rad/m}$ $\lambda = \frac{2\pi}{k} = \boxed{2.98 \text{ m}}$

$\omega = 3.62 \text{ rad/s}$ $f = \frac{\omega}{2\pi} = \boxed{0.576 \text{ Hz}}$

$v = f\lambda = \frac{\omega}{2\pi} \frac{2\pi}{k} = \frac{3.62}{2.11} = \boxed{1.72 \text{ m/s}}$

P13.7 (a) $\omega = 2\pi f = 2\pi(5 \text{ s}^{-1}) = \boxed{31.4 \text{ rad/s}}$

(b) $\lambda = \frac{v}{f} = \frac{20 \text{ m/s}}{5 \text{ s}^{-1}} = 4.00 \text{ m}$

$k = \frac{2\pi}{\lambda} = \frac{2\pi}{4 \text{ m}} = \boxed{1.57 \text{ rad/m}}$

(c) In $y = A \sin(kx - \omega t + \phi)$ we take $A = 12$ cm. At $x = 0$ and $t = 0$ we have $y = (12 \text{ cm}) \sin \phi$. To make this fit $y = 0$, we take $\phi = 0$. Then $y = (12.0 \text{ cm}) \sin(1.57 \text{ rad/m} x - (31.4 \text{ rad/s}) t)$

(d) The transverse velocity is $\frac{\partial y}{\partial t} = -A\omega \cos(kx - \omega t)$. Its maximum magnitude is

$$A\omega = 12 \text{ cm}(31.4 \text{ rad/s}) = \boxed{3.77 \text{ m/s}}$$

(e) $a_y = \frac{\partial^2 y}{\partial t^2} = \frac{\partial}{\partial t}(-A\omega \cos(kx - \omega t)) = -A\omega^2 \sin(kx - \omega t)$

The maximum value is $A\omega^2 = (0.12 \text{ m})(31.4 \text{ s}^{-1})^2 = \boxed{118 \text{ m/s}^2}$.

*P13.8

At time t , the phase of $y = (15.0 \text{ cm}) \cos(0.157x - 50.3t)$ at coordinate x is $\phi = (0.157 \text{ rad/cm})x - (50.3 \text{ rad/s})t$. Since $60.0^\circ = \frac{\pi}{3}$ rad, the requirement for point B is that $\phi_B = \phi_A \pm \frac{\pi}{3}$ rad, or (since $x_A = 0$),

$$(0.157 \text{ rad/cm})x_B - (50.3 \text{ rad/s})t = 0 - (50.3 \text{ rad/s})t \pm \frac{\pi}{3} \text{ rad}.$$

This reduces to $x_B = \frac{\pm \pi \text{ rad}}{3(0.157 \text{ rad/cm})} = \boxed{\pm 6.67 \text{ cm}}$.

P13.9 (a) $A = y_{\text{max}} = 8.00 \text{ cm} = 0.0800 \text{ m}$ $k = \frac{2\pi}{\lambda} = \frac{2\pi}{0.800 \text{ m}} = 7.85 \text{ m}^{-1}$

$\omega = 2\pi f = 2\pi(3.00) = 6.00\pi \text{ rad/s}$

Therefore, $y = A \sin(kx + \omega t)$

Or (where $y(0, t) = 0$ at $t = 0$) $y = (0.0800 \text{ m}) \sin(7.85x + 6\pi t) \text{ m}$

(b) In general, $y = 0.0800 \sin(7.85x + 6\pi t + \phi)$

Assuming $y(x, 0) = 0$ at $x = 0.100 \text{ m}$

then we require that $0 = 0.0800 \sin(0.785 + \phi)$

or $\phi = -0.785$

Therefore, $y = 0.0800 \sin(7.85x + 6\pi t - 0.785) \text{ m}$

P13.10 $y = (0.120 \text{ m}) \sin\left(\frac{\pi}{8}x + 4\pi t\right)$

(a) $v_y = \frac{dy}{dt} = v_y = (0.120)(4\pi) \cos\left(\frac{\pi}{8}x + 4\pi t\right)$

$v_y(0.200 \text{ s}, 1.60 \text{ m}) = \boxed{-1.51 \text{ m/s}}$

$a_y = \frac{dv}{dt} = a_y = (-0.120 \text{ m})(4\pi)^2 \sin\left(\frac{\pi}{8}x + 4\pi t\right)$

$a_y(0.200 \text{ s}, 1.60 \text{ m}) = \boxed{0}$

(b) $k = \frac{\pi}{8} = \frac{2\pi}{\lambda}$; $\lambda = \boxed{16.0 \text{ m}}$

$\omega = 4\pi = \frac{2\pi}{T}$; $T = \boxed{0.500 \text{ s}}$

$v = \frac{\lambda}{T} = \frac{16.0 \text{ m}}{0.500 \text{ s}} = \boxed{32.0 \text{ m/s}}$

