CJ5 10.CQ.003. **REASONING AND SOLUTION**  Figures 10.11 and 10.14 show the velocity and the acceleration, respectively, of the shadow of a ball that undergoes uniform circular motion. The shadow undergoes simple harmonic motion.

a. The velocity of the shadow is given by Equation 10.7: \( v = -A \omega \sin \theta \). The velocity of the shadow will be zero when \( \theta = 0 \) or \( \pi \) rad. From Figure 10.11, we see that the velocity equals zero each time the shadow reaches the right and left endpoints of its motion (that is, when the ball crosses the \( x \) axis).

b. The acceleration of the shadow is given by Equation 10.9: \( a = -A \omega^2 \cos \theta \). The acceleration of the shadow will be zero when \( \theta = \pi/2 \) or \( 3\pi/2 \). From Figure 10.14, we see that the acceleration equals zero each time that the shadow passes through the point \( x = 0 \) m (that is, when the ball crosses the \( y \) axis).

CJ5 10.CQ.006. **REASONING AND SOLUTION** A block is attached to a horizontal spring and slides back and forth in simple harmonic motion on a frictionless horizontal surface. A second identical block is suddenly attached to the first block when the first block is at one extreme end of the oscillation cycle.

a. Since the attachment is made at one extreme end of the oscillation cycle, where the velocity is zero, the extreme end of the oscillation cycle will remain at the same point; in other words, the amplitude remains the same.

b. The angular frequency of an object of mass \( m \) in simple harmonic motion at the end of a spring of force constant \( k \) is given by Equation 10.11: \( \omega = \sqrt{k/m} \). Since the mass \( m \) is doubled while the force constant \( k \) remains the same, the angular frequency decreases by a factor of \( \sqrt{2} \). The vibrational frequency \( f \) is related to \( \omega \) by \( f = \omega (2\pi) \); the vibrational frequency \( f \) will also decrease by a factor of \( \sqrt{2} \).

c. The maximum speed of oscillation is given by Equation 10.8: \( v_{\text{max}} = A \omega \). Since the amplitude, \( A \), remains the same and the angular frequency, \( \omega \), decreases by a factor of \( \sqrt{2} \), the maximum speed of oscillation also decreases by a factor of \( \sqrt{2} \).

CJ5 10.P.007. **REASONING AND SOLUTION** The two forces that act on the 5.0-kg object are the upward force \( F \) of the spring and the downward weight \( mg \) of the object. Accordingly, Newton's second law gives (with up taken as the positive direction), \( F - mg = ma \), where \( a \) is the acceleration of the elevator. Substituting this into Equation 10.2 and solving for \( x \), we find

\[
x = -\frac{F}{k} = -\frac{m(g + a)}{k} = -\frac{(5.0 \text{ kg})(9.80 \text{ m/s}^2 + 0.60 \text{ m/s}^2)}{830 \text{ N/m}} = -6.3 \times 10^{-2} \text{ m}
\]

The amount that the spring stretches is \( 6.3 \times 10^{-2} \text{ m} \).

10. **REASONING AND SOLUTION** From the figure we see that the maximum frictional force, \( f_s^{\text{max}} \), must balance the force of gravity, \( mg \), on the block; \( f_s^{\text{max}} = mg \).
Since $f_s^{\text{max}} = \mu_s F_N$, where $F_N$ is the normal force due to the spring pushing perpendicular to the block (i.e., $F_N = kx$) we have that

$$f_s^{\text{max}} = \mu_s F_N = \mu_s (kx)$$

Therefore, $\mu_s (kx) = mg$, and we can write

$$\mu_s = \frac{mg}{kx} = \frac{2.3 \text{ kg}(9.80 \text{ m/s}^2)}{480 \text{ N/m}(0.051 \text{ m})} = 0.92$$

CJ5 10.P.017. **REASONING AND SOLUTION**

a. Since the object oscillates between $\pm 0.080 \text{ m}$, the amplitude of the motion is $0.080 \text{ m}$.

b. From the graph, the period is $T = 4.0 \text{ s}$. Therefore, according to Equation 10.4,

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{4.0 \text{ s}} = 1.6 \text{ rad/s}$$

c. Equation 10.11 relates the angular frequency to the spring constant: $\omega = \sqrt{k/m}$. Solving for $k$ we find

$$k = \omega^2 m = (1.6 \text{ rad/s})^2 (0.80 \text{ kg}) = 2.0 \text{ N/m}$$

d. At $t = 1.0 \text{ s}$, the graph shows that the spring has its maximum displacement. At this location, the object is momentarily at rest, so that its speed is $v = 0 \text{ m/s}$.

