Chapter 13
Vibrations and Waves

Answers to Even Numbered Conceptual Questions

4. To understand how we might have anticipated this similarity in speeds, consider sound as a motion of air molecules in a certain direction superimposed on the random, high speed, thermal molecular motions predicted by kinetic theory. Individual molecules experience billions of collisions per second with their neighbors, and as a result, do not travel very far in any appreciable time interval. With this interpretation, the energy of a sound wave is carried as kinetic energy of a molecule and transferred to neighboring molecules by collision. Thus, the energy transmitted by a sound wave in, say, a compression, travels from molecule to molecule at about the rms speed, or actually somewhat less, as observed, since multiple collisions slow the process a bit.

6. Friction. This includes both air-resistance and damping within the spring.

12. The speed of the pulse is $v=\sqrt{F/\mu}$, so increasing the tension *F* in the hose increases the speed of the pulse. Filling the hose with water increases the mass per unit length μ, and will decrease the speed of the pulse.

16. If the tension remains the same, the speed of a wave on the string does not change. This means, from $v=\lambda f$, that if the frequency is doubled, the wavelength must decrease by a factor of two.

18. The speed of a wave on a string is given by $v=\sqrt{F/\mu}$. This says the speed is independent of the frequency of the wave. Thus, doubling the frequency leaves the speed unaffected.

Problem Solutions

13.1 (a) The force exerted on the block by the spring is

$$F_s = -kx = -(160\text{ N/m})(-0.15\text{ m}) = +24\text{ N}$$

or $F_s = \boxed{24\text{ N directed toward equilibrium position}}$

(b) From Newton's second law, the acceleration is

$$a = \frac{F_s}{m} = \frac{+24\text{ N}}{0.40\text{ kg}} = +60\ \frac{\text{m}}{\text{s}^2} = \boxed{60\ \frac{\text{m}}{\text{s}^2}\text{ toward equilibrium position}}$$

13.15 From conservation of mechanical energy,

$$\left(KE + PE_g + PE_s\right)_f = \left(KE + PE_g + PE_s\right)_i$$

we have $\frac{1}{2}mv^2 + 0 + \frac{1}{2}kx^2 = 0 + 0 + \frac{1}{2}kA^2$, or $v = \sqrt{\frac{k}{m}\left(A^2 - x^2\right)}$

(a) The speed is a maximum at the equilibrium position, $x = 0$.

$$v_{max} = \sqrt{\frac{k}{m}A^2} = \sqrt{\frac{(19.6\text{ N/m})}{(0.40\text{ kg})}(0.040\text{ m})^2} = \boxed{0.28\text{ m/s}}$$

(b) When $x = -0.015\text{ m}$,

$$v = \sqrt{\frac{(19.6\text{ N/m})}{(0.40\text{ kg})}\left[(0.040\text{ m})^2 - (-0.015\text{ m})^2\right]} = \boxed{0.26\text{ m/s}}$$

(c) When $x = +0.015\text{ m}$,

$$v = \sqrt{\frac{(19.6\text{ N/m})}{(0.40\text{ kg})}\left[(0.040\text{ m})^2 - (+0.015\text{ m})^2\right]} = \boxed{0.26\text{ m/s}}$$

(d) If $v = \frac{1}{2}v_{max}$, then $\sqrt{\frac{k}{m}\left(A^2 - x^2\right)} = \frac{1}{2}\sqrt{\frac{k}{m}A^2}$

This gives $A^2 - x^2 = \frac{A^2}{4}$, or $x = A\frac{\sqrt{3}}{2} = (4.0\text{ cm})\frac{\sqrt{3}}{2} = \boxed{3.5\text{ cm}}$

13.19 (a) The motion is simple harmonic because the tire is rotating with constant velocity and you are looking at the uniform circular motion of the "bump" projected on a plane perpendicular to the tire.