P13.11 (a) Let us write the wave function as

$$y(x, t) = A \sin(kx + \omega t + \phi)$$

$$y(0, 0) = A \sin \phi = 0.0200 \text{ m}$$

$$\left. \frac{dy}{dt} \right|_{0,0} = A\omega \cos \phi = -2.00 \text{ m/s}$$

$$\text{Also, } \omega = \frac{2\pi}{T} = \frac{2\pi}{0.0250 \text{ s}} = 80.0 \pi/\text{s}$$

$$A^2 = x_1^2 + \left(\frac{v_1}{\omega}\right)^2 = (0.0200 \text{ m})^2 + \left(\frac{2.00 \text{ m/s}}{80.0 \pi/\text{s}}\right)^2$$

$$A = \boxed{0.0215 \text{ m}}$$

$$(b) \frac{A \sin \phi}{A \cos \phi} = \frac{0.0200}{-2.51} = \tan \phi$$

Your calculator's answer $\tan^{-1}(-2.51) = -1.19 \text{ rad}$ has a negative sine and positive cosine, just the reverse of what is required. You must look beyond your calculator to find

$$\phi = \pi - 1.19 \text{ rad} = \boxed{1.95 \text{ rad}}$$

$$(c) v_{y,\max} = A\omega = 0.0215 \text{ m}(80.0 \pi/\text{s}) = \boxed{5.41 \text{ m/s}}$$

$$(d) \lambda = v_y T = (30.0 \text{ m/s})(0.0250 \text{ s}) = 0.750 \text{ m}$$

$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{0.750 \text{ m}} = 8.38/\text{m}$$

$$\omega = 80.0 \pi/\text{s}$$

$$y(x, t) = (0.0215 \text{ m}) \sin(8.38x \text{ rad/m} + 80.0\pi t \text{ rad/s} + 1.95 \text{ rad})$$

P13.12 The linear wave equation is

$$\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2} \frac{\partial^2 y}{\partial t^2}$$

$$\text{If } y = e^{k(x-vt)}$$

$$\text{then } \frac{\partial y}{\partial t} = -kv e^{k(x-vt)} \text{ and } \frac{\partial y}{\partial x} = k e^{k(x-vt)}$$

$$\frac{\partial^2 y}{\partial t^2} = b^2 v^2 e^{k(x-vt)} \text{ and } \frac{\partial^2 y}{\partial x^2} = b^2 e^{k(x-vt)}$$

Therefore, $\frac{\partial^2 y}{\partial t^2} = v^2 \frac{\partial^2 y}{\partial x^2}$, demonstrating that $e^{k(x-vt)}$ is a solution

Section 13.4 The Speed of Transverse Waves on Strings

P13.13 The down and back distance is $4.00 \text{ m} + 4.00 \text{ m} = 8.00 \text{ m}$.

$$\text{The speed is then } v = \frac{d_{\text{total}}}{t} = \frac{4(8.00 \text{ m})}{0.800 \text{ s}} = 40.0 \text{ m/s} = \sqrt{\frac{T}{\mu}}$$

$$\text{Now, } \mu = \frac{0.200 \text{ kg}}{4.00 \text{ m}} = 5.00 \times 10^{-2} \text{ kg/m}$$

$$\text{So } T = \mu v^2 = (5.00 \times 10^{-2} \text{ kg/m})(40.0 \text{ m/s})^2 = \boxed{80.0 \text{ N}}$$

P13.14 $T = Mg$ is the tension; $v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{Mg}{\frac{MgL}{l}}} = \sqrt{\frac{g l}{L}}$ is the wave speed.

$$\text{Then, } \frac{MgL}{m} = \frac{l^2}{T^2}$$

$$\text{and } g = \frac{Lm}{Mt^2} = \frac{1.60 \text{ m}(4.00 \times 10^{-3} \text{ kg})}{3.00 \text{ kg}(3.61 \times 10^{-2} \text{ s})^2} = \boxed{1.64 \text{ m/s}^2}$$

*P13.15 Since μ is constant, $\mu = \frac{T_2}{v_2^2} = \frac{T_1}{v_1^2}$ and

$$T_2 = \left(\frac{v_2}{v_1}\right)^2 T_1 = \left(\frac{30.0 \text{ m/s}}{20.0 \text{ m/s}}\right)^2 (6.00 \text{ N}) = \boxed{13.5 \text{ N}}$$

P13.16 From the free-body diagram $mg = 2T \sin \theta$

$$T = \frac{mg}{2 \sin \theta}$$

$$\text{The angle } \theta \text{ is found from } \cos \theta = \frac{\frac{3}{4}}{\frac{3}{2}} = \frac{1}{2}$$

$$\therefore \theta = 41.4^\circ$$

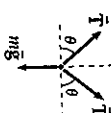


FIG. P13.16

$$(a) v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{mg}{2 \mu \sin 41.4^\circ}} = \sqrt{\frac{9.80 \text{ m/s}^2}{2(8.00 \times 10^{-3} \text{ kg/m}) \sin 41.4^\circ}} = \boxed{v}$$

or

$$v = \sqrt{\frac{30.4 \text{ m/s}}{\sqrt{\text{kg}}}} \sqrt{\text{m}}$$

$$(b) v = 60.0 = 30.4 \sqrt{m} \text{ and } \boxed{m = 3.89 \text{ kg}}$$

P13.17 The total time is the sum of the two times.

$$t = \frac{L}{v} = L \sqrt{\frac{\mu}{T}}$$

In each wire

Let A represent the cross-sectional area of one wire. The mass of one wire can be written both as $m = \rho V = \rho AL$ and also as $m = \mu L$.

$$\text{Then we have } \mu = \rho A = \frac{\rho d^2}{4} L$$

$$\text{Thus, } t = L \left(\frac{\rho d^2}{4T} \right)^{1/2}$$

$$\text{For copper, } t = (20.0) \left[\frac{(\pi)(8920)(1.00 \times 10^{-3})^2}{(4)(150)} \right]^{1/2} = 0.137 \text{ s}$$

$$\text{For steel, } t = (30.0) \left[\frac{(\pi)(7860)(1.00 \times 10^{-3})^2}{(4)(150)} \right]^{1/2} = 0.192 \text{ s}$$

$$\text{The total time is } 0.137 + 0.192 = \boxed{0.329 \text{ s}}$$

Section 13.5 Reflection and Transmission of Waves

P13.18 (a) If the end is fixed, there is inversion of the pulse upon reflection. Thus, when they meet, they cancel and the amplitude is $\boxed{\text{zero}}$.