e. The acceleration of the object at $t = 1.0 \text{ s}$ is a maximum, and its magnitude is

$$a_{\text{max}} = A \omega^2 = (0.080 \text{ m})(1.6 \text{ rad/s})^2 = 0.20 \text{ m/s}^2$$

CJ5 10.P.020. **REASONING AND SOLUTION** For mass 1 we have

$$f_1 = \frac{1}{2\pi} \sqrt{\frac{k}{m_1}} \quad (10.11)$$

For mass 2 we have

$$f_2 = \frac{1}{2\pi} \sqrt{\frac{k}{m_1 + m_2}}$$

Therefore,

$$\frac{f_1}{f_2} = \sqrt{\frac{m_1 + m_2}{m_1}} = 3.00$$
Squaring and solving yields

\[
\frac{m_1 + m_2}{m_1} = 9.00 \quad \text{or} \quad m_1 + m_2 = 9.00 \ m_1
\]

Solving for the ratio \( \frac{m_2}{m_1} \) gives \( \frac{m_1}{m_2} = 8.00 \).

**CJ5 10.P.029. REASONING AND SOLUTION** If we neglect air resistance, only the conservative forces of the spring and gravity act on the ball. Therefore, the principle of conservation of mechanical energy applies.

When the 2.00 kg object is hung on the end of the vertical spring, it stretches the spring by an amount \( x \), where

\[
x = \frac{F}{k} = \frac{mg}{k} = \frac{(2.00 \ \text{kg})(9.80 \ \text{m/s}^2)}{50.0 \ \text{N/m}} = 0.392 \ \text{m}
\]

This position represents the equilibrium position of the system with the 2.00-kg object suspended from the spring. The object is then pulled down another 0.200 m and released from rest \( (v_0 = 0 \ \text{m/s}) \). At this point the spring is stretched by an amount of 0.392 m + 0.200 m = 0.592 m. This point represents the zero reference level \( (h = 0 \ \text{m}) \) for the gravitational potential energy.

**\( h = 0 \ \text{m} \):** The kinetic energy, the gravitational potential energy, and the elastic potential energy at the point of release are:

\[
\text{KE} = \frac{1}{2}mv_0^2 = \frac{1}{2}m(0 \ \text{m/s})^2 = 0 \ \text{J}
\]

\[
\text{PE}_{\text{gravity}} = mgh = mg(0 \ \text{m}) = 0 \ \text{J}
\]

\[
\text{PE}_{\text{elastic}} = \frac{1}{2}kx_0^2 = \frac{1}{2}(50.0 \ \text{N/m})(0.592 \ \text{m})^2 = 8.76 \ \text{J}
\]

The total mechanical energy \( E_0 \) at the point of release is the sum of the three energies above: \( E_0 = 8.76 \ \text{J} \).

**\( h = 0.200 \ \text{m} \):** When the object has risen a distance of \( h = 0.200 \ \text{m} \) above the release point, the spring is stretched by an amount of 0.592 m – 0.200 m = 0.392 m. Since the total mechanical energy is conserved, its value at this point is still \( E = 8.76 \ \text{J} \). The gravitational and elastic potential energies are:

\[
\text{PE}_{\text{gravity}} = mgh = (2.00 \ \text{kg})(9.80 \ \text{m/s}^2)(0.200 \ \text{m}) = 3.92 \ \text{J}
\]
PE_{elastic} = \frac{1}{2} kx^2 = \frac{1}{2} (50.0 \text{ N/m})(0.392 \text{ m})^2 = 3.84 \text{ J}

Since KE + PE_{gravity} + PE_{elastic} = E,

KE = E - PE_{gravity} - PE_{elastic} = 8.76 \text{ J} - 3.92 \text{ J} - 3.84 \text{ J} = 1.00 \text{ J}

\( h = 0.400 \text{ m} \): When the object has risen a distance of \( h = 0.400 \text{ m} \) above the release point, the spring is stretched by an amount of \( 0.592 \text{ m} - 0.400 \text{ m} = 0.192 \text{ m} \). At this point, the total mechanical energy is still \( E = 8.76 \text{ J} \). The gravitational and elastic potential energies are:

\[ PE_{gravity} = mgh = (2.00 \text{ kg})(9.80 \text{ m/s}^2)(0.400 \text{ m}) = 7.84 \text{ J} \]

\[ PE_{elastic} = \frac{1}{2} kx^2 = \frac{1}{2} (50.0 \text{ N/m})(0.192 \text{ m})^2 = 0.92 \text{ J} \]

The kinetic energy is

\[ KE = E - PE_{gravity} - PE_{elastic} = 8.76 \text{ J} - 7.84 \text{ J} - 0.92 \text{ J} = 0 \text{ J} \]

The results are summarized in the table below:

<table>
<thead>
<tr>
<th>( h )</th>
<th>( KE )</th>
<th>( PE_{grav} )</th>
<th>( PE_{elastic} )</th>
<th>( E )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000 \text{ m}</td>
<td>0.00 \text{ J}</td>
<td>0.00 \text{ J}</td>
<td>8.76 \text{ J}</td>
<td>8.76 \text{ J}</td>
</tr>
<tr>
<td>0.200 \text{ m}</td>
<td>1.00 \text{ J}</td>
<td>3.92 \text{ J}</td>
<td>3.84 \text{ J}</td>
<td>8.76 \text{ J}</td>
</tr>
<tr>
<td>0.400 \text{ m}</td>
<td>0.00 \text{ J}</td>
<td>7.84 \text{ J}</td>
<td>0.92 \text{ J}</td>
<td>8.76 \text{ J}</td>
</tr>
</tbody>
</table>

Chapter 16

REASONING AND SOLUTION  A wave moves on a string with constant velocity. It is not correct to conclude that the particles of the string always have zero acceleration. As Conceptual Example 3 discusses, it is important to distinguish between the speed of the waves on the string, \( v_{\text{wave}} \), and the speed of the particles in the string, \( v_{\text{particle}} \). The wave speed \( v_{\text{wave}} \) is determined by the properties of the string; namely, the tension in the string and the linear mass density of the string. These properties determine the speed with which the disturbance travels along the string. The wave speed will remain constant as long as these properties remain unchanged.
The particles in the string oscillate transversely in simple harmonic motion with the same amplitude and frequency as the source of the disturbance. Like all particles in simple harmonic motion, the acceleration of the particles continually changes. It is zero when the particles pass through their equilibrium positions and is a maximum when the particles are at their maximum displacements from their equilibrium positions.

**CJ5 16.CQ.011. REASONING AND SOLUTION**  A loudspeaker produces a sound wave. The sound wave travels from air into water. As indicated in Table 16.1, the speed of sound in water is approximately four times greater than it is in air. We are told in the hint that the frequency of the sound wave does not change as the sound enters the water. The relationship between the frequency $f$, the wavelength $\lambda$, and the speed $v$ of a wave is given by Equation 16.1: $v = f \lambda$. Since the wave speed increases and the frequency remains the same as the sound enters the water, the wavelength of the sound must increase.

**CJ5 16.CQ.017. REASONING AND SOLUTION**  According to Table 16.1, the speed of sound in air at 20 °C is $v_a = 343$ m/s, while its value in water at the same temperature is $v_w = 1482$ m/s. These values influence the Doppler effect, because of which an observer hears a frequency $f_o$ that is different from the frequency $f_s$ that is emitted by the source of sound. For purposes of this question, we assume that $f_s = 1000$ Hz and that the speed at which the source moves is $v_s = 25$ m/s. Our conclusions, however, will be valid for any values of $f_s$ and $v_s$.

a. The Doppler-shifted frequency when the source approaches the observer is given by Equation 16.11 as $f_o = f_s / \left[1 - (v_s / v)\right]$. Applying this equation for air and water, we find

- **Air**
  
  $f_o = \frac{1000 \text{ Hz}}{1 - (25 \text{ m/s})/(343 \text{ m/s})} = 1079$ Hz

- **Water**
  
  $f_o = \frac{1000 \text{ Hz}}{1 - (25 \text{ m/s})/(1482 \text{ m/s})} = 1017$ Hz

The change in frequency due to the Doppler effect in air is greater.

b. The Doppler-shifted frequency when the source moves away from the observer is given by Equation 16.12 as $f_o = f_s / \left[1 + (v_s / v)\right]$. Applying this equation for air and water, we find

- **Air**
  
  $f_o = \frac{1000 \text{ Hz}}{1 + (25 \text{ m/s})/(343 \text{ m/s})} = 932$ Hz

- **Water**
  
  $f_o = \frac{1000 \text{ Hz}}{1 + (25 \text{ m/s})/(1482 \text{ m/s})} = 983$ Hz
The change in frequency due to the Doppler effect in air is greater.

**REASONING AND SOLUTION** Initially, the speed of the wave is \( v_o = \frac{\lambda}{f_o} \). After the adjustment the speed of the wave is \( v = 2\lambda f_o \). Dividing, we obtain \( \frac{v}{v_o} = 2 \).