(b) Note that the tangential speed of a point on the rim of a rolling tire is the same as the translational speed of the axle. Thus, $v_t = v_{car} = 3.00 \text{ m/s}$ and the angular velocity of the tire is

$$\omega = \frac{v_t}{r} = \frac{3.00 \text{ m/s}}{0.300 \text{ m}} = 10.0 \text{ rad/s}$$

Therefore, the period of the motion is

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{10.0 \text{ rad/s}} = \boxed{0.628 \text{ s}}$$

13.25 (a) The period of oscillation is $T = 2\pi\sqrt{m/k}$ where *k* is the spring constant and *m* is the mass of the object attached to the end of the spring. Hence,

$$T = 2\pi\sqrt{\frac{0.250 \text{ kg}}{9.5 \text{ N/m}}} = \boxed{1.0 \text{ s}}$$

(b) If the cart is released from rest when it is 4.5 cm from the equilibrium position, the amplitude of oscillation will be $A = 4.5 \text{ cm} = 4.5 \times 10^{-2} \text{ m}$. The maximum speed is then given by

$$v_{max} = A\omega = A\sqrt{\frac{k}{m}} = \left(4.5 \times 10^{-2} \text{ m}\right)\sqrt{\frac{9.5 \text{ N/m}}{0.250 \text{ kg}}} = \boxed{0.28 \text{ m/s}}$$

(c) When the cart is 14 cm from the left end of the track, it has a displacement of $x = 14 \text{ cm} - 12 \text{ cm} = 2.0 \text{ cm}$ from the equilibrium position. The speed of the cart at this distance from equilibrium is

$$v = \sqrt{\frac{k}{m}\left(A^2 - x^2\right)} = \sqrt{\frac{9.5 \text{ N/m}}{0.250 \text{ kg}}\left[\left(0.045 \text{ m}\right)^2 - \left(0.020 \text{ m}\right)^2\right]} = \boxed{0.25 \text{ m/s}}$$

13.31 The period of a simple pendulum is $T = 2\pi\sqrt{L/g}$ where L is its length. The number of complete oscillations per second (that is, the frequency) for this pendulum is then given by

$$f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{g}{L}} = \frac{1}{2\pi}\sqrt{\frac{9.80\text{ m/s}^2}{2.00\text{ m}}} = 0.352\text{ s}^{-1}$$

Hence, the number of oscillations in a time $\Delta t = 5.00\text{ min} = 300\text{ s}$ is

$$N = f(\Delta t) = \left(0.352\text{ s}^{-1}\right)(300\text{ s}) = 105.7 \text{ or } \boxed{105\text{ complete oscillations}}$$

13.37 (a) The amplitude, A, is the maximum displacement from equilibrium. Thus, from Figure P13.37, $A = \frac{1}{2}(18.0\text{ cm}) = \boxed{9.00\text{ cm}}$

(b) The wavelength, λ, is the distance between successive crests (or successive troughs). From Figure P13.37, $\lambda = 2(10.0\text{ cm}) = \boxed{20.0\text{ cm}}$

(c) The period is $T = \frac{1}{f} = \frac{1}{25.0\text{ Hz}} = 4.00\times10^{-2}\text{ s} = \boxed{40.0\text{ ms}}$

(d) The speed of the wave is $v = \lambda f = (0.200\text{ m})(25.0\text{ Hz}) = \boxed{5.00\text{ m/s}}$

13.39 (a) $T = \frac{1}{f} = \frac{1}{88.0\times10^{6}\text{ Hz}} = 1.14\times10^{-8}\text{ s} = \boxed{11.4\text{ ns}}$

(b) $\lambda = \frac{v}{f} = \frac{3.00\times10^{8}\text{ m/s}}{88.0\times10^{6}\text{ Hz}} = \boxed{3.41\text{ m}}$

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

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

Now, $\mu = \frac{m}{L} = \frac{0.200\text{ kg}}{4.00\text{ m}} = 5.00\times10^{-2}\text{ kg/m}$, so

$$F = \mu v^2 = \left(5.00\times10^{-2}\text{ kg/m}\right)(40.0\text{ m/s})^2 = \boxed{80.0\text{ N}}$$

13.49 (a) The tension in the string is $F = mg = (3.0\text{ kg})(9.80\text{ m/s}^2) = 29\text{ N}$. Then, from $v = \sqrt{F/\mu}$, the mass per unit length is

$$\mu = \frac{F}{v^2} = \frac{29\text{ N}}{(24\text{ m/s})^2} = \boxed{0.051\text{ kg/m}}$$

(b) When $m = 2.00\text{ kg}$, the tension is

$$F = mg = (2.0\text{ kg})(9.80\text{ m/s}^2) = 20\text{ N}$$

and the speed of transverse waves in the string is

$$v = \sqrt{\frac{F}{\mu}} = \sqrt{\frac{20\text{ N}}{0.051\text{ kg/m}}} = \boxed{20\text{ m/s}}$$

13.52 (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 $A' = 2A = 2(0.15\text{ m}) = \boxed{0.30\text{ m}}$.