(b) If the end is free, there is no inversion on reflection. When they meet, the amplitude is $2A = 2(0.150 \text{ m}) = \boxed{0.300 \text{ m}}$.

Section 13.6 Rate of Energy Transfer by Sinusoidal Waves on Strings

$$\text{P13.19 } f = \frac{v}{\lambda} = \frac{30.0}{0.500} = 60.0 \text{ Hz} \quad \omega = 2\pi f = 120\pi \text{ rad/s}$$

$$\mathcal{P} = \frac{1}{2} \mu \omega^2 A^2 v = \frac{1}{2} \left(\frac{0.180}{3.60} \right) (120\pi)^2 (0.100)^2 (30.0) = \boxed{1.07 \text{ kW}}$$

$$\text{P13.20 } \mu = 30.0 \text{ g/m} = 30.0 \times 10^{-3} \text{ kg/m}$$

$$\lambda = 1.50 \text{ m}$$

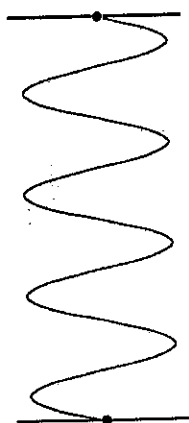
$$f = 50.0 \text{ Hz} \quad \omega = 2\pi f = 314 \text{ s}^{-1}$$

$$2A = 0.150 \text{ m} \quad A = 7.50 \times 10^{-2} \text{ m}$$

$$(a) \quad y = A \sin \left(\frac{2\pi}{\lambda} x - \omega t \right)$$

$$y = (7.50 \times 10^{-2}) \sin(4.19x - 314t)$$

FIG. P13.20



$$(b) \quad \mathcal{P} = \frac{1}{2} \mu \omega^2 A^2 v = \frac{1}{2} (30.0 \times 10^{-3}) (314)^2 (7.50 \times 10^{-2})^2 \left(\frac{314}{4.19} \right) \quad \mathcal{P} = \boxed{625 \text{ W}}$$

$$\text{P13.21 } A = 5.00 \times 10^{-2} \text{ m} \quad \mu = 4.00 \times 10^{-2} \text{ kg/m} \quad \mathcal{P} = 300 \text{ W} \quad T = 100 \text{ N}$$

$$\text{Therefore, } v = \sqrt{\frac{T}{\mu}} = 50.0 \text{ m/s}$$

$$\mathcal{P} = \frac{1}{2} \mu \omega^2 A^2 v : \quad \omega^2 = \frac{2\mathcal{P}}{\mu A^2 v} = \frac{2(300)}{(4.00 \times 10^{-2})(5.00 \times 10^{-2})^2 (50.0)}$$

$$\omega = 346 \text{ rad/s}$$

$$f = \frac{\omega}{2\pi} = \boxed{55.1 \text{ Hz}}$$

*P13.22 Originally,

$$\mathcal{P}_0 = \frac{1}{2} \mu \omega^2 A^2 v$$

$$\mathcal{P}_0 = \frac{1}{2} \mu \omega^2 A^2 \sqrt{\frac{T}{\mu}}$$

$$\mathcal{P}_0 = \frac{1}{2} \omega^2 A^2 \sqrt{T\mu}$$

The doubled string will have doubled mass-per-length. Presuming that we hold tension constant, it can carry power larger by $\sqrt{2}$ times.

$$\sqrt{2}\mathcal{P}_0 = \frac{1}{2} \omega^2 A^2 \sqrt{T(2\mu)}$$

Section 13.7 Sound Waves

$$\text{P13.23 } \text{Since } v_{\text{light}} \gg v_{\text{sound}} : d \approx (343 \text{ m/s})(16.2 \text{ s}) = \boxed{5.56 \text{ km}}$$

*P13.24 The sound pulse must travel 150 m before reflection and 150 m after reflection. We have $d = vt$

$$t = \frac{d}{v} = \frac{300 \text{ m}}{1533 \text{ m/s}} = \boxed{0.196 \text{ s}}$$

P13.25 (a) $\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{1480 \text{ s}^{-1}} = \boxed{0.232 \text{ m}}$

(b) $\lambda' = \frac{v}{f'} = \frac{343 \text{ m/s}}{1397 \text{ s}^{-1}} = 0.246 \text{ m}$, $\Delta\lambda = \lambda' - \lambda = \boxed{13.8 \text{ mm}}$

P13.26 $\lambda = \frac{v}{f} = \frac{340 \text{ m/s}}{60.0 \times 10^3 \text{ s}^{-1}} = \boxed{5.67 \text{ mm}}$

*P13.27 The sound speed is $v = 331 \text{ m/s} + 0.6 \text{ m/s}^\circ\text{C}(26^\circ\text{C}) = 347 \text{ m/s}$.