Now for each case

\[
F_o = (m/L)v_o^2 \quad \text{and} \quad F = (m/L)v^2
\]

Division yields

\[
\frac{F}{F_o} = \frac{v^2}{v_o^2} = 4
\]

Hence,

\[
F = 4F_o = 4(58 \text{ N}) = 230 \text{ N}
\]

**REASONING** The mathematical form for the displacement of a wave traveling in the \(-x\) direction is given by Equation 16.4:

\[
y = A \sin\left(2\pi f t + \frac{2\pi x}{\lambda}\right).
\]

Using Equation 16.1 and the fact that \( f = \frac{1}{T} \), we obtain the following numerical values for \( f \) and \( \lambda \): \( f = 1/T = 1.3 \text{ Hz} \), and \( \lambda = v / f = 9.2 \text{ m} \). Omitting units and substituting these values for \( f \) and \( \lambda \) into Equation 16.4 gives

\[
y = (0.37 \text{ m}) \sin(2.6\pi t + 0.22\pi x)
\]

**REASONING AND SOLUTION** We find from the upper graph that \( \lambda = 0.060 \text{ m} - 0.020 \text{ m} = 0.040 \text{ m} \) and \( A = 0.010 \text{ m} \). From the lower graph we find that \( T = 0.30 \text{ s} - 0.10 \text{ s} = 0.20 \text{ s} \). Then, \( f = 1/(0.20 \text{ s}) = 5.0 \text{ Hz} \). Substituting these into Equation 16.3 we get

\[
y = A \sin\left(2\pi f t - \frac{2\pi x}{\lambda}\right) \quad \text{and} \quad y = (0.010 \text{ m}) \sin(10\pi t - 50\pi x)
\]

**REASONING AND SOLUTION**

a. In order to determine the order of arrival of the three waves, we need to know the speeds of each wave. The speeds for air, water and steel are

\[
v_a = 343 \text{ m/s}, \quad v_w = 1482 \text{ m/s}, \quad v_s = 5040 \text{ m/s}
\]

The order of arrival is steel wave first, water wave second, air wave third.

b. Calculate the length of time each wave takes to travel 125 m.

\[
t_s = \frac{125 \text{ m}}{5040 \text{ m/s}} = 0.025 \text{ s}
\]

\[
t_w = \frac{125 \text{ m}}{1482 \text{ m/s}} = 0.084 \text{ s}
\]

\[
t_a = \frac{125 \text{ m}}{343 \text{ m/s}} = 0.364 \text{ s}
\]

Therefore, the delay times are
\[ \Delta t_{12} = t_w - t_s = 0.084 \text{ s} - 0.025 \text{ s} = \mathbf{0.059 \text{ s}} \]

\[ \Delta t_{13} = t_a - t_s = 0.364 \text{ s} - 0.025 \text{ s} = \mathbf{0.339 \text{ s}} \]

CJ5 16.P.052. **REASONING AND SOLUTION** The intensity of the "direct" sound is given by text Equation 16.9,

\[ I_{\text{DIRECT}} = \frac{P}{4 \pi r^2} \]

The total intensity at the point in question is

\[ I_{\text{TOTAL}} = I_{\text{DIRECT}} + I_{\text{REFLECTED}} \]

\[ = \left[ 1.1 \times 10^{-3} \text{ W} \right] + 4.4 \times 10^{-6} \text{ W/m}^2 = \mathbf{1.4 \times 10^{-5} \text{ W/m}^2} \]

CJ5 16.P.058. **REASONING AND SOLUTION** We know \( \beta_2 - \beta_1 = (10 \text{ dB}) \log \left( \frac{I_2}{I_1} \right) \), so that the ratio of the intensities can be written as

\[ \frac{I_2}{I_1} = 10^{(\beta_2 - \beta_1)/(10 \text{ dB})} = 10^{(61 \text{ dB} - 23 \text{ dB})/(10 \text{ dB})} = \mathbf{6300} \]

CJ5 16.P.071. **REASONING** The observed frequency changes because of the Doppler effect. As you drive toward the parked car (a stationary source of sound), the Doppler effect is that given by Equation 16.13. As you drive away from the parked car, Equation 16.14 applies.

**SOLUTION** Equations 16.13 and 16.14 give the observed frequency \( f_0 \) in each case:

\[ f_{0, \text{toward}} = f_s \left( 1 + \frac{v_o}{v} \right) \quad \text{and} \quad f_{0, \text{away}} = f_s \left( 1 - \frac{v_o}{v} \right) \]

Driving toward parked car

Driving away from parked car

Subtracting the equation on the right from the one on the left gives the change in the observed frequency:

\[ f_{0, \text{toward}} - f_{0, \text{away}} = 2f_s \frac{v_o}{v} \]

Solving for the observer’s speed (which is your speed), we obtain

\[ v_o = \frac{v \left( f_{0, \text{toward}} - f_{0, \text{away}} \right)}{2f_s} = \frac{(343 \text{ m/s})(95 \text{ Hz})}{2(960 \text{ Hz})} = \mathbf{17 \text{ m/s}} \]