(a) Let t represent the time for the echo to return. Then

$$d = \frac{1}{2}vt = \frac{1}{2}(347 \text{ m/s})(24 \times 10^{-3} \text{ s}) = \boxed{4.16 \text{ m}}$$

(b) Let Δt represent the duration of the pulse:

$$\Delta t = \frac{10\lambda}{v} = \frac{10\lambda}{f\lambda} = \frac{10}{f} = \frac{10}{22 \times 10^6 \text{ 1/s}} = \boxed{0.455 \mu\text{s}}$$

(c) $L = 10\lambda = \frac{10v}{f} = \frac{10(347 \text{ m/s})}{22 \times 10^6 \text{ 1/s}} = \boxed{0.158 \text{ mm}}$

*P13.28 (a) If $f = 2.4 \text{ MHz}$, $\lambda = \frac{v}{f} = \frac{1500 \text{ m/s}}{2.4 \times 10^6 \text{ s}^{-1}} = \boxed{0.625 \text{ mm}}$

(b) If $f = 1 \text{ MHz}$, $\lambda = \frac{v}{f} = \frac{1500 \text{ m/s}}{10^6 \text{ s}^{-1}} = \boxed{1.50 \text{ mm}}$

If $f = 20 \text{ MHz}$, $\lambda = \frac{1500 \text{ m/s}}{2 \times 10^7 \text{ s}^{-1}} = \boxed{75.0 \mu\text{m}}$

P13.29 $\Delta P_{\text{max}} = \rho v \omega s_{\text{max}} = \rho v \left(\frac{2\pi v}{\lambda} \right) s_{\text{max}}$

$$\lambda = \frac{2\pi \rho v^2 s_{\text{max}}}{\Delta P_{\text{max}}} = \frac{2\pi(1.20)(343)^2(5.50 \times 10^{-6})}{0.840} = \boxed{5.81 \text{ m}}$$

P13.30 (a)

$$A = \boxed{2.00 \mu\text{m}}$$

$$\lambda = \frac{2\pi}{15.7} = 0.400 \text{ m} = \boxed{40.0 \text{ cm}}$$

$$v = \frac{\omega}{k} = \frac{858}{15.7} = \boxed{54.6 \text{ m/s}}$$

(b) $s = 2.00 \cos[(15.7)(0.0500) - (858)(3.00 \times 10^{-3})] = \boxed{-0.433 \mu\text{m}}$

(c) $v_{\text{max}} = A\omega = (2.00 \mu\text{m})(858 \text{ s}^{-1}) = \boxed{1.72 \text{ mm/s}}$

P13.31 $k = \frac{2\pi}{\lambda} = \frac{2\pi}{(0.100 \text{ m})} = 62.8 \text{ m}^{-1}$

$$\omega = \frac{2\pi v}{\lambda} = \frac{2\pi(343 \text{ m/s})}{(0.100 \text{ m})} = 2.16 \times 10^4 \text{ s}^{-1}$$

Therefore, $\Delta P = (0.200 \text{ N/m}^2) \sin[62.8 \text{ x/m} - 2.16 \times 10^4 \text{ t/s}]$.

P13.32 $\Delta P_{\text{max}} = \rho \omega v s_{\text{max}} = (1.20 \text{ kg/m}^3)[2\pi(2000 \text{ s}^{-1})](343 \text{ m/s})(2.00 \times 10^{-8} \text{ m})$

$$\Delta P_{\text{max}} = \boxed{0.103 \text{ Pa}}$$

Section 13.8 The Doppler Effect

P13.33 (a) $f' = \frac{f(v+v_o)}{(v-v_s)}$

$$f' = 2500 \frac{(343 + 25.0)}{(343 - 40.0)} = \boxed{3.04 \text{ kHz}}$$

(b) $f' = 2500 \frac{(343 + (-25.0))}{(343 - (-40.0))} = \boxed{2.08 \text{ kHz}}$

(c) $f' = 2500 \frac{(343 + (-25.0))}{(343 - 40.0)} = \boxed{2.62 \text{ kHz}}$ while police car overtakes

$$f' = 2500 \frac{(343 + 25.0)}{(343 - (-40.0))} = \boxed{2.40 \text{ kHz}}$$
 after police car passes

$$\omega = 2\pi f = 2\pi \left(\frac{115/\text{min}}{60.0/\text{s/min}} \right) = 12.0 \text{ rad/s}$$

$$v_{\text{max}} = \omega A = (12.0 \text{ rad/s}) (1.80 \times 10^{-3} \text{ m}) = \boxed{0.0217 \text{ m/s}}$$

(b) The heart wall is a moving observer.

$$f' = f \left(\frac{v+v_o}{v} \right) = (2000 \text{ Hz}) \left(\frac{1500+0.0217}{1500} \right) = \boxed{2000.0289 \text{ Hz}}$$

(c) Now the heart wall is a moving source.

$$f'' = f' \left(\frac{v}{v-v_s} \right) = (2000.029 \text{ Hz}) \left(\frac{1500}{1500-0.0217} \right) = \boxed{2000.0578 \text{ Hz}}$$

P13.35 Approaching ambulance:

$$f' = \frac{f}{(1-v_s/v)}$$

Departing ambulance:

$$f'' = \frac{f}{(1-v_s/v)}$$

$$\text{Since } f = 560 \text{ Hz and } f'' = 480 \text{ Hz} \quad 560 \left(1 - \frac{v_s}{v} \right) = 480 \left(1 + \frac{v_s}{v} \right)$$

$$1040 \frac{v_s}{v} = 80.0$$

$$v_s = \frac{80.0(343)}{1040} \text{ m/s} = \boxed{26.4 \text{ m/s}}$$

P13.36 The maximum speed of the speaker is described by

$$\frac{1}{2} m v_{\text{max}}^2 = \frac{1}{2} k A^2$$

$$v_{\text{max}} = \sqrt{\frac{k}{m}} A = \sqrt{\frac{20.0 \text{ N/m}}{5.00 \text{ kg}}} (0.500 \text{ m}) = 1.00 \text{ m/s}$$

The frequencies heard by the stationary observer range from

$$f_{\text{min}} = f \left(\frac{v}{v+v_{\text{max}}} \right) \text{ to } f_{\text{max}} = f \left(\frac{v}{v-v_{\text{max}}} \right)$$

where v is the speed of sound.

$$f_{\text{min}} = 440 \text{ Hz} \left(\frac{343 \text{ m/s}}{343 \text{ m/s} + 1.00 \text{ m/s}} \right) = \boxed{439 \text{ Hz}}$$

$$f_{\text{max}} = 440 \text{ Hz} \left(\frac{343 \text{ m/s}}{343 \text{ m/s} - 1.00 \text{ m/s}} \right) = \boxed{441 \text{ Hz}}$$

$$f' = f \left(\frac{v}{v-v_s} \right)$$

$$485 = 512 \left(\frac{340}{340 - (-9.80 t_{\text{fall}})} \right)$$

$$485(340) + (485)(9.80 t_f) = (512)(340)$$

$$t_f = \left(\frac{512 - 485}{485} \right) \frac{340}{9.80} = 1.93 \text{ s}$$

$$d_1 = \frac{1}{2} g t_f^2 = 18.3 \text{ m};$$

$$t_{\text{return}} = \frac{18.3}{340} = 0.0538 \text{ s}$$

The fork continues to fall while the sound returns.

$$t_{\text{total fall}} = t_f + t_{\text{return}} = 1.93 \text{ s} + 0.0538 \text{ s} = 1.985 \text{ s}$$

$$d_{\text{total}} = \frac{1}{2} g t_{\text{total fall}}^2 = \boxed{19.3 \text{ m}}$$

P13.38

$$(a) \quad v = (331 \text{ m/s}) + 0.6 \frac{\text{m}}{\text{s}^\circ\text{C}} (-10^\circ\text{C}) = \boxed{325 \text{ m/s}}$$

(b) Approaching the bell, the athlete hears a frequency of

$$f' = f \left(\frac{v+v_o}{v} \right)$$

After passing the bell, she hears a lower frequency of

$$f'' = f \left(\frac{v+(-v_o)}{v} \right)$$

The ratio is

$$\frac{f''}{f'} = \frac{v-v_o}{v+v_o} = \frac{5}{6}$$

which gives $6v - 6v_o = 5v + 5v_o$ or

$$v_o = \frac{v}{11} = \frac{325 \text{ m/s}}{11} = \boxed{29.5 \text{ m/s}}$$

P13.39

(a) Sound moves upwind with speed $(343 - 15) \text{ m/s}$. Crests pass a stationary upwind point at frequency 900 Hz.

Then

$$\lambda = \frac{v}{f} = \frac{328 \text{ m/s}}{900/\text{s}} = \boxed{0.364 \text{ m}}$$

$$(b) \quad \text{By similar logic, } \lambda = \frac{v}{f} = \frac{(343+15) \text{ m/s}}{900/\text{s}} = \boxed{0.398 \text{ m}}$$

(c) The source is moving through the air at 15 m/s toward the observer. The observer is stationary relative to the air.

$$f' = f \left(\frac{v+v_o}{v-v_s} \right) = 900 \text{ Hz} \left(\frac{343+0}{343-15} \right) = \boxed{941 \text{ Hz}}$$

(d) The source is moving through the air at 15 m/s away from the downwind firefighter. Her speed relative to the air is 30 m/s toward the source.

$$f' = f \left(\frac{v+v_o}{v-v_s} \right) = 900 \text{ Hz} \left(\frac{343+30}{343-(-15)} \right) = 900 \text{ Hz} \left(\frac{373}{358} \right) = \boxed{938 \text{ Hz}}$$

Section 13.9 Context Connection—Seismic Waves

P13.40 (a)

The longitudinal wave travels a shorter distance and is moving faster, so it will arrive at point B first.

(b)

The wave that travels through the Earth must travel

a distance of $2R \sin 30.0^\circ = 2(6.37 \times 10^6 \text{ m}) \sin 30.0^\circ = 6.37 \times 10^6 \text{ m}$

at a speed of 7800 m/s

Therefore, it takes $\frac{6.37 \times 10^6 \text{ m}}{7800 \text{ m/s}} = 817 \text{ s}$

The wave that travels along the Earth's surface must travel

a distance of $s = R\theta = R\left(\frac{\pi}{3} \text{ rad}\right) = 6.67 \times 10^6 \text{ m}$

at a speed of 4500 m/s

Therefore, it takes $\frac{6.67 \times 10^6 \text{ m}}{4500} = 1482 \text{ s}$

The time difference is $\boxed{665 \text{ s}} = 11.1 \text{ min}$

P13.41

The distance the waves have traveled is $d = (780 \text{ km/s})t = (450 \text{ km/s})(t + 17.3 \text{ s})$

where t is the travel time for the faster wave.

Then, $(780 - 450)(\text{km/s})t = (450 \text{ km/s})(17.3 \text{ s})$

or $t = \frac{(450 \text{ km/s})(17.3 \text{ s})}{(780 - 450) \text{ km/s}} = 23.6 \text{ s}$

and the distance is $d = (780 \text{ km/s})(23.6 \text{ s}) = \boxed{184 \text{ km}}$.

Additional Problems

P13.42

Assume a typical distance between adjacent people $\sim 1 \text{ m}$.

Then the wave speed is $v = \frac{\Delta x}{\Delta t} = \frac{1 \text{ m}}{0.1 \text{ s}} \sim 10 \text{ m/s}$

Model the stadium as a circle with a radius of order 100 m . Then, the time for one circuit around the stadium is

$$T = \frac{2\pi r}{v} = \frac{2\pi(10^2)}{10 \text{ m/s}} = 63 \text{ s} \sim \boxed{1 \text{ min}}$$

P13.43

Assuming the incline to be frictionless and taking the positive x -direction to be up the incline:

$\sum F_x = T - Mg \sin \theta = 0$ or the tension in the string is

$$T = Mg \sin \theta$$

The speed of transverse waves in the string is then

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{Mg \sin \theta}{m/L}} = \sqrt{\frac{MgL \sin \theta}{m}}$$

The time interval for a pulse to travel the string's length is $\Delta t = \frac{L}{v} = L \sqrt{\frac{m}{MgL \sin \theta}} = \sqrt{\frac{mL}{Mg \sin \theta}}$

$$\Delta t = \sqrt{\frac{mL}{Mg \sin \theta}}$$

P13.44

$$Mgx = \frac{1}{2} kx^2$$

$$(a) \quad T = kx = \boxed{2Mg}$$

$$(b) \quad L = L_0 + x = \boxed{L_0 + \frac{2Mg}{k}}$$

$$(c) \quad v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{TL}{m}} = \sqrt{\frac{2Mg}{m} \left(L_0 + \frac{2Mg}{k} \right)}$$

*P13.45

Let M = mass of block, m = mass of string. For the block, $\sum F = ma$ implies $T = \frac{mv^2}{r} = m\omega^2 r$. The speed of a wave on the string is then

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{M\omega^2 r}{m}} = r\omega \sqrt{\frac{M}{m}}$$

$$t = \frac{r}{v} = \frac{1}{\omega} \sqrt{\frac{m}{M}}$$

$$\theta = \omega t = \sqrt{\frac{m}{M}} = \sqrt{\frac{0.003 \text{ kg}}{0.450 \text{ kg}}} = \boxed{0.0843 \text{ rad}}$$

P13.46

(a)

Assume the spring is originally stationary throughout, extended to have a length L much greater than its equilibrium length. We start moving one end forward with the speed v at which a wave propagates on the spring. In this way we create a single pulse of compression that moves down the length of the spring. For an increment of spring with length dx and mass dm , just as the pulse swallows it up, $\sum F = ma$ becomes $kdx = adm$ or $\frac{k}{dx} = a$. But

$\frac{dm}{dx} = \mu$ so $a = \frac{k}{\mu}$. Also, $a = \frac{dv}{dt} = \frac{v}{t}$ when $v_i = 0$. But $L = vt$, so $a = \frac{v^2}{L}$. Equating the two

$$\text{expressions for } a, \text{ we have } \frac{k}{L} = \frac{v^2}{L} \text{ or } v = \sqrt{\frac{kL}{\mu}}$$

(b)

$$\text{Using the expression from part (a) } v = \sqrt{\frac{kL}{\mu}} = \sqrt{\frac{(100 \text{ N/m})(2.00 \text{ m})}{0.400 \text{ kg}}} = \boxed{31.6 \text{ m/s}}$$

P13.47 $T = \mu g x$, the weight of a length x of rope.

Therefore,

$$v = \sqrt{gx}$$

But $v = \frac{dx}{dt}$, so that

$$\frac{dx}{dt} = \sqrt{gx}$$

$$t = \int_0^L \frac{dx}{\sqrt{gx}} = \frac{1}{\sqrt{g}} \left[\frac{2\sqrt{x}}{1} \right]_0^L = \frac{2}{\sqrt{g}} \sqrt{L}$$

P13.48 At distance x from the bottom, the tension is $T = \left(\frac{mx}{L} \right) + Mg$, so the wave speed is:

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{TL}{m}} = \sqrt{\frac{mgx}{m}} = \sqrt{gx}$$

(a) Then $t = \int_0^L \frac{dx}{v} = \int_0^L \frac{dx}{\sqrt{gx}} = \frac{1}{\sqrt{g}} \left[\frac{2\sqrt{x}}{1} \right]_0^L = \frac{2}{\sqrt{g}} \sqrt{L}$

$$t = \frac{2}{g} \left[Lg + \frac{MgL}{m} \right]^{1/2} - \left(\frac{MgL}{m} \right)^{1/2}$$

(b) When $M = 0$, as in the previous problem,

$$t = 2 \sqrt{\frac{L}{g}} \left(\frac{\sqrt{m} - 0}{\sqrt{m}} \right) = 2 \sqrt{\frac{L}{g}}$$

(c) As $m \rightarrow 0$ we expand $\sqrt{m+M} = \sqrt{M} \left(1 + \frac{m}{M} \right)^{1/2} = \sqrt{M} \left(1 + \frac{1}{2} \frac{m}{M} - \frac{1}{8} \frac{m^2}{M^2} + \dots \right)$

$$\text{to obtain } t = 2 \sqrt{\frac{L}{g}} \left(\frac{\sqrt{M} + \frac{1}{2} \frac{m}{\sqrt{M}} - \frac{1}{8} \frac{m^2}{M^{3/2}} + \dots}{\sqrt{M}} \right)$$

$$t = 2 \sqrt{\frac{L}{g}} \left(\frac{1}{2} \sqrt{\frac{m}{M}} \right) = \sqrt{\frac{mL}{Mg}}$$

P13.49 (a) $\phi(x) = \frac{1}{2} \mu \omega^2 A^2 v = \frac{1}{2} \mu \omega^2 A_0^2 e^{-2ikx} \left(\frac{\omega}{k} \right) = \frac{\mu \omega^3 A_0^2 e^{-2ikx}}{2k}$

(b) $\phi(0) = \frac{\mu \omega^3 A_0^2}{2k}$

(c) $\frac{\phi(x)}{\phi(0)} = e^{-2ikx}$

P13.50 $v = \frac{4.450 \text{ km}}{9.50 \text{ h}} = 468 \text{ km/h} = 130 \text{ m/s}$

$$\bar{a} = \frac{v^2}{g} = \frac{(130 \text{ m/s})^2}{9.80 \text{ m/s}^2} = 1730 \text{ m}$$

P13.51 (a)

$\mu(x)$ is a linear function, so it is of the form

$$\mu(x) = mx + b$$

To have $\mu(0) = \mu_0$ we require $b = \mu_0$. Then

$$\mu(L) = \mu_L = mL + \mu_0$$

so

$$m = \frac{\mu_L - \mu_0}{L}$$

Then

$$\mu(x) = \frac{(\mu_L - \mu_0)x}{L} + \mu_0$$

(b) From $v = \frac{dx}{dt}$, the time required to move from x to $x+dx$ is $\frac{dx}{v}$. The time required to move from 0 to L is

$$\Delta t = \int_0^L \frac{dx}{v} = \int_0^L \frac{1}{\sqrt{T}} \int_0^L \sqrt{\mu(x)} dx$$

$$\Delta t = \frac{1}{\sqrt{T}} \int_0^L \left(\frac{\mu_L - \mu_0}{L} x + \mu_0 \right)^{1/2} \left(\frac{\mu_L - \mu_0}{L} \right) dx \left(\frac{L}{\mu_L - \mu_0} \right)$$

$$\Delta t = \frac{1}{\sqrt{T}} \left(\frac{L}{\mu_L - \mu_0} \right) \left(\frac{\mu_L - \mu_0}{L} \right) \left(\frac{L}{2} \right) \left(\frac{L}{\mu_L - \mu_0} \right)^{3/2} \left(\frac{1}{2} \right)$$

$$\Delta t = \frac{2L}{3\sqrt{T}(\mu_L - \mu_0)} (\mu_L^{3/2} - \mu_0^{3/2})$$

$$\Delta t = \frac{2L}{3\sqrt{T}(\mu_L - \mu_0)} (\mu_L + \sqrt{\mu_L \mu_0} + \mu_0)$$

$$\Delta t = \frac{2L}{3\sqrt{T}} \left(\frac{\mu_L + \sqrt{\mu_L \mu_0} + \mu_0}{\sqrt{\mu_L} + \sqrt{\mu_0}} \right)$$

P13.52

Sound takes this time to reach the man:

$$\frac{(20.0 \text{ m} - 1.75 \text{ m})}{343 \text{ m/s}} = 5.32 \times 10^{-2} \text{ s}$$

so the warning should be shouted no later than $0.300 \text{ s} + 5.32 \times 10^{-2} \text{ s} = 0.353 \text{ s}$ before the pot strikes.

Since the whole time of fall is given by $y = \frac{1}{2} g t^2$, $18.25 \text{ m} = \frac{1}{2} (9.80 \text{ m/s}^2) t^2$

$$t = 1.93 \text{ s}$$

the warning needs to come $1.93 \text{ s} - 0.353 \text{ s} = 1.58 \text{ s}$

into the fall, when the pot has fallen $\frac{1}{2} (9.80 \text{ m/s}^2) (1.58 \text{ s})^2 = 12.2 \text{ m}$

to be above the ground by $20.0 \text{ m} - 12.2 \text{ m} = 7.82 \text{ m}$

P13.53

Since $\cos^2 \theta + \sin^2 \theta = 1$, $\sin \theta = \pm \sqrt{1 - \cos^2 \theta}$ (each sign applying half the time)

$$\Delta P = \Delta P_{\max} \sin(kx - \omega t) = \pm \rho v \omega s_{\max} \sqrt{1 - \cos^2(kx - \omega t)}$$

Therefore $\Delta P = \pm \rho v \omega \sqrt{s_{\max}^2 - s_{\max}^2 \cos^2(kx - \omega t)} = \pm \rho v \omega \sqrt{s_{\max}^2 - s^2}$

P13.54 (b) The trucks form a train analogous to a wave train of crests with speed $v = 19.7 \text{ m/s}$ and unshifted frequency $f = \frac{2}{3.00 \text{ min}} = 0.667 \text{ min}^{-1}$.

(a) The cyclist as observer measures a lower Doppler-shifted frequency:

$$f' = f \left(\frac{v + v_o}{v} \right) = (0.667 \text{ min}^{-1}) \left(\frac{19.7 + (-4.47)}{19.7} \right) = \boxed{0.515/\text{min}}$$

$$(b) \quad f'' = f \left(\frac{v + v_o}{v} \right) = (0.667 \text{ min}^{-1}) \left(\frac{19.7 + (-1.56)}{19.7} \right) = \boxed{0.614/\text{min}}$$

The cyclist's speed has decreased very significantly, but there is only a modest increase in the frequency of trucks passing him.

P13.55 $v = \frac{2d}{f} = \frac{2}{f} = \frac{1}{2} (6.50 \times 10^3 \text{ m/s}) (1.85 \text{ s}) = \boxed{6.01 \text{ km}}$

P13.56 (a) $f' = \frac{fv}{v - u}$

$$f'' = \frac{fv}{v - (-u)}$$

$$f' - f'' = fv \left(\frac{1}{v - u} - \frac{1}{v + u} \right)$$

$$\Delta f = \frac{fv(v + u - v + u)}{v^2 - u^2} = \frac{2uvf}{v^2(1 - \frac{u^2}{v^2})} = \boxed{\frac{2u}{1 - \frac{u^2}{v^2}} f}$$

(b) $130 \text{ km/h} = 36.1 \text{ m/s}$
 $\therefore \Delta f = \frac{2(36.1)(400)}{340[1 - \frac{36.1^2}{340^2}]} = \boxed{85.9 \text{ Hz}}$

*P13.57 (a) $f' = f \frac{v}{(v - v_{\text{diver}})}$

$$\text{so } 1 - \frac{v_{\text{diver}}}{v} = \frac{f}{f'}$$

$$\Rightarrow v_{\text{diver}} = v \left(1 - \frac{f}{f'} \right)$$

with $v = 343 \text{ m/s}$, $f = 1800 \text{ Hz}$ and $f' = 2150 \text{ Hz}$ we find

$$v_{\text{diver}} = 343 \left(1 - \frac{1800}{2150} \right) = \boxed{55.8 \text{ m/s}}$$

(b) If the waves are reflected, and the skydiver is moving into them, we have

$$f'' = f' \left(\frac{v + v_{\text{diver}}}{v} \right) \Rightarrow f'' = f \left[\frac{v}{(v - v_{\text{diver}})} \right] \left(\frac{v + v_{\text{diver}}}{v} \right)$$

$$\text{so } f'' = 1800 \left(\frac{343 + 55.8}{343 - 55.8} \right) = \boxed{2560 \text{ Hz}}$$

*P13.58 (a)

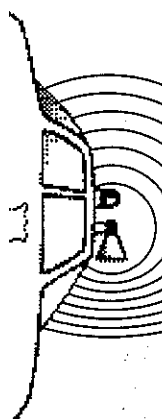


FIG. P13.58(a)

(b) $\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{1000 \text{ s}^{-1}} = \boxed{0.343 \text{ m}}$

(c) $\lambda' = \frac{v}{f'} = \frac{v}{f} \left(\frac{v - v_s}{v} \right) = \frac{(343 - 40.0) \text{ m/s}}{1000 \text{ s}^{-1}} = \boxed{0.303 \text{ m}}$

(d) $\lambda'' = \frac{v}{f''} = \frac{v}{f} \left(\frac{v + v_s}{v} \right) = \frac{(343 + 40.0) \text{ m/s}}{1000 \text{ s}^{-1}} = \boxed{0.383 \text{ m}}$

(e) $f' = f \left(\frac{v - v_o}{v - v_s} \right) = (1000 \text{ Hz}) \frac{(343 - 30.0) \text{ m/s}}{(343 - 40.0) \text{ m/s}} = \boxed{1.03 \text{ kHz}}$

*P13.59 Use the Doppler formula, and remember that the bat is a moving source. If the velocity of the insect is v_x ,

$$40.4 = 40.0 \frac{(340 + 5.00)(340 - v_x)}{(340 - 5.00)(340 + v_x)}$$

Solving, $v_x = 3.31 \text{ m/s}$. Therefore, the bat is gaining on its prey at 1.69 m/s .

P13.60 (a) If the source and the observer are moving away from each other, we have: $\theta_s - \theta_o = 180^\circ$, and since $\cos 180^\circ = -1$, we get Equation 13.30 with negative values for both v_o and v_s .

(b) If $v_o = 0 \text{ m/s}$ then $f' = \frac{v}{v - v_s \cos \theta_s} f$. Also, when the train is 40.0 m from the intersection, and the car is 30.0 m from the intersection, $\cos \theta_s = \frac{4}{5}$ so

$$f' = \frac{343 \text{ m/s}}{343 \text{ m/s} - 0.800(25.0 \text{ m/s})} (500 \text{ Hz})$$

or $f' = \boxed{531 \text{ Hz}}$. Note that as the train approaches, passes, and departs from the

intersection, θ_s varies from 0° to 180° and the frequency heard by the observer varies from:

$$f_{\text{max}} = \frac{v}{v - v_s \cos 0^\circ} f = \frac{343 \text{ m/s}}{343 \text{ m/s} - 25.0 \text{ m/s}} (500 \text{ Hz}) = 539 \text{ Hz}$$

$$f_{\text{min}} = \frac{v}{v - v_s \cos 180^\circ} f = \frac{343 \text{ m/s}}{343 \text{ m/s} + 25.0 \text{ m/s}} (500 \text{ Hz}) = 466 \text{ Hz}